Objectively measured sedentary behaviour, physical activity and health in adolescent females

Kieran P. Dowd

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Objectively Measured Sedentary Behaviour, Physical Activity and Health in Adolescent Females

Kieran Dowd

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Supervised by: Professor Alan Donnelly

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Abstract

Title: Objectively Measured Physical Activity, Sedentary Behaviours and Health in Adolescent Females

Author: Kieran Dowd

The primary purpose of this thesis was to determine the associations between low intensity physical activities and indices of health in a particularly inactive population, adolescent females. To achieve this, methodologies which enabled the accurate, reliable and objective measurement of low intensity physical activities were examined and developed.

The inclinometer-based activPAL activity monitor was selected as the objective measure of physical activity due to its ability to distinguish between sitting/lying and standing. The validity of the activPAL as a measure of free-living physical activity was investigated, and a count to activity threshold was developed to quantify moderate to vigorous physical activity. Protocols which allowed the examination of both sedentary and physical activity variables were developed and implemented based on activity monitoring best practice.

Three sets of cross-sectional data were pooled to examine whether relations existed between low intensity physical activity variables and body composition in Irish adolescent females (n=195). No associations were evident between body composition and sedentary variables. However, negative associations were observed between light intensity physical activity and body composition. Furthermore, in this population, light intensity physical activity appears to protect adolescent females against sedentary time to a greater extent than moderate to vigorous physical activity. The associations between low intensity physical activity variables and more powerful indices of cardiovascular health, including blood lipids, carotid intima-media thickness and arterial stiffness, were also examined in a smaller sample of adolescent females (n=64). Similarly, no significant relationships were evident between sedentary variables and cardio-metabolic risk factors, while light intensity physical activity was negatively associated with body mass index.

In summary, the activPAL has been identified as a valid measure of physical activity in an adolescent female population. The novel examination of light intensity physical activity, which distinguishes between sitting and standing activities, has been described and presented. Negative associations have been observed between activPAL determined light intensity physical activity and body composition in this population. To conclude, the evidence presented in this thesis suggests that a worthwhile public health initiative may be to encourage Irish adolescent females to increase the amount of time spent in light intensity physical activity by reducing the amount of time spent in sedentary behaviours.

Authors Declaration

I hereby declare that the work contained within this thesis is my own work other than the counsel of my supervisor, Professor Alan Donnelly of the Department of Physical Education and Sport Sciences, University of Limerick and of collaborative work completed with Dr. Deirdre Harrington, Pennington Biomedical Research Center, Baton Rouge, LA, USA. Forty four sets of data, which have been analysed in Chapter 4 and Chapter 5, were shared data which was collected in collaborative research between Dr. Deirdre Harrington and I during her time as a Ph.D. research student within the Department of Physical Education and Sport Sciences, University of Limerick. All shared data has been processed and analysed using updated techniques and all data has been presented in a different manner to that which has previously been submitted for academic award. This work has not been submitted for any academic award, at this or any other educational establishment. Where the use has been made of the work of other people, it has been fully acknowledged and referenced (Bibliography).

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Kieran Dowd, September 2012

Acknowledgements

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Chapter 1. Introduction

1. 1. Background:

1. 1. 1. The Importance of Physical Activity Type and Intensity

The health benefits of moderate to vigorous physical activity are now firmly established (Paffenbarger Jr *et al.*, 1986, Blair *et al.*, 1989b, Lee *et al.*, 2012). Increased levels of moderate to vigorous physical activity have positive effects on human health at all stages of development, while moderate to vigorous physical activity guidelines are widely incorporated into national and international recommendations (Physical Activity Guidelines Advisory Committee, 2008). However, a large proportion of the population achieve little daily moderate to vigorous physical activity (Troiano *et al.*, 2008, Colley *et al.*, 2011a), while activities at the lower end of the activity intensity continuum, such as sitting/lying time and light intensity physical activity, account for the majority of an individual's active time (Matthews *et al.*, 2008, Colley *et al.*, 2011a, Matthews *et al.*, 2012). It is therefore unlikely that moderate to vigorous physical activity is the dominant determinant of variability in daily energy expenditure (Donahoo *et al.*, 2004, Levine *et al.*, 2006, Tremblay *et al.*, 2007). It is now postulated that activity intensities at the lower end of the continuum are more likely the dominant determinant of variability in daily energy expenditure rather than moderate to vigorous physical activity (Donahoo *et al.*, 2004, Levine *et al.*, 2006). Furthermore, physiological evidence on the damaging effects of excess sitting time have encouraged the promotion of reduced sitting time as an added protective mechanism against non-communicable diseases, including obesity, type 2 diabetes and site specific cancers (Hamilton *et al.*, 2007, Hamilton *et al.*, 2008, Owen *et al.*, 2010, Tremblay *et al.*, 2010). Consequently, it has been proposed that the promotion of moderate to vigorous physical activity alone may not be sufficient, and that guidelines on the whole spectrum of activity intensities may be necessary (Owen *et al.*, 2010).

1. 1. 2. Adolescence as a Study Population

Adolescence has been identified as a particularly inactive stage of human development. The prevalence of achieving physical activity recommendations significantly decreases throughout adolescence (Riddoch *et al.*, 2004, Troiano *et al.*, 2008). A recent longitudinal

study has also highlighted that sedentary time increases throughout adolescence at the expense of light intensity physical activity (Mitchell *et al.*, 2012). Furthermore, adolescent females are significantly less active and more sedentary during this period than their male counterparts (Troiano *et al.*, 2008, Mitchell *et al.*, 2012). This has a public health significance, as adolescence is a critical period in the development of excess adiposity (Dietz, 2004). Overweight and obese adolescents are also at increased risk of remaining overweight or obese in adulthood (Must, 2003, Reilly *et al.*, 2003). Similarly, patterns and trends of physical activity are relatively stable from adolescence through to adulthood, meaning less active and more sedentary adolescents are more likely to maintain this behaviour into adulthood (Malina, 1996, Telama, 2009).

1. 1. 3. The Assessment of Subcomponents of Physical Activity

Free-living sedentary behaviours have predominantly been measured using subjective measures such as self-reported time spent in screen-based activities (e.g. TV viewing). Unfortunately, the validity and reliability of self-reported screen-based measures is relatively low (Bryant *et al.*, 2007, Lubans *et al.*, 2011). Self-reported screen-based activities in children and adolescents also may suffer from similar biases observed in self-reported physical activity, while such measures do not examine the subcomponents of sedentary behaviour (Lubans *et al.*, 2011). Accelerometry has also been employed as a measure of sedentary and light intensity activities, whereby sedentary time is estimated using a sedentary threshold. Although this measure of sedentary time is more accurate and reliable than self-reported screen-based activities, it also has fundamental limitations. Accelerometers measure the accelerations of an object relative to free-fall, and provide an estimate of ambulation (Esliger *et al.*, 2005, Warren *et al.*, 2010). Consequently, sedentary time determined using an accelerometer is a measure of the lack of ambulation (Ridgers *et al.*, 2012), and cannot distinguish between sitting time and standing time (Hart *et al.*, 2011, Kozey-Keadle *et al.*, 2011). Technological developments have incorporated inclinometers within accelerometer devices, which now enable the examination of posture while also examining ambulation or non-stationary activities. With this, inclinometer-based activity monitors have been encouraged for use in studies which aim to examine the associations between sedentary behaviours and health (Bassett Jr *et al.*, 2010, Owen *et al.*, 2010).

This thesis presents data from 4 different research studies that took place in the mid-western region of Ireland between September 2008 and December 2011. The first of these studies aimed to validate and perform a unit calibration of an inclinometer-based activity monitor (activPAL™ Professional Physical Activity Monitor) to enable the valid and reliable measurement of physical activity and sedentary behaviours in an adolescent female population. The remaining three studies each involved the examination of indices of health and patterns and trends of free-living physical activity and sedentary behaviours in adolescent female populations.

1. 2. Thesis Aims:

1. To develop accurate methods of examining free-living activity behaviours using a valid and reliable inclinometer-based activity monitor in an adolescent female population;
2. To examine the associations between free-living activity behaviours, specifically low intensity activity behaviours, and indices of health in this population

1. 3. Thesis Objectives:

➢ To examine the criterion and concurrent validity of the activPAL™ Professional Physical Activity Monitor
➢ To perform a value-calibration of the activPAL for moderate and vigorous physical activity in an adolescent female population
➢ To develop methodologies to quantify free-living sedentary time, prolonged sedentary periods, standing time, light intensity physical activity and moderate to vigorous physical activity examined using the activPAL
➢ To examine and describe physical activity patterns and sedentary behaviours in a cohort of adolescent females
➢ To determine the relationship between activity variables of different intensity in this population

- ➢ To examine the associations between activPAL-determined activity variables and adiposity in a cohort of adolescent females
- ➢ To examine the associations between activPAL determined activity variables and cardio-metabolic risk factors in a cohort of adolescent females

1. 4. Thesis Structure:

The thesis examines the methods used to assess physical activity and sedentary behaviour, while also considering the potential associations between specific activity behaviours and health. Chapter 1 of this thesis provides a brief introduction to the research topic while also outlining the primary aims of the thesis. Chapter 2 presents a review of the literature on a broad range of research areas, including the associations between activity variables and health, methods of assessment of activity variables and the national and international prevalence of physical activity and inactivity in child and adolescent populations. Chapter 3 examines the potential of the activPAL™ Professional Physical Activity Monitor as a measure of physical activity intensities in an adolescent female population. This chapter describes the validation of the activPAL activity monitor, and performs a value calibration and cross-validation of count to activity thresholds for moderate and vigorous physical activity in a group of adolescent females. Chapter 3 has been accepted for publication in the journal *PLoS ONE*. Chapter 4 describes, employs and discusses the methodologies used to examine and analyse free-living activity variables measured using an inclinometer-based activity monitor. This chapter is an adapted version of a paper that is currently under review in *Physiological Measurement*. Chapter 5 examines the relationships between activity variables at the lower end of the intensity continuum and health in a group of 194 adolescent females. Activity variables, including sedentary time, light intensity physical activity and prolonged sedentary periods, are quantified using methodologies outlined in Chapters 3 and 4 and associations of these variables with measures of adiposity are examined. Chapter 6 advances on the analysis in Chapter 5, introducing the examination of relationships between low intensity activity variables and cardio-metabolic biomarkers (blood lipids, insulin, glucose, high molecular weight adiponectin) and measures of arterial health (carotid intima-media thickness and large arterial stiffness) in a smaller cohort of adolescent females (n=64). The final chapter, Chapter 7, critically analyses and discusses the results observed and the research completed throughout this thesis. The implications of

these results are also discussed in this chapter, while potential areas of future research are highlighted.

Chapter 2. Literature Review

2. 1. Introduction

This literature review will describe the origination of physical activity research, and provide evidence of the early epidemiological findings which are the foundation for modern physical activity and health-related research. This review will examine the relationship between physical activity and indices of health in both children and adolescents and adult populations. The review will also examine the evidence to date of the deleterious effect of sedentary patterns and behaviours on indices of health in both adults and youths, and will discuss the contribution of non-exercise activity thermogenesis to total daily energy expenditure. The relationship between activity patterns and behaviours in childhood/adolescence and adulthood will be examined and discussed. The examination of physical activity and sedentary behaviours using a range of assessment methods will be discussed. This review will focus on the use of accelerometry and on the use of inclinometer-based accelerometers when examining free-living physical activity and sedentary behaviours. Methodological issues with the assessment of health indices will be considered, and the validity, reproducibility and reliability of these measures will be examined. Additionally, the suitability of using different health measures in different populations and research settings will be discussed. Irish and international prevalence of physical activity levels and sedentary behaviours in adolescents and adults will be reviewed. Finally, this literature review will examine the effectiveness of interventions in free-living populations which aim to increasing levels of physical activity and/or decrease the amount of time spent in sedentary behaviours.

2. 2. Section A: Physical Activity

Physical activity is defined as any bodily movement produced by skeletal muscles that results in the expenditure of energy (Caspersen *et al.*, 1985). Academics and scholars have highlighted the relationship between physical activity and inactivity and indices of health for centuries (Pate *et al.*, 2008). Many of the fundamental concepts and theories of modern physical activity and health-related research were advocated by Hippocrates and Galen centuries ago (U.S. Dept. of Health and Human Services, 1996). Hippocrates and Galen were among the first in Western history to highlight the importance of the balance between

energy intake and expenditure, the medicinal benefits that specific exercises may have on the human body and the effect of exercise across the lifespan (Jones, 1967, Sallis *et al.*, 2000, Hardman and Stensel, 2009). Their work has been the basis of medical training and teaching in Western civilisation over the centuries, and has been the foundation of modern preventive medicine (U.S. Dept. of Health and Human Services, 1996, Hardman and Stensel, 2009).

2. 2. 1. Early Scientific Observations

Interest in the relationships between non-communicable disease and individual behaviours has increased dramatically since the 1950's (Hardman and Stensel, 2009). One of the first and potentially most significant research studies in the area of physical activity and health-related research was conducted by Dr. Jeremy Morris on London bus conductors. The findings of Morris et al. (1953) identified that active bus conductors (climbing approximately 600 stairs per working day) were at a significantly lower risk of onset of coronary heart disease when compared to their more sedentary bus driving colleagues (Morris *et al.*, 1953). A similar study conducted by Taylor and colleagues (1962) on US railroad employees highlighted lower mortality rates among the most active section men compared with the least active clerks and switchmen (Taylor *et al.*, 1962). Although these studies had limitations, such as robust measures of physical activity and not accounting for additional risk factors (family history, smoking or diet), the results highlighted the positive association between physical activity and health, and consequently have provided the rationale for the investigation of the effects of physical activity on health since (Sallis *et al.*, 2000, Hardman and Stensel, 2009).

2. 2. 2. The Epidemiological Evidence in Adults

These initial observations were later supported by studies of longevity, which examined the effect that physical activity had on mortality rates in adults. The Harvard alumni study, one of the first large-scale longevity studies to examine self-reported physical activity and risk of mortality, highlighted that adults who achieved three hours of sports per week were 53%

less likely to die from all causes compared with those who achieved less than one hour of sport per week (Paffenbarger Jr *et al.*, 1986). Research by Blair and colleagues (1989), who were the first to examine the relationship between physical fitness and mortality in a large population, identified strong inverse associations between increased levels of physical fitness and all-cause mortality in both male and female adults (Blair *et al.*, 1989b). Furthermore, these researchers highlighted that physical activity and physical fitness did not only reduce risk of coronary heart disease in healthy populations, but could also reduce risk of coronary heart disease and mortality in all risk groups, including smokers and those with poor family history and risk factor status (Paffenbarger Jr *et al.*, 1986, Blair *et al.*, 1989b, Lee *et al.*, 2012).

Many factors contribute to the development of coronary heart disease, with the most recognised of these being dyslipidemia (Després *et al.*, 2000), hypertension (Kannel *et al.*, 1969, Chobanian *et al.*, 2003), physical inactivity (Paffenbarger *et al.*, 1983, Haskell, 1994, Blair *et al.*, 1996, Lee *et al.*, 2012), obesity (Hubert *et al.*, 1983, Nielsen and Jensen, 1997, Grundy, 2004), and smoking (Wang *et al.*, 1996, Yusuf *et al.*, 2004). Each of these factors significantly increases the chance of developing coronary heart disease. However, obesity and inactivity are considered particularly important, as they directly affect other risk factors, while also exerting an independent effect of their own (Powell *et al.*, 1987, U.S. Dept. of Health and Human Services, 1996).

Incontrovertible evidence now supports the hypothesis that moderate to vigorous physical activity assists in the prevention of coronary heart disease (Paffenbarger *et al.*, 1983, Ekelund *et al.*, 1988, Blair *et al.*, 1989b, Slattery *et al.*, 1989, Berlin and Colditz, 1990, Helmrich *et al.*, 1991, Sesso *et al.*, 2000, Lee *et al.*, 2012), associated comorbidities such as type II diabetes (Haffner *et al.*, 1998, Fox *et al.*, 2006, Lee *et al.*, 2012) as well as colon and breast cancer (Lee, 2003, Lee *et al.*, 2012). Physical activity induces caloric/energy expenditure, which positively affects weight loss and weight management (Bar-Or *et al.*, 1998, Moran, 1999, Dietz, 2004). It increases the transportation of glucose, and can reduce the production of insulin in the pancreas, aiding the prevention or delay of the onset of type II diabetes mellitus (Helmrich *et al.*, 1991, Manson *et al.*, 1991, Manson *et al.*, 1992). The correct physical activity dose reduces blood pressure (Chobanian *et al.*, 2003, Katzmarzyk and Janssen, 2004) and improves blood lipid profiles, hence reducing the build-up of atherosclerotic plaques in the coronary arteries (Armstrong and Simons-Morton, 1994). This 'prescribed dose' of regular physical activity is essential in reducing

risk of coronary heart disease (Sisson and Katzmarzyk, 2008, Lee *et al.*, 2012), and will be discussed in more detail in Section 2. 5.

2. 2. 3. Non-Exercise Activity Thermogenesis (NEAT)

Caspersen and colleagues have stated that physical activity is a complex behaviour, which can be categorised into mutually exclusive intensities, such as light, moderate and vigorous activity (Caspersen *et al.*, 1985). Researchers have focused on the examination of moderate and vigorous physical activity intensities, while activities of lower intensities of the spectrum have not been studied in great detail (Pate *et al.*, 2008). More recently, researchers have begun to place more importance on the lower intensities of physical activity, and have suggested an alternative categorisation of activity energy expenditure, whereby three components of total daily energy expenditure exist; 1) basal metabolic rate (energy expended when a body is at complete rest), 2) thermic effect of food (increase in energy expended due to ingestion, absorption and storage of food) and 3) activity thermogenesis (Levine *et al.*, 2006). Activity thermogenesis is the energy expended by an individual from all other daily activities. The sum of energy expended through basal metabolic rate, thermic effect of food and activity thermogenesis should amount to an individual's total daily energy expenditure (Levine *et al.*, 2006). It has been suggested that the variance in total daily energy expenditure can be best explained through activity thermogenesis (Levine, 2002).

Activity thermogenesis is divided into two sub-categories comprising of energy expenditure of exercise and non-exercise activity thermogenesis (NEAT; all daily activity that is non-volitional) (Levine *et al.*, 1999). Non-exercise activity thermogenesis is defined as the energy expended through physical activity other than volitional exercise (Levine *et al.*, 2006) and is predominantly the result of light intensity physical activity (Hamilton *et al.*, 2004). Evidence from epidemiological studies indicates that the majority of adolescents and adults do not participate in exercise of a moderate to vigorous intensity, with negligible exercise-related energy expenditure (Riddoch *et al.*, 2004, Healy *et al.*, 2008c, Troiano *et al.*, 2008). As a result, it has been postulated that differences in total daily energy expenditure can be explained through variances in NEAT, or low levels of light intensity physical activity, rather than through variance in energy expenditure of exercise (Ravussin *et al.*, 1986, Levine, 2002, Levine *et al.*, 2006). Figure 2.1 provides a graphical representation of the

importance of non-exercise activity thermogenesis, whereby participating in the recommended amount of moderate to vigorous physical activity produces less energy expenditure and fewer muscle contractions than normal amounts of NEAT (Hamilton *et al.*, 2007). Considering the significant effect that energy expenditure has on weight loss/gain in both adolescent and adult populations, it is essential that NEAT is examined when assessing the relationship between activity and health (Levine *et al.*, 2006).
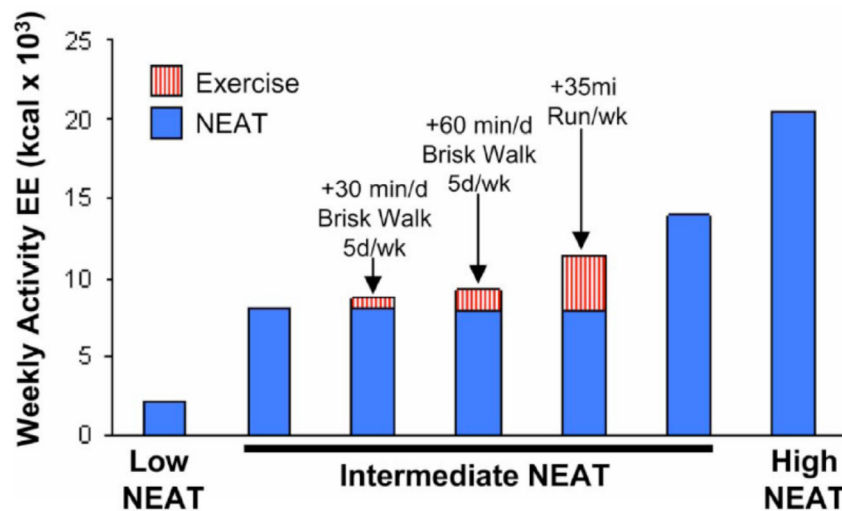
<div align="right">(Hamilton et al. 2007, page 2661)</div>

Figure 2.1 A comparison of exercise activity thermogenesis and non-exercise activity thermogenesis.

2. 3. The Physical Inactivity Paradigm: A Modern Phenomenon

As highlighted in Section 2. 2. 1, early epidemiological evidence from Morris et al. (1953) and Taylor et al. (1962) contrasted the disease outcomes and mortality rates of co-workers who were sedentary for the majority of their working day with those who were exposed to relatively high levels of work related physical activity (Morris *et al.*, 1953, Taylor *et al.*, 1962). Since these initial scientific observations, researchers have focused on the effect of physical activity on health, primarily the frequency (Pate *et al.*, 1995, Physical Activity Guidelines Advisory Committee, 2008, Garber *et al.*, 2011), intensity (Bouchard *et al.*, 1993, Després *et al.*, 2000, Warburton *et al.*, 2006) and duration (DeBusk *et al.*, 1990, Duncan *et al.*, 1991, Jakicic *et al.*, 1995, Murphy *et al.*, 2000) of physical activity. However, evidence suggests that the least active (Morris *et al.*, 1953, Paffenbarger Jr *et al.*, 1986, Leon *et al.*, 1987, Lee *et al.*,

2012) and least fit (Ekelund *et al.*, 1988, Blair *et al.*, 1989b) populations are at the greatest risk of disease and mortality (Figure 2.2)(Haskell, 1994). This evidence has led to the emergence of the inactivity physiology paradigm, whereby researchers have emphasised the necessity to identify the causal links explaining why inactivity significantly raises the risk of disease and mortality (Hamilton *et al.*, 2004).
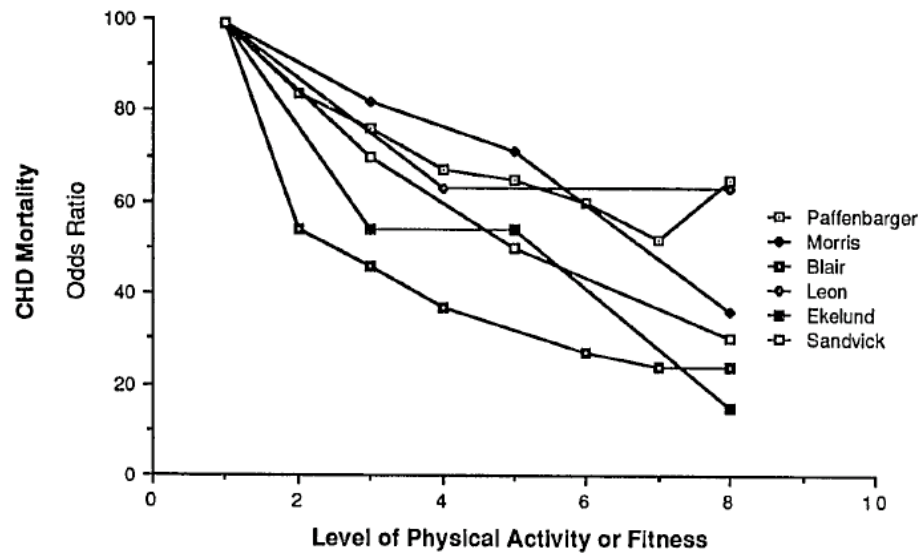
Figure 2.2 The relationship between level of physical activity or exercise capacity and Coronary Heart Disease Mortality.

(Haskell 1994, page 653)

2. 3. 1. Sedentariness: A Distinct Activity Behaviour

In population-based research, the definition of the term sedentary determines the prevalence of sedentary lifestyle, and differing definitions can provide dramatically different findings in population activity and behaviour (Caspersen *et al.*, 1985, Bennett *et al.*, 2006). The terms inactive and sedentary have previously been used interchangeably, whereby the term physically inactive or sedentary have described populations that have 1) not achieved any moderate to vigorous physical activity or 2) levels of moderate to vigorous physical activity below a specific threshold (Pate *et al.*, 1995, Bernstein *et al.*, 1999, Booth and Chakravarthy, 2002, Varo *et al.*, 2003, Tremblay *et al.*, 2012). However, research over the

last decade (discussed in more detail in Section 2. 3. 2) has suggested that sedentariness (or the behaviour of sitting and lying) is a distinct risk factor to disease and premature mortality independent of levels of physical activity (Owen *et al.*, 2010). To differentiate between sedentary behaviours and inactivity, clear and distinct definitions are necessary. At present, physical inactivity is described as engaging in no leisure time physical activity, or an individual's/populations failure to achieve sufficient daily physical activity (Pate *et al.*, 2008). In contrast, sedentariness is described as a discrete behaviour separate to physical activity (Schofield *et al.*, 2009), and is distinct to physical inactivity (Owen *et al.*, 2010). The term sedentary refers to a specific behaviour which describes activities that do not substantially increase energy expenditure above resting level (Pate *et al.*, 2008, Tremblay *et al.*, 2012). Resting level is defined as 1.0 metabolic equivalent of task (MET) for both adults and youths, and includes a range of activities such as sleeping, sitting and lying (Ainsworth *et al.*, 2011, Tremblay *et al.*, 2012).

2. 3. 2. Studies Underpinning the Physical Inactivity Paradigm

The basic premise of the inactivity physiology paradigm is that responses to sitting and lying may have a deleterious effect on specific molecular and cellular mechanisms which are important for disease-related proteins. These mechanisms have their own unique metabolic consequences that are different to those of intense exercise training (Hamilton *et al.*, 2004).

The metabolic risks associated with sedentary behaviours are reliant on the activity of the skeletal muscle enzyme lipoprotein lipase (LPL)(Hamilton *et al.*, 1998). Lipoprotein lipase is a soluble enzyme that is attached to the luminal surface of endothelial cells. The enzyme hydrolyses triglycerides into two free fatty acids and one monoacylglycerol molecule in adipose tissue, while LPL also promotes the uptake of free fatty acids, high-density lipoprotein cholesterol and complex lipoprotein remnants from the blood (Hamilton *et al.*, 2004). Insulin stimulates the activity of LPL, and consequently stimulates glucose uptake in adipose tissues.

Local contractile activity or local inactivity of large skeletal muscles has been identified as one of the major physiological variables regulating LPL (Hamilton *et al.*, 1998). The loss of contractile stimulation of large skeletal muscles may lead to the suppression of LPL activity

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and reduced glucose uptake (Bey and Hamilton, 2003, Hamilton *et al.*, 2004). Additionally, strong and inverse muscle LPL activity has been documented with aging (Bey *et al.*, 2001, Hamilton *et al.*, 2001), while significant increases in LPL activity have been identified during moderate walking (Bey and Hamilton, 2003) and more vigorous activity like running (Hamilton *et al.*, 1998).

These findings are of great significance for physical activity epidemiology and health-related research. The suggestion that isometric contraction of antigravity muscles elicit changes to skeletal muscle LPL (Zderic and Hamilton, 2006, Hamilton *et al.*, 2007, Hamilton *et al.*, 2008) implies that activities such as standing, which would previously have been considered sedentary, should now be considered as a distinct activity behaviour (Owen *et al.*, 2010). Furthermore, these findings support the classification of sedentary behaviours as activities that do not involve the contraction of antigravity skeletal muscles (Zderic and Hamilton, 2006).

2. 3. 3. Sedentariness: The Epidemiological Evidence in Adults

Research groups and international bodies have begun to examine the specific effect of sedentary patterns and behaviours on indices of health in large-scale epidemiological studies. To date, large-scale studies have identified strong associations between self-reported TV viewing time and metabolic risk factors in adult populations (Jakes *et al.*, 2003, Dunstan *et al.*, 2004, Dunstan *et al.*, 2005, Dunstan *et al.*, 2007, Healy *et al.*, 2008b, Dunstan *et al.*, 2010, Thorp *et al.*, 2010). Furthermore, it has been highlighted that when individuals achieve the recommended amount of weekly moderate to vigorous physical activity (150 minutes), there remained a significant dose response relationship between TV viewing time and waist circumference, systolic blood pressure and 2 hour plasma glucose in men and women. Additional risks, including fasting plasma glucose, triglycerides and high-density lipoproteins, were evident in women (Healy *et al.*, 2008b). These initial epidemiological observations supported the hypothesis that sedentariness is a risk factor for disease and mortality, independent of physical activity.

Although TV viewing time has been identified as significantly associated with sedentary time, the objective examination of physical activity and sedentary behaviours has been

recommended, as more detailed patterns and behaviours can be observed (Bassett Jr et al., 2010, Clark et al., 2011). Large-scale epidemiology studies, which have examined the relationship between sedentary time and health using more accurate and objective measures of physical activity and sedentary time, have been conducted (Section 2. 7. 4. 2). Initial objective findings by Healy and colleagues (2007) highlighted that sedentary time was unfavourably associated with blood glucose (Healy et al., 2007). This group provided additional epidemiological support to the inactivity physiology paradigm with their findings on a relatively small sample (AusDIAB study), noting that breaks in sedentary time were beneficially associated with indices of health (Healy et al., 2008a). Results from the National Health and Nutrition Examination Survey (NHANES), have provided perhaps the most significant epidemiologic findings in the examination of sedentary behaviours due to the large sample size (n≈4750). Sedentary time was detrimentally associated with triglycerides, C-reactive protein and markers of insulin resistance, while further analysis of results highlighted that breaks in sedentary time (i.e. less prolonged sedentary periods), independent of total sedentary time, was beneficially associated with waist circumference (Healy et al., 2011b).

Results from large-scale epidemiological studies support the inactivity physiology paradigm, presenting evidence on the damaging effect of sedentary time on indices of health in adults, independent of physical activity, while additionally emphasising that prolonged sedentary periods have a negative effect on metabolic risk factors (Hamilton et al., 2007, Hamilton et al., 2008, Owen et al., 2010). However, these epidemiological findings should initially be interpreted with some caution, primarily due to issues regarding the measurement of sedentariness, which will be discussed in more detail in Section 2. 7. 2 and Section 2. 7. 4. 2.

2. 4. Physical Activity and Health in Childhood and Adolescence

Increased activity thermogenesis and reduced sedentary time in childhood and adolescence has primarily been associated with physiologic and lifestyle benefits in three specific domains; 1) directly affects indices of health in youth, 2) directly affects indices of health in adulthood and 3) indirectly affects adult health status by increasing the probability of becoming more active in adulthood (Blair et al., 1989a, Hallal et al., 2006).

2. 4. 1. Physical Activity and Indices of Health in Childhood and Adolescence

There is much less scientific evidence available in children and adolescents to support the relationship between physical activity and health than that available for adults. This is predominantly due to the fact that children and adolescents to not suffer from diseases associated with physical inactivity, such as coronary heart disease, type II diabetes, hypertension and osteoporosis, as these diseases manifest in adult years (Blair *et al.*, 1989b, Hallal *et al.*, 2006, Hardman and Stensel, 2009, Andersen *et al.*, 2011). Despite this, physiological and epidemiological evidence supports the positive association between increased levels of physical activity and health in children and adolescents. The most effective method of examining the current and future effect of physical activity on the health of children and adolescents is through the examination of surrogate markers of future cardiac risk, including serum lipid profiles, blood pressure and body fat content (Rowlands, 2007b). The relationship between surrogate markers of cardiac risk and physical activity are discussed below.

2. 4. 1. 1. Physical Activity and Blood Lipids

According to the Irish Central Statistics Office, cardiovascular disease is the primary cause of death in Ireland for both men and women (Central Statistics Office, 2004). A key risk factor for cardiovascular disease is dyslipidemia. Dyslipidaemia is defined as an abnormal amount of lipids and lipoproteins in the blood. The most prevalent form of dyslipidemia is hyperlipidaemia, which is an elevated amount of lipids in the blood. General population blood lipid reference values specifically for adolescent females have previously been described (Ruiz *et al.*, 2006) and are presented in Table 2.1.

Table 2.1 Blood Lipid Reference Values in Adolescent Females

	Desirable Values in adolescent females
Total Cholesterol	<5.2 mmol/L
HDL Cholesterol	> 2.0 mmol/L
LDL Cholesterol	< 3.3 mmol/L
Triglyceride	< 1.1 mmol/L

Desirable values describe the values below the 90th percentile (i.e. a HDL value of 5.2 mmol/L was defined as in the 90th percentile, therefore values below this were deemed desirable).

2. 4. 1. 1. 1 . Blood Lipids

Cholesterol is a steroid that serves as the basis to steroid-based hormones and is not very soluble in blood. It is most commonly transported around the bloodstream while attached to chylomicrons. Different cholesterols are named for their density of protein as compared to lipids. The most commonly referred to lipoproteins are high-density lipoproteins (HDL-C), which have the most protein and least amount of cholesterol and low-density lipoproteins (LDL-C), which have lower protein levels but more cholesterol. The amount of cholesterol which is bound to different plasma protein carriers in the blood is significantly associated with an increased incidence of atherosclerosis and coronary heart disease (Antonopoulos, 2002). Low-density lipoproteins transports cholesterol from the intestinal endothelium around the body, and deposit them at specific sites, including arterials walls, throughout the body. In contrast, HDL-C transports cholesterols from these cells and deposits them in the liver, where they are partially removed from the body.

Additionally, high levels of triglycerides in the blood have also been associated with increased risk of atherosclerosis and coronary heart disease. Triglyceride is a lipid which is composed of one glycerol and three free fatty acids, and is a mechanism for storing unused energy. When required, triglycerides are broken down by the special enzyme lipoprotein lipase (LPL) to release the free fatty acids and glycerol components. Free fatty acids are an energy source for many tissues throughout the body. Glycerol is synthesised to glycogen, which is stored or used as fuel in skeletal and brain muscle or stored as a reserve in the

liver. Unused free fatty acids and glycerol in the bloodstream are catalysed and stored in adipose cells as triacylglycerol (Brouns, 2002, Silverthorn, 2012).

2. 4. 1. 1. 2 . Pathology of Atherosclerosis

High Density Lipoprotein-cholesterol concentration is inversely related to the risk of atherosclerosis in the body (Assmann *et al.*, 1996). High Density Lipoprotein-cholesterol protects the body by inhibiting oxidation of LDL-C (Silverthorn, 2012). The presence of high levels of oxidised LDL-C is particularly important in the process that leads to atherosclerosis and coronary heart disease. Low-density lipoproteins transport cholesterol to specific cell sites, including blood vessel walls. The presence of LDL-C on vessel walls is a trigger for the inflammatory process that leads to the development of atherosclerotic plaques. Essentially, LDL-C is deposited, and cholesterol accumulates beneath the endothelium cells, between the endothelium and the connective tissues, where it is oxidised. Smooth muscle cells beneath the endothelium and connective tissue are attracted towards the deposits, and fatty streaks are formed. Over time, as cholesterol accumulates within the fatty streak, fibrous scar tissue forms at the surface, while smooth muscle cells divide within the plaque build-up, causing a narrowing of the lumen of the artery, placing more pressure on the arterial walls. If this build-up is damaged, platelets stick to the damaged area, and a blood clot is formed. If the flow of blood in the vessel is stopped, a stroke or myocardial infarction is likely to occur.

2. 4. 1. 1. 3 . Blood Lipids and Cardiovascular Risk in Childhood and Adolescence

It has been widely accepted that risk factors for coronary heart disease, including unfavourable blood lipids, are applicable to children and adolescents (Armstrong and Simons-Morton, 1994, Anding *et al.*, 1996). Early observational evidence examining the relationship between physical activity and blood lipids reported that children who participated in above normal levels of physical activity had lower levels of total cholesterol and higher levels of HDL-C when compared with less active (Armstrong and Simons-Morton, 1994). Findings from the European youth heart study, a large-scale study using objective measures of physical activity, reported significant associations between physical activity levels and both total cholesterol and triglycerides, but not HDL-C (Andersen *et al.*,

2006, Ruiz *et al.*, 2007). Recent reviews have examined the literature relating physical activity to blood lipids (Twisk, 2001, Janssen and LeBlanc, 2010, Andersen *et al.*, 2011). However, these reviews have reported inconsistent findings, stating that evidence from observational studies supporting the positive effect of physical activity on blood lipids are generally weak.

2. 4. 1. 1. 4 . Physical Activity and Blood Lipids

The association between physical activity and blood lipids from school based randomised and non-randomised control trials have also been reviewed. These reviews have concluded that weak improvements in blood lipids were observed with increases in levels of physical activity (Janssen and LeBlanc, 2010, Andersen *et al.*, 2011). In contrast to the findings of the European youth heart study, the most commonly observed improvements across school-based interventions were triglycerides and HDL-C, with limited or no improvements observed in LDL-C or total cholesterol (Strong *et al.*, 2005, Janssen and LeBlanc, 2010, Andersen *et al.*, 2011). Of the reviewed non-school based randomised and non-randomised control trials, it was highlighted that aerobic interventions produced the greatest likelihood of blood lipid improvement. While strength and circuit training interventions were beneficial, no significant improvements were observed (Janssen and LeBlanc, 2010).

Limited results have been published linking increases in physical activity to improvements in blood lipids in children and adolescents. Andersen and colleagues have highlighted that significant improvements in blood lipids are usually observed when significant improvements in physical activity and physical fitness are observed, yet a large number of interventions were unsuccessful in achieving these improvements (Andersen *et al.*, 2011). It has also been suggested that studies that have identified significant associations to date have had the greatest power, while the majority of studies that have reported limited or no associations have tended to be quite small, and possibly underpowered (Janssen and LeBlanc, 2010). Consequently, although it is recommended that further research is required to more accurately determine the association between physical activity and blood lipids in children and adolescence, it has been proposed that a sustained amount of daily physical activity (≈40 minutes) has the potential to improve blood lipid profiles in this population (Andersen *et al.*, 2011).

2. 4. 1. 2. Physical Activity and Blood Pressure

Blood flow through the cardiovascular system stems from ventricular contraction. When the ventricles of the heart contract, the semilunar valves open and release blood into the arteries. To accommodate the pressure, the arteries expand. Upon the relaxation of the ventricles, the semilunar valves close, preventing flow back from the arteries. The elastic arteries recoil due to the stored pressure in the elastic walls, and propel the blood forward throughout the circulatory system. The sustained driving pressure maintains continuous blood flow through the blood vessels (Silverthorn, 2012). The arterial pressure of the circulatory system is measured using blood pressure. Blood pressure is defined as the pressure exerted by blood on the walls of the blood vessels, and usually measured in the systemic arteries. During ventricular systole, pressure on the walls of blood vessels reaches an average high of 120 mmHg, while during ventricular diastole it reaches an average low of 80 mmHg. Criteria for normal blood pressure in child and adolescent populations is defined as less than the 90th percentile for age, sex and height, while hypertension (or elevated blood pressure) is defined as systolic or diastolic blood pressure persistently greater than the 95th percentile measured on three separate occasions (National High Blood Pressure Education Program, 2005).

Elevated blood pressure in childhood and adolescence increases the risk of hypertension in adulthood (Bao *et al.*, 1995, Sun *et al.*, 2007). Reviews have highlighted that intervention studies, which aimed to reduce systolic and diastolic blood pressure in obese and hypertensive youths, have reported significant reductions in systolic blood pressure (Strong *et al.*, 2005, Janssen and LeBlanc, 2010). The majority of results from intervention studies in normotensive youths have not reported any significant relationships between blood pressure and physical activity (Alpert and Wilmore, 1994, Kelley *et al.*, 2003, Rowlands, 2007b). However, it has been suggested that these insignificant differences may be due to inadequate intensity and duration of intervention in this specific age population (Kelley *et al.*, 2003, Janssen and LeBlanc, 2010). Only one observational study has examined the dose-response relationship between blood pressure and objectively measured physical activity in youth (Mark and Janssen, 2008). Findings from this study identified that a dose-response relationship exists between physical activity and blood pressure. Furthermore, this study highlighted that children and adolescents who achieved the recommended amount of

daily moderate to vigorous physical activity significantly reduced their risk of hypertension (Mark and Janssen, 2008).

This evidence suggests that increases in levels of physical activity improve blood pressure in hypertensive or obese children and adolescents, and that a dose response relation exists between levels of physical activity and blood pressure. Although the required dose or amount of physical activity necessary to reduce resting systolic and diastolic blood pressure remains unclear (Alpert and Wilmore, 1994), it is likely that increases in physical activity of a moderate to vigorous intensity over a prolonged period will have positive effects on blood pressure in children and adolescents (Kelley *et al.*, 2003).

2. 4. 1. 3. Physical Activity and Adiposity

Obesity is associated with unfavourable blood lipid profiles and elevated blood pressure in childhood and adolescence (McMurray *et al.*, 1995, Dietz, 1998, Sorof and Daniels, 2002, Reich *et al.*, 2003, Weiss *et al.*, 2004). However, complications in relation to childhood overweight and obesity normally do not become apparent until a later stage of life (Must and Strauss, 1999). The predominant risk factor associated with childhood and adolescent obesity is obesity in adulthood (World Health Organisation, 2000, Rowlands, 2007b, Daniels *et al.*, 2009). This is primarily due to the tracking of obesity levels from childhood and adolescence into adulthood (Serdula *et al.*, 1993, Guo and Chumlea, 1999, Freedman *et al.*, 2005, Thompson *et al.*, 2007, Franks *et al.*, 2010a, Nakano *et al.*, 2010).

The fundamental cause of overweight and obesity is an imbalance of energy intake and energy expenditure (Reilly, 2005, Daniels *et al.*, 2009). Physical activity provides the potential to increase energy expenditure (Harrell *et al.*, 2005, Ainsworth *et al.*, 2011), and hence assist in maintaining an adequate energy balance. However, to date, limited evidence is available to support the claim that increased levels of physical activity can reduce childhood overweight and obesity. An early review, which critically appraised paediatric obesity treatment and prevention interventions, suggested that "circumstantial" evidence existed to support the role that levels of physical activity and energy expenditure play the causation of overweight and obesity (Reilly and McDowell, 2003). More recent reviews of the literature concur with this, noting that the majority of studies, which examined both

subjective and objective measure of physical activity and weight gain did not find any association of measures or that associations were small (Wareham *et al.*, 2005, Janssen and LeBlanc, 2010, Wilks *et al.*, 2011). In contrast, Strong and colleagues noted that intervention programs of a moderate intensity (≈30-60 minutes on 3-7 days per week) were effective in reducing total body and visceral adiposity in overweight and obese children and adolescents, but had no significant effect on populations with normal weight profiles (Strong *et al.*, 2005). Strong et al. (2005) added that limited evidence has been provided to suggest that activities of a more vigorous intensity may be more effective in reducing percentage body fat in normal weight children and adolescents. Differing inclusion and exclusion criteria across reviews makes interpretation of the collective evidence of the effect of physical activity on obesity difficult. Additionally, a complex relationship exists between physical activity, diet and obesity, whereby the contribution of energy expenditure and energy intake to obesity remains unclear (Rowlands, 2007b, Wilks *et al.*, 2011).

Regardless of difficulties in determining the causation of childhood and adolescent obesity and of the inconsistent findings on the relation between physical activity and obesity, each review discussed above has drawn similar conclusions. Although limited evidence supports the hypothesis that increased physical activity reduces childhood overweight and obesity, physical activity should continue to be promoted across the lifespan (Must, 2003, Wareham *et al.*, 2005, Wilks *et al.*, 2011).

2. 4. 2. Associations between Physical Activity in Childhood and Adolescence and Indices of Health in Adulthood

There is incontrovertible evidence of the associations between physical inactivity and premature mortality and comorbidities including obesity, hypertension, type II diabetes and dyslipidemia in adult populations (Powell *et al.*, 2011). However, it has often been assumed that high levels of physical activity and physical fitness in childhood and adolescence is beneficial for indices of health in adulthood (Boreham *et al.*, 2002). The Harvard Alumni Study was among the first to examine the associations between physical activity in an adolescent and young adult population and indices of health in adulthood (Twisk, 2001). Published findings highlighted that no associations were observed between physical activity

levels in adolescence and the incidence of cardiovascular disease in adulthood (Paffenbarger Jr *et al.*, 1986).

In recent years, research has begun to examine the relationships between levels of physical activity in childhood and adolescence and indices of health in adulthood in more detail (Hallal *et al.*, 2006). Interestingly, Hallal and colleagues have noted that the majority of the literature is in agreement with initial observation from the Harvard Alumni Study, stating that little or no positive long-term effects of adolescent physical activity were associated with risk factors for cardiovascular morbidity in adults (Hallal *et al.*, 2006). However, research studies have identified significant associations between adolescent physical fitness, rather than physical activity, and risk factors for cardiovascular morbidity including total cholesterol, HDL-C, both systolic and diastolic blood pressure and percentage body fat in adulthood (Boreham *et al.*, 2002, Hernelahti *et al.*, 2004). As physical activity is significantly associated (albeit a weak to moderate association) with physical fitness (Kemper and Koppes, 2006, Martínez-Vizcaíno and Sánchez-López, 2008), it has been hypothesised that the lack of association between adolescent physical activity and cardiovascular morbidity in adulthood may be due to measurement issues (Hallal *et al.*, 2006). Although no associations have been observed between increased levels of physical activity in childhood and adolescents and cardiovascular morbidity in adulthood, positive associations have consistently been observed between physical activity in childhood and adolescence and reduced risk of breast cancer (Okasha *et al.*, 2003) and improved bone health in adulthood (Karlsson, 2004, Kohrt *et al.*, 2004).

The evidence associating physical activity in childhood and adolescence and cardiovascular disease in adulthood remains unclear. Regardless, the long term protective effect of participation in physical activity in childhood and adolescents should continue to be promoted. It is plausible that increased levels of physical activity in adolescence may reduce the risk of cardiovascular disease in adulthood. The majority of findings support the argument that physical activity in childhood and adolescence increases bone health, reduces the risk of breast cancer (Hallal *et al.*, 2006) and is positively associated with physical growth and behavioural development (Warburton *et al.*, 2006).

2. 4. 3. Tracking of Physical Activity from Childhood and Adolescence into Adulthood

Increased levels of physical activity in adulthood are associated with reduced risk of mortality and chronic diseases (Powell *et al.*, 2011). It has been hypothesised that increasing physical activity levels in childhood and adolescence can indirectly reduce the risk of mortality and chronic disease in adulthood through increasing the likelihood that individuals will become more active in adulthood (Blair *et al.*, 1989a). This idea is known as long-term stability or tracking of physical activity (Twisk, 2001). The concept of tracking refers to an individual's tendency to maintain their relative rank within a group over a period of time (Malina, 1996, Malina, 2001a). In terms of physical activity, tracking examines the tendencies of individuals to maintain their levels of physical activity across specific age ranges, normally from childhood and/or adolescence through to adulthood (Malina, 2001b).

Detailed reviews have examined the literature on the stability of physical activity levels across childhood and adolescence and into adulthood (Malina, 2001b, Telama, 2009). Malina and colleagues (2001) highlighted that a low to moderate inter-age correlation exists between early to middle childhood (≈4-8 years), while limited information was available on the tracking of physical activity between middle childhood and adolescence. Furthermore, this review identified that tracking varied across adolescence depending on the duration of follow up, with shorter studies (≈ 3 years) noting moderate inter-age correlations and longer studies (≈ 5-6 years) noting lower inter-age correlations. However, when examined together, a consistent low to moderate tracking of physical activity was evident across adolescence (Malina, 2001b). In a more recent review of the literature, Telama and colleagues (2009) have acknowledged that tracking studies have significantly low or moderate stability across all ages (Telama, 2009). Both reviews conclude that physical activity tracks reasonably well from childhood and adolescence to adulthood (Malina, 2001b, Telama, 2009).

The stability of sedentary behaviours has also been examined across the lifespan. Biddle and colleagues concluded that sedentary behaviours tracked moderately well (regardless of measurement type) during childhood and adolescence and into adulthood, with TV viewing time producing the strongest inter-age correlations (Biddle *et al.*, 2010). Malina has also

highlighted that long-term stability of inactivity is higher than that of activity (Malina, 1996). However, it is critical to understand that although stability for a specific variable, such as inactivity, is high over time, stability refers to the relative rank within a group. This does not imply that levels of inactivity remain consistent, rather it is more likely that the measured population are becoming less/more inactive together (Twisk, 2001). It is also important to acknowledge that all forms of tracking are highly influenced by measurement error (Twisk, 2001). The majority of studies referred to by Malina, Biddle and Telama were self-reported studies, which have significant validity and reliability limitations (as discussed in more detail in Section 2. 7. 2. 1), particularly in children and young adolescents (Welk *et al.*, 2000, Trost, 2007). This may further contribute to the low to moderate correlations that have been observed when tracking physical activity across childhood, adolescence and adulthood (Twisk, 2001, Trudeau *et al.*, 2004). Regardless of these low to moderate findings, researchers emphasise the importance of participating in regular physical activity and reducing sedentary time during childhood and adolescence. This may be effective in increasing physical activity and reducing sedentary time in adulthood, hence improving indices of health and reducing the risk of chronic disease (Malina, 2001b, Biddle *et al.*, 2010).

2. 4. 4. Sedentary Behaviour and Health in Childhood and Adolescence

Technological developments, including the dependence on motor transport and the development of labour saving devices in the home, work and school environments have increased sedentary patterns and behaviours in recent years across all ages, including children and adolescents (Salmon *et al.*, 2011). Although a relatively new area of interest, epidemiological studies have examined the effect of subjectively measured sedentary patterns and behaviours on indices of health in childhood and adolescence. A recent review, which examined the relationship between self-reported TV viewing and sedentary time and health indicators, highlighted that there is moderate evidence of an inverse longitudinal relationship between sedentary behaviour and aerobic fitness in childhood (Chinapaw *et al.*, 2011). However, publications which have identified significant relationships between self-report measures of sedentary time and indices of health should be viewed with caution (Marshall *et al.*, 2004), as TV viewing is associated with unhealthy

snacking (Utter *et al.*, 2006) and sleeping patterns (Johnson *et al.*, 2004), which may distort identified associations. Furthermore, self-reported physical activity and sedentary behaviours in childhood and adolescence have well-documented limitations, as discussed in Section 2. 7. 2.

Researchers have examined the effects of sedentary patterns and behaviours on health parameters in children and adolescents using more accurate objective measures. Martinez-Gomez and colleagues have identified that total daily sedentary time was associated with higher cardiovascular risk in two hundred and ten 13-17 year olds, adding that those with a less favourable adiposity were at a greater cardiovascular risk (Martinez-Gomez *et al.*, 2010). Findings from the European youth heart study identified that an inverse correlation existed between objectively measured total sedentary time and metabolic risk factors in one thousand seven hundred and nine 9-10 and 15-16 year olds (Ekelund *et al.*, 2007a). However, it should be noted that neither of these studies accounted for moderate to vigorous physical activity, which is an independent predictor of cardio-metabolic risk (Carson and Janssen, 2011). Findings from "The HELENA Study" have also highlighted significant associations between total sedentary time and low levels of cardiorespiratory fitness in 12-17 year old adolescents, while also highlighting that adolescent females that spend greater than 2/3 or their waking time sedentary are more likely to have low levels of cardiorespiratory fitness, independent of physical activity (Martinez-Gomez *et al.*, 2011b). In contrast with these findings, research has demonstrated that although a positive association was observed between sedentary behaviour and obesity in a large cohort of 12 year olds, this relationship was not apparent when moderate to vigorous physical activity was taken into consideration (Mitchell *et al.*, 2009). Additionally, Carson and Janssen examined the associations of total sedentary time and patterns of sedentary behaviour with cardio-metabolic risk factors in 6-19 year olds and found no association independent of moderate to vigorous physical activity, while TV viewing time and low levels of moderate to vigorous physical activity were both associated with cardio-metabolic risk (Carson and Janssen, 2011).

The contrasting results identified here are not surprising. Differences in sedentary cut-points employed and differences in data processing, cleaning and presentation are evident across each article (Lubans *et al.*, 2011). Similar to the objective examination of physical activity, the lack of a standardised method of analysing these variables poses significant problems in the objective examination of sedentary patterns and behaviours, as

comparability of research findings between studies is extremely difficult (Ward *et al.*, 2005, Rowlands, 2007a). Furthermore, the effectiveness of the use of cut-points in the examination of sedentary behaviours must be taken into consideration (discussed further in Section 2. 9. 2).

2. 5. Current Physical Activity Recommendations

Public health experts have produced physical activity guidelines and recommendations to educate general populations on the optimal amount of physical activity necessary to maintain and/or improve indices of health, hence enabling them to make informed decisions on their level of participation (U.S. Dept. of Health and Human Services, 1996, Department of Health and Ageing, 1999, Haskell *et al.*, 2007, Physical Activity Guidelines Advisory Committee, 2008). There is now a consensus that the risk of chronic disease is reduced when adults participate in at least 30 minutes of moderate to vigorous physical activity on at least 5 days of the week. Furthermore, accumulating the activity in intermittent bouts as short as ten minutes was a suitable way of meeting the 30 min goal (DeBusk *et al.*, 1990, Jakicic *et al.*, 1995, Murphy *et al.*, 2000, Warburton *et al.*, 2006, Pate, 2007). For children and adolescents, it has been suggested that 60 minutes of moderate to vigorous physical activity be accumulated on at least 5 days per week for optimal health benefits (World Health Organisation, 2011, Department of Health and Children, 2012). The prescribed recommendation for frequency of physical activity is based on the re-examination of recommendations by the U.S. Dietary Advisory Committee (U.S. Department of Health and Human Services and U.S. Department of Agriculture, 2005, Department of Health and Children, 2012).

2. 5. 1. Dose-Response Relationship

It is important to recognise that the guidelines outline the minimum recommended frequency, intensity and duration of activity that will reduce the risk of onset of chronic illness (Pate, 2007). A dose-response relation of intensity, duration and frequency exists, suggesting that greater health benefits can be obtained by participating in physical activity

more vigorously, more frequently and for a longer duration then suggested in guidelines (Masse *et al.*, 1999, Kohl, 2001, Haskell *et al.*, 2007, Powell *et al.*, 2011). However, it is essential that the dose-response needs to consider not only what dose induces the most health benefits, but also the risk profile for that dose, for example in people with underlying diseases or health complications (Pate, 2007).

2. 5. 2. Intensity

Intensity is a key component to be examined when analysing the appropriate dose of physical activity required to impact specific health and fitness outcomes (U.S. Dept. of Health and Human Services, 1996, Garber *et al.*, 2011). Intensity is described as the required overload that is exerted on specific systems (i.e. cardiovascular) that is necessary to bring about improvements (Sisson and Katzmarzyk, 2008). Initial recommendations of physical activity indicated that vigorous activity was required to produce health benefits (American College of Sports Medicine, 2007). However, it is now accepted that most health benefits experienced at vigorous intensity physical activity are also experienced at activities of a moderate intensity (American College of Sports Medicine, 2007, Haskell *et al.*, 2007, Garber *et al.*, 2011). These recommendations are based on experimental exercise training studies published during the 1980's and 1990's. These studies found similar health improvements, such as increases in levels of high-density lipoprotein (HDL) and reductions in blood pressure between individuals who participated in moderate physical activity and vigorous physical activity (Duncan *et al.*, 1991, Bouchard *et al.*, 1993, Després *et al.*, 2000). As identified above, a dose-response relationship exists between physical activity and health benefits (Powell *et al.*, 2011). This relationship applies to intensity also, highlighting that health improvements occur at low levels of exercise intensity or total energy expenditure, yet a higher intensity of physical activity produces greater improvements to health (U.S. Dept. of Health and Human Services, 1996, Lee *et al.*, 2000, Kohl, 2001).

2. 5. 3. Duration

Physical activity dose is a combination of frequency, intensity and duration of activity. Duration must be viewed with intensity, as the volume of energy expended throughout the day is essential when comparing physical activity and health benefits (American College of Sports Medicine, 2007). The majority of physical activity recommendations identify 30 minutes of moderate to vigorous physical activity as the minimum duration of daily activity necessary for adults, while 60 minutes of moderate to vigorous activity is recommended children and adolescents (U.S. Dept. of Health and Human Services, 1996, Department of Health and Ageing, 1999, Haskell *et al.*, 2007, Physical Activity Guidelines Advisory Committee, 2008, Department of Health and Children, 2012). These recommendations have been based on findings from large-scale epidemiological research (Morris *et al.*, 1953, Paffenbarger Jr *et al.*, 1986, Powell *et al.*, 1987). It is proposed that regularly participating in 30 minutes of moderate to vigorous physical activity (60 minutes for children and adolescents) helps increase caloric/energy expenditure, which positively affects weight loss (Jakicic *et al.*, 1995). It is also suggested that participating in the recommended amount of activity reduces risk of diseases such as osteoporosis, type II diabetes and hypertension (U.S. Department of Health and Human Services, 2008, Powell *et al.*, 2011).

2. 5. 4. Accumulation:

Accumulation of physical activity is the concept of achieving one's daily recommended activity using multiple short bouts of a specific intensity throughout the day (i.e. moderate to vigorous physical activity). Accumulation of physical activity was first included in public health guidelines in 1995 (Pate *et al.*, 1995). The guidelines state the prescribed 30 minutes of daily physical activity can be accumulated in short bouts throughout the day. These guidelines were developed from perspective observational studies relating amounts of activity to coronary heart disease, along with results of experimental studies that examined the effect of a single, longer bout of activity versus three shorter bouts of activity on health benefits (Paffenbarger Jr *et al.*, 1986, Leon *et al.*, 1987, DeBusk *et al.*, 1990). Since the concept of accumulation was introduced in public health guidelines, research reported that similar health benefits achieved by completing 30 minutes of consecutive moderate to

vigorous physical activity can also be achieved by accumulating 3 ten minute bouts of activity (Jakicic *et al.*, 1995, Murphy and Hardman, 1998, Murphy *et al.*, 2000). Murphy and colleagues (2000) highlighted the similarity in levels of triglyceride concentration after two separate exercise interventions, 1 continuous 30 minute bout of moderate physical activity versus 3 intermittent 10 minute bouts of moderate physical activity (Murphy *et al.*, 2000). Jakicic *et al.* (1995) noted similar increases in peak oxygen uptake and weight loss between participants completing an intervention involving 1 continuous bout of moderate activity versus participants completing 3 intermittent bouts of moderate activity (Jakicic *et al.*, 1995). It is now widely accepted that the accumulation of shorter bouts of activity lasting 10 minutes shows similar benefits when compared with one longer bout, and these guidelines continue to be an important aspect in physical activity recommendations (Physical Activity Guidelines Advisory Committee, 2008, Department of Health and Children, 2012). The promotion of intermittent bouts of activity is essential in encouraging participation in physical activity, as poor adherence to planned physical activity programs due to perceived lack of available time is a key contributing cause to physical inactivity (Marcus *et al.*, 1996, Murphy *et al.*, 2002). Inactive individuals are more likely to perform multiple short bouts of activity throughout the day, as 10 minute bouts of free time are more available in modern, hectic lifestyle (Marcus *et al.*, 1996, Murphy *et al.*, 2002).

It should be acknowledged that researchers have continued to examine the relationship between the length of physical activity bouts and health indices. Miyashita *et al.* (2006) identified similar reductions in postprandial triacylglycerol concentrations when ten three-minute bouts of moderate to vigorous physical activity were compared to 1 continuous 30 minute bout, further questioning whether the duration of activity recommended in current guidelines is accurate or effective (Miyashita *et al.*, 2006). Other studies have highlighted that lower levels of physical activity, as low as half the current recommendations, may be sufficient to induce health benefits (Warburton *et al.*, 2006). Further studies examining the effect of shorter physical activity bouts (< 10 mins) on daily accumulated activity are required to determine if even shorter bouts of physical activity can provide significant health improvements. Nevertheless, until this research is undertaken, current guidelines on accumulated physical activity bouts should be adhered to.

2. 6. Summary: Section A

Although there is evidence that increased levels of physical activity in childhood and adolescence are beneficial to indices of health (Strong *et al.*, 2005, Hallal *et al.*, 2006, Janssen and LeBlanc, 2010), it is clear from the findings presented throughout this section that further research on the effects of physical activity and sedentary behaviours on indices of health is necessary. A significant limitation of existing research may be the lack of accurate and objective measures of both physical activity and sedentary behaviours (Pate *et al.*, 2008, Owen *et al.*, 2010), which has potentially reduced the associations made between specific activity patterns and behaviours and indices of health across all ages. Until further large-scale epidemiological studies have objectively examined both levels of physical activity and sedentary behaviours in children, adolescents and adults, and have compared these patterns and behaviours with accurate health measures, current guidelines on the recommended amount of physical activity across the lifespan should be adhered to. Furthermore, the target of reducing total sedentary time and prolonged sedentary periods, as in the Canadian guidelines for sedentary behaviour (Tremblay *et al.*, 2011), should be recommended in all future physical activity guidelines (Hamilton *et al.*, 2008).

2. 7. Section B: Physical Activity Assessment in Childhood and Adolescence

As identified in Section 2. 2. 2, physical activity is inversely associated with improvements in indices of health, whereby individuals with higher levels of physical activity are at a lower risk of disease and all-cause mortality (U.S. Dept. of Health and Human Services, 1996, Physical Activity Guidelines Advisory Committee, 2008, Garber *et al.*, 2011). However, physical activity is a complex construct and is a particularly difficult behaviour to assess (Caspersen *et al.*, 1985, Kohl *et al.*, 2000, Butte *et al.*, 2012). Almost 60 years since the publication of initial physical activity and health-related findings, researchers continue to examine human activity behaviour in an attempt to accurately identify the relationship between different activity patterns and behaviours and indices of health (Sallis *et al.*, 2000). Furthermore, the relatively new research areas of sedentary patterns and behaviours and non-exercise activity thermogenesis have added new dimensions to be considered in

physical activity assessment (Levine *et al.*, 2001, Bassett Jr *et al.*, 2010, Bauman *et al.*, 2011, Loprinzi and Cardinal, 2011).

The assessment of physical activity provides independent variables when examining relationships with indices of health and behavioural correlates of physical activity (Welk, 2002). The ability to make strong associations between variables of activity and health is dependent on its reliability and validity (Caspersen *et al.*, 1985, Trost, 2007, Westerterp, 2009, Loprinzi and Cardinal, 2011, Intille *et al.*, 2012). The reliability of an instrument is the consistency with which the instrument measures what it is intended to measure (Kohl *et al.*, 2000, Warren *et al.*, 2010). Reliability is a prerequisite for validity, as reliability must be established before a measure can be valid (Morrow, 2002). Validity is the degree to which an instrument can measure what it is intended to measure (Kohl *et al.*, 2000, Morrow, 2002, Warren *et al.*, 2010). The reliability and validity of a measurement tool must be considered prior to being employed in specific populations, specific settings and when examining specific activity variables of physical activity (Morrow, 2002, Ward *et al.*, 2005, Trost, 2007).

Different methods of examining physical activity can be categorised into calorimetry, behavioural observation, self-report, physiological variables, and motion sensors (Westerterp, 2009). During this section, the validity, reliability and practicality of each methodology will be considered.

2. 7. 1. Calorimetry

The law of thermodynamics state that energy is neither created nor destroyed, but is rather changed from one form to another. Within the human body, chemical energy (energy intake in the form of food) is used to produce mechanical energy (energy expended throughout daily living) (Starling, 2002). The predominant categories by which energy is expended in the human body have been discussed in detail in Section 2. 2. 3 (resting metabolic rate, thermic effect of food and activity thermogenesis). Three methods of accurately examining energy expenditure in humans are direct calorimetry, indirect calorimetry and doubly labelled water. Direct calorimetry measures energy expenditure directly by assessing heat production (Jequier, 1981, Brychta *et al.*, 2010). Although this is a valid and reliable measure for energy expenditure, it is extremely expensive to establish and

run, requires enormous knowledge and expertise of equipment and does not provide more accurate results than indirect measures (Levine, 2005, Brychta *et al.*, 2010). Additionally, the use of indirect calorimetry chambers are limited in physical activity and health-related research due to high costs and their inability to examine realistic free-living activities due to its artificial setting (Starling, 2002, Brychta *et al.*, 2010). For this reason, this review will focus on indirect calorimetry using open circuit calorimetry and doubly labelled water.

2. 7. 1. 1. Indirect Calorimetry

Indirect calorimetry measures heat production indirectly through examining oxygen consumption (Starling, 2002). Initially, closed circuit indirect calorimetry systems that consisted of sealed respiratory gas circuits (which measured levels of expired gas over time) were the predominant method of indirect calorimetry measurement. However, the most common and easiest indirect calorimetry measures currently in use are the open circuit indirect calorimeter systems (Levine, 2005). Levine has provided a detailed description of the processes involved in open circuit indirect calorimetry methodologies (Levine, 2005). Briefly, different forms of open circuit systems exist, including ventilated open circuit systems (ventilated hood technique) and expiratory collection systems (portable metabolic systems such as the Cosmed K4B^2 and the Jaeger Oxycon Mobile). Ventilated open circuit systems tend to be laboratory-based systems which are fixed to mobile carts and are predominantly used for the examination of resting metabolic rate and the thermic effect of food, while expiratory collection systems are mobile metabolic systems which can be employed in both laboratory or field-based settings and are normally used to examine activity thermogenesis (Matarese, 1997, Starling, 2002, Brychta *et al.*, 2010).

When compared with similar measures (such as direct calorimetry and doubly labelled water), indirect calorimetry provides an accurate measure of energy expenditure at a lower cost using equipment that does not require specialist training (Levine, 2005). It has commonly been employed as a criterion measure for energy expenditure (Trost, 2007), and has historically been used to validate heart rate monitors (Treiber *et al.*, 1989, Emons *et al.*, 1992, Bitar *et al.*, 1996, Eston *et al.*, 1998, Troutman *et al.*, 1999), pedometers (Eston *et al.*, 1998) and motion sensors (Rowlands *et al.*, 2004, Pate *et al.*, 2006, Calabró *et al.*, 2009, Esliger *et al.*, 2011). Unfortunately, the use of indirect calorimetry in validation studies is

not without its limitations. Mobile metabolic devices (which are worn over the shoulders or on the back) alter the variable being measured through adding additional weight to the individual being measured (Brychta *et al.*, 2010). However, when validating instruments for measurement of habitual physical activity, it is critical to include activities of daily living (Bassett Jr *et al.*, 2012), and the advantages obtained through using indirect calorimetry outweigh the disadvantages. With this, indirect calorimetry has been recommended as an appropriate criterion for minute by minute energy expenditure to be used during the validation of free-living measures of physical activity (Bassett Jr *et al.*, 2012, Freedson *et al.*, 2012).

2. 7. 1. 2. Doubly labelled water

Doubly labelled water has been highlighted as the most valid and reliable criterion measurement for energy expenditure (Schoeller *et al.*, 1986, Schoeller, 1988). This method of examining energy expenditure is based on the chemical reactions of two stable isotopes of water, ^2H_2O (deuterium labelled water) and $H_2^{18}O$ (Oxygen labelled water) (Trost, 2007). An individual is required to provide a baseline urine sample, ingest a standardised dosage of both stable isotopes, provide an additional two urine sample the morning after ingesting the dosage and return to their normal daily life (Starling, 2002). After a specified period (protocols have ranged between 12 and 21 days), two final urine samples are provided (Welk *et al.*, 2000). The urine samples are then examined using a mass spectrometer to identify the rates of elimination of ^2H_2O and $H_2^{18}O$ (Starling, 2002). The declining level of deuterium labelled water is a function of H_2O turnover, while the decline in oxygen labelled water is a function of both H_2O and CO_2. The difference between the two stable isotopes is then examined over the measurement period to determine the total CO_2 production over this period (Goran, 1994, Shetty, 2002). A graph of the elimination of ^2H_2O and $H_2^{18}O$ is provided in Figure 2.3. Once CO_2 production over the examination period has been determined, a series of calculations involving basal metabolic rate and the thermic effect of food are used to provide information of energy expended through activity thermogenesis (Starling, 2002).
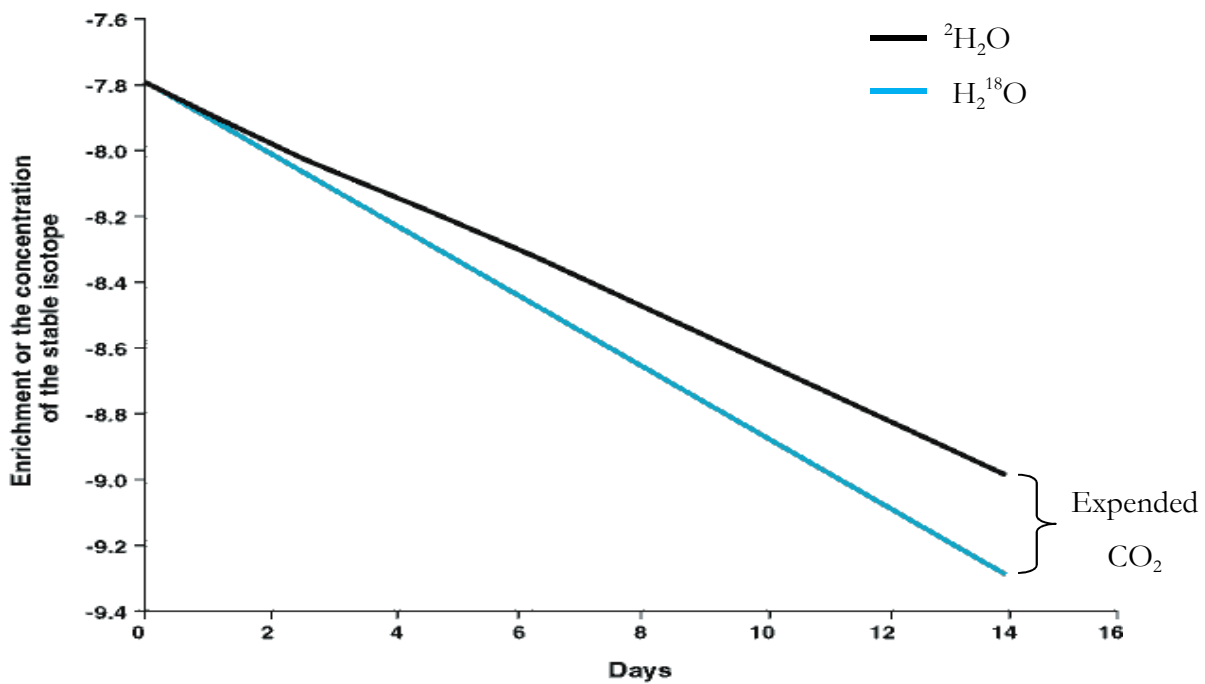
Figure 2.3: The elimination rates of ^2H_2O and $H_2^{18}O$ over a 14 day period.

Doubly labelled water has been validated in both children and adults with indirect calorimetry and has been found to be accurate between 5 and 10% (Goran, 1994). Due to its high accuracy, doubly labelled water has been suggested as the gold standard of energy expenditure measurement (Schoeller, 1999, Trost, 2007). It is a relatively unobtrusive and non-invasive method of examining total energy expenditure in free-living youths (Welk *et al.*, 2000, Starling, 2002, Trost, 2007). Unlike objective measures of physical activity, there is no continuous measurement over prolonged periods (Welk *et al.*, 2000). Additionally, participants can be blinded from the experiment, as the measurement can also be used to examine body composition, and should not result in individuals reacting by increasing their levels of physical activity (Starling, 2002). Unfortunately, doubly labelled water is not applicable in large-scale studies due to the high cost of the relevant isotopes and the potential burden for participants to visit testing centres to provide urine samples (Schoeller, 1999, Kohl *et al.*, 2000, Welk *et al.*, 2000). Furthermore, doubly labelled water only provides information on total energy expenditure and total activity energy expenditure, and cannot provide any information on frequency, intensity or duration of activities (Kohl *et al.*, 2000, Welk *et al.*, 2000, Trost, 2001, Trost, 2007). However, the accuracy of doubly labelled water has resulted in its use to examine the validity of measures of physical activity such as self-

report (Philippaerts *et al.*, 1999, Conway *et al.*, 2002), accelerometry (Plasqui and Westerterp, 2007) and heart rate monitoring (Emons *et al.*, 1992, Livingstone *et al.*, 1992, Maffeis *et al.*, 1995), which may in turn be used in epidemiological studies.

2. 7. 1. 3. Behavioural Observation

In a physical activity and health-related research setting, direct observation is a behavioural observation methodology which is particularly effective when examining physical activity in young children (Welk *et al.*, 2000, McKenzie, 2002). This is primarily due to measurement limitations with self-reported and accelerometer determined physical activity in these populations. Direct observation is employed to classify physical activity behaviours into specific categories which can be examined and analysed in detail (McKenzie, 2002). This methodology involves observing a child/group of children for a specific time period while recording activity levels and types of activity on a momentary time-sampling basis (Trost, 2007). Specific activities, types of activities and locations are recorded and coded in a log or handheld computer device (e.g. laptop/tablet) (Kohl *et al.*, 2000, Trost, 2007).

2. 7. 1. 4. Reliability and validity:

Direct observation has been identified as both a valid and reliable measure of physical activity in children (Trost, 2007). When examining the validity of direct observation protocols, Kohl and colleagues identified that 9 studies were validated with physiological measures (heart rate = 4; observation = 1; self-report = 1; activity monitor = 1; indirect calorimetry = 2) (Kohl *et al.*, 2000). Each study reported some amount of validity, while one particular study, which employed indirect calorimetry (the gold standard when validating an activity measurement device), reported particularly high levels of validity (Bailey *et al.*, 1995). The reviewed studies which employed direct observation methodologies also highlighted high levels of inter-observer reliability (Klesges, 1984, O'Hara *et al.*, 1989, Puhl *et al.*, 1990, McKenzie *et al.*, 1991a, McKenzie *et al.*, 1991b, Bailey *et al.*, 1995) and moderate to high levels of test-retest reliability (Klesges, 1984, DuRant *et al.*, 1993, Rowe *et al.*, 1997). In contrast, one study found inconsistent aerobic activity

between 2 day test-retest reliability (Baranowski *et al.*, 1987), which is not unexpected. This is due to the variance in activity patterns of children from day to day (Klesges, 1984).

2. 7. 1. 5. Practicality

Due to the labour intensive nature of direct observation, its use in large-scale epidemiological studies as a measure of activity patterns and behaviours is unrealistic (Kohl *et al.*, 2000). As evidenced in a review by McKenzie, data collection among children and adolescents is normally only possible in a small sample in specific environments (school, home, organised sports locations) for particular periods of the day (class time, break time etc.) (McKenzie, 1991, McKenzie, 2002). Observers are required to be trained in the specific protocol for data collection and to spend long periods examining the momentary changes in an individual's activity patterns and behaviours (Kohl *et al.*, 2000, McKenzie, 2002, Trost, 2007). Additionally, direct observation can be reactive, whereby the presence of an observer causes the observed to react to the variable being measured, and may result in increased levels of physical activity. This limitation can be overcome by repeated observations (Trost, 2007).

However, despite the described shortcomings, direct observation has specific advantages over other forms of physical activity assessment (McKenzie, 1991). This methodology provides researchers with rich information on the type of activity an individual participates in, the location of the activity and the environment in which the activity takes place (Welk *et al.*, 2000, Trost, 2007), which cannot be accurately gathered using other measures of physical activity. Furthermore, the development and validation of community-based behavioural observation methodologies, such as SOPARC, allow the examination of a range of physical activity variables including type of activity, activity domain, age, sex and a range of additional contextual information in large cohorts of individuals at one time (McKenzie *et al.*, 2000). This type of observation may be particularly informative for community and governmental bodies, as it provides details regarding the influences of the physical and social environments on youth physical activity (Trost, 2007).

2. 7. 2. Self-Report

Self-report is one of the most valuable and commonly employed measurement instrument in physical activity and health-related research (Kohl *et al.*, 2000, Matthews, 2002, Trost, 2007). It is a cheap and easy method of collecting physical activity information from large cohorts in a short time period (Warren *et al.*, 2010). To date, the majority of significant epidemiological evidence associating physical activity patterns and behaviours with health indices in adults has been observed using self-reported physical activity (Paffenbarger Jr *et al.*, 1986, Wannamethee *et al.*, 1998, Gregg *et al.*, 2003). However, the relationships between physical activity and indices of health in youths using self-reported measures are less well established.

2. 7. 2. 1. Validity and reliability:

Self-reported physical activity includes self-administered recall questionnaires, interview administered recall questionnaires, diaries and proxy reports (Sallis and Saelens, 2000, Trost, 2007). As with all measures of physical activity, the accuracy of the information obtained using self-report is dependent on the validity and reliability of the measurement instrument (Chinapaw *et al.*, 2010). A number of detailed reviews have highlighted levels of validity and reliability of self-reported instruments in the measurement of physical activity (Kohl *et al.*, 2000, Sallis and Saelens, 2000, Trost, 2007, Chinapaw *et al.*, 2010).

Published reviews of self-report measurement instruments in youths have acknowledged that validity varies significantly across validation methodology and measurement protocol (Kohl *et al.*, 2000, Sallis and Saelens, 2000, Trost, 2007). Sallis and Saelens highlighted that validity correlations ranged from 0.4 to 0.77 for proxy reports, 0.07 to 0.88 for self-administered questionnaires and from 0.17 to 0.72 for interviews (Sallis and Saelens, 2000). The authors highlighted that although all measures reported some form of validity, interview-administered measures appeared to consistently correlate better (2/3 of interview administered validity correlations were greater than 0.5) (Sallis and Saelens, 2000). Similar findings for validation of self-report instruments were reported by Kohl and colleagues, who added that the majority of instrument validation correlations fell in the 0.3 to 0.5 range (Kohl *et al.*, 2000). Although reviews have compared the validity of self-reported physical

activity in adult populations using the gold standard doubly labelled water (Prince *et al.*, 2008), only one study validated self-reported physical activity against doubly labelled water in children and adolescence (Craig *et al.*, 1996). A correlation of 0.47 was identified between measures, however methodological issues with this validation have been raised (comparison of 1-year recall with doubly labelled water) (Kohl *et al.*, 2000).

The comparison of the reliability of self-reported measures of physical activity from study to study is extremely difficult. This is primarily due to the nature of self-reported physical activity, whereby inaccurate cognitive processing and recall, coupled with high variability in physical activity levels of children and adolescents significantly contribute to variability between test/re-test results (Shephard, 2003, Chinapaw *et al.*, 2010, Warren *et al.*, 2010). A review of self-reported physical activity conducted by Sallis and Saelens reported acceptable levels of reliability for all reviewed self-reported measures, ranging from 0.6 to 0.98 (Sallis and Saelens, 2000), while a recent review by Chinapaw and colleagues identified that test/re-test correlations for self-report instruments varied from 0.02 to 0.96 (Chinapaw *et al.*, 2010). Kohl and colleagues reviewed test-re-test reliability of self-report measures over specified time periods (ranging from 45 minutes to 8 years), and reliability coefficients ranged from 0.2 to 0.99 (Kohl *et al.*, 2000). Upon further analysis, the reliability of measures which were examined over a shorter period produced the greatest correlations, while the reliability of measurement instruments in children younger than 10 years was limited. Furthermore, reliability generally improved with age from childhood to adolescence (Kohl *et al.*, 2000). With the large body of self-reported physical activity literature, it is not surprising to see wide ranges of variability in reliability across self-report measurement instruments due to the variance in cognitive processes and activity levels across childhood and adolescence (Matthews, 2002).

The benefits and limitations of self-report as a measure of physical activity in epidemiological research have been discussed in great detail in a number of literature reviews (Sallis and Saelens, 2000, Shephard, 2003, Prince *et al.*, 2008, Chinapaw *et al.*, 2010). Self-reported physical activity is a cheap method of examining physical activity as it normally only requires a pencil and a self-report measurement instrument and, as a result, can be implemented in large cohorts of individuals at one time (Sallis and Saelens, 2000, Matthews, 2002, Prince *et al.*, 2008). Additionally, the information obtained is non-reactive as it normally involves recall of activities and does not alter the behaviour under investigation (Sallis and Saelens, 2000). Along with recording activity type, self-report also

has the ability to provide researchers with behavioural, environmental and contextual information of physical activity patterns and behaviours (Kohl *et al.*, 2000, Matthews, 2002, Trost, 2007, Warren *et al.*, 2010). However, levels of recall bias and misinterpretation of the term 'physical activity' are significant constraints in self-reported physical activity in children (Baranowski, 1984, Trost *et al.*, 2000). Furthermore, as discussed earlier, the majority of validation studies have reported only moderate correlations, which has led to concerns regarding the accuracy of self-report information from children and adolescents (Sallis and Saelens, 2000). There also appears to be an enormous lack of consistency when examining youth physical activity via self-report, with investigators feeling obligated to design and validate a self-report instrument of their own rather than using an existing instrument with acceptable validity and reliability (Trost, 2007). Although self-report is a practical measure of physical activity in large populations (Shephard, 2003), substantial research of a high quality is needed in children and adolescents to improve their validity and reliability (Chinapaw *et al.*, 2010).

2. 7. 3. Heart Rate Monitoring

Heart rate monitoring provides investigators with an estimation of the level at which the cardio-respiratory system works during movement (Armstrong, 1998). A linear relationship exists between increases in heart rate and increases in energy expenditure during exercise (Berggren and Christensen, 1950), primarily due to the requirement of the heart to deliver oxygen to these muscles (Welk *et al.*, 2000, Janz, 2002, Warren *et al.*, 2010). As physical activity and energy expenditure are interrelated (Caspersen *et al.*, 1985), heart rate monitoring is used to provide an objective, indirect measure of physical activity based on physiological effects (Welk *et al.*, 2000). Heart rate monitoring (using flex HR method at a group level to determine activity intensity) has been validated for free-living physical activity against total energy expenditure and physical activity energy expenditure using calorimetry and doubly labelled water in children and adults, and has provided valid and acceptable data (Ceesay *et al.*, 1989, Livingstone *et al.*, 1990, Emons *et al.*, 1992).

Compared with other objective field measures, heart rate monitoring is a relatively inexpensive method of estimating levels of physical activity (Janz, 2002). Heart rate monitors record information for several days, and provide relatively accurate information

to investigators. Initially, the use of heart rate monitors in large-scale epidemiological studies was recommended (Livingstone *et al.*, 1990, Emons *et al.*, 1992). Although heart rate is a physiologically determined estimate of physical activity, its limitations must be considered. Many different factors affect heart rate and the resulting relationship with VO_2 including age, body composition and cardio-respiratory fitness, resulting in various sources of error influencing validity (Welk *et al.*, 2000, Rowlands and Eston, 2007, Trost, 2007). Additional fundamental measurement limitations of heart rate in the examination of youth physical activity exist. There is a delay between physical activity and heart rate response. Also, heart rate tends to remain elevated for prolonged periods after physical activity. Due to these limitations, the ability of heart rate monitors to provide detailed activity information in youths, who have more sporadic activity patterns than adults, has been questioned (Welk *et al.*, 2000, Trost, 2007). Furthermore, the loss of data due to signal loss and low compliance due to discomfort are additional disadvantages in using heart rate monitors in youths (Welk *et al.*, 2000). The substantial limitations associated with heart rate monitoring have impacted its use in large-scale epidemiological studies, but its full potential may yet be seen, as some motion devices now incorporate both accelerometry and heart rate as an estimate of physical activity and energy expenditure with significant reliability and validity (Brage *et al.*, 2005, Barreira *et al.*, 2009).

2. 7. 4. Motion Sensors

2. 7. 4. 1. Pedometers

There is a need for low cost, accurate and objective devices to examine ambulatory activity (Bassett Jr and Strath, 2002). It has been suggested that pedometers may be the most practical solution (Welk *et al.*, 2000, Tudor-Locke *et al.*, 2002). Pedometers are small, objective devices that measure the number of steps taken and distance walked/run over a specific measurement period (Washburn *et al.*, 1980, Sirard and Pate, 2001, Rowlands and Eston, 2007, Warren *et al.*, 2010). Most electronic pedometers contain a horizontal spring suspended lever arm that moves up and down due to vertical acceleration during ambulation of the hips (Bassett Jr and Strath, 2002, Tudor-Locke *et al.*, 2002). This opens and closes an electrical circuit, which registers a step count on a digital display. These

devices are normally attached to the waist using a specific belt or waistband, and are normally worn in the midline of the thigh to best examine the vertical accelerations (Bassett Jr and Strath, 2002).

A review by Tudor-Locke and colleagues has highlighted the concurrent validity of pedometers when compared against accelerometers, behavioural observation, self-report and energy expenditure (Tudor-Locke *et al.*, 2002). Output from pedometers was highly correlated with that from accelerometers when raw data from both was compared for free-living conditions (median r = 0.86). Pedometers also perform well when validated against direct observation for ambulatory activity, but poorly when ambulation was slow and in individuals with increased adiposity (median r = 0.82). The validity of pedometers varied dramatically when compared with different measures of self-report, with high correlations between measures that examine distance walked and ambulatory activities, and poor correlations between pedometers and self-reported measures that examine sitting times (median r = 0.33). However, this is to be expected due to the sensitivity of pedometers when examining distance and ambulation (Welk *et al.*, 2000, Tudor-Locke *et al.*, 2002). Pedometers correlated relatively poorly when compared to other measures of physical activity against energy expenditure (median r = 0.68). However, fundamental limitations exist when making such comparisons, while physical activity and energy expenditure are interrelated, they are not synonymous nor are they interchangeable (Tudor-Locke *et al.*, 2002).

Pedometers provide a relatively accurate, objective and low cost measure of walking behaviours (Bassett Jr and Strath, 2002, Tudor-Locke *et al.*, 2002). However, pedometers do have significant limitations, which must be considered. The majority of low cost pedometers are unable to provide information on the intensity of physical activity (Rowlands and Eston, 2007, Trost, 2007). Additionally, pedometers only provide ambulatory information and are insensitive to some forms of movement such as upper body activities and activities of a cyclic nature such as cycling or rowing (Rowlands and Eston, 2007, Trost, 2007). Historically, the majority of pedometers do not use real time data storage nor do they have the ability to download information collected (Trost, 2007). As a result of these limitations, the use of pedometers when examining physical activity in health-related research has been limited. However, it has been suggested that pedometers may be an effective intervention tool when used as a motivational or behavioural trigger (Welk *et al.*, 2000, Rowlands and Eston, 2007).

2. 7. 4. 2. Accelerometers

Over the last three decades, accelerometry has become the most commonly used method of assessing free-living physical activity in health-related research (Esliger *et al.*, 2005, Freedson *et al.*, 2005, Rowlands, 2007a, Trost, 2007, Reilly *et al.*, 2008). The basic concept behind accelerometry is that accelerations are directly proportional to muscular forces used, and are therefore related to energy expenditure (Freedson and Miller, 2000, Warren *et al.*, 2010). Accelerometers measure the acceleration of an object relative to free-fall. In most accelerometers, the magnitude of the acceleration is measured using piezo-resistive or piezoelectric technology, which emits voltages proportional to acceleration experienced (Chen and Bassett Jr, 2005, Esliger *et al.*, 2005). Filtering programs remove accelerations which are too high or too low to be generated by human movement (Welk, 2002, Chen and Bassett Jr, 2005). The outputs are then processed to produce what are known as accelerometer/activity counts. Proprietary algorithms sum these results over a specific time interval or epoch (Chen and Bassett Jr, 2005, Rowlands, 2007a, Rowlands and Eston, 2007). These accelerometer counts provide an objective measure of movement intensity, with greater accelerations providing more counts (Esliger *et al.*, 2005, Warren *et al.*, 2010). As time is also recorded during measurement, it is possible for researchers to calculate frequency, intensity and duration of PA (Melanson Jr *et al.*, 1996, Welk *et al.*, 2000, Trost, 2001, Puyau *et al.*, 2002, Rowlands and Eston, 2007).

A broad range of commercially available accelerometers are employed in the assessment of physical activity across all ages. Although each device has the same fundamental function, different procedures (e.g. filtering, data storage etc.) are used to process the information (Welk, 2005). However, it is essential that each measurement instrument is effective at measuring what it is intended to measure (that each device is a valid measure) (Chinapaw *et al.*, 2010). In accelerometry, the most common method of evaluating whether an accelerometer device is a valid measure is through criterion validation, normally using indirect calorimetry or doubly labelled water (De Vries *et al.*, 2009). Several reviews have examined the criterion validity of accelerometers in youths using indirect calorimetry and doubly labelled water (Westerterp, 1999, Sirard and Pate, 2001, Welk *et al.*, 2004, Trost *et al.*, 2005, De Vries *et al.*, 2006, Bassett Jr *et al.*, 2012). The most common method of validating these accelerometers is by comparing accelerometer output with energy expenditure through indirect calorimetry in lab-based settings. Some accelerometers have been validated

in field-based settings using doubly labelled water. Literature reviews have examined the published validity of accelerometers and have shown moderate to high correlations between activity counts and energy expenditure (e.g. ActiGraph r ≈ 0.69 - 0.94 (Sirard and Pate, 2001); Tritrac-R3D r ≈ 0.34 - 0.91(De Vries *et al.*, 2006); GENEA ≈ 0.83 - 0.87 (Esliger *et al.*, 2011)). An examination of different types of accelerometers and their validation and calibration will be further discussed in Section 2. 8. 1.

The use of accelerometers in the assessment of free-living physical activity has many advantages. Accelerometers are valid, objective (Welk *et al.*, 2000, Janz, 2006, Rowlands and Eston, 2007), can directly measure an individual's movement (Rowlands and Eston, 2007, Warren *et al.*, 2010) and can be worn for prolonged periods by all populations (Westerterp, 2009). However, perhaps the greatest advantage of accelerometry is its time sampling capabilities (Janz, 2006, Westerterp, 2009). Accelerometers have the ability to record physical activity information over specific time intervals, or epochs (Trost *et al.*, 2005). With this, researchers have the capability to examine frequency, intensity and duration of physical activity, which is essential when comparing physical activity behaviour to indices of health (Melanson Jr *et al.*, 1996, Welk *et al.*, 2000, Trost, 2007, Butte *et al.*, 2012).

As with all measures of physical activity, accelerometry has distinct limitations. Accelerometers are not "plug and play" devices, as several variables including validity, positioning, compliance and output analysis must all be considered for each specific population prior to use (Trost *et al.*, 2005). Output analysis is a particularly important characteristic that must be considered, and will be discussed in detail in Chapter 4. Additionally, the output received from an accelerometer is not a measure of an individual's total activity, as most accelerometers cannot examine upper body, water-based, cyclic activities (such as cycling and rowing) or loaded activities (such as weight training) (Westerterp, 1999, Welk *et al.*, 2000, Sirard and Pate, 2001, Warren *et al.*, 2010). Nevertheless, accelerometer output is still recognised as an accurate measure of ambulation, which comprises the bulk of daily activity (Welk, 2002, Welk *et al.*, 2004), and accelerometry remains the most effective and practical method of objectively examining physical activity in field-based research (Welk *et al.*, 2000, Ward *et al.*, 2005, Welk, 2005).

2. 8. Measuring Physical Activity and Sedentary Behaviours using Accelerometry

Accelerometry is currently the most commonly employed method of objectively assessing physical activity in field-based research (Trost *et al.*, 2005, Rowlands, 2007a, Bassett Jr *et al.*, 2012). As described in Section 2. 7. 4. 2, accelerometers produce raw accelerations which are classified into an arbitrary score, or count, through proprietary algorithms (Esliger *et al.*, 2005, Freedson *et al.*, 2012). Accelerometer or activity counts are a dimensionless unit, and it is the analysis of these counts that predicts physical activity (Freedson *et al.*, 2005, Welk, 2005, Rowlands, 2007a). As proprietary algorithms vary across accelerometers, the output obtained from accelerometers is not comparable across differing devices. Consequently, the most common method of analysing accelerometer output is through calibration, where researchers classify counts into physical activity levels or energy expenditure by using predetermined thresholds (Freedson *et al.*, 2005, Trost *et al.*, 2011).

2. 8. 1. Calibration and Validation of Accelerometers

The calibration and validation of motion sensors is essential when seeking to objectively obtain accurate and reliable measures of physical activity (Bassett Jr *et al.*, 2012). Although the majority of motion sensors and activity monitors are sold "off the shelf" with in-built calibration equations, it is essential that researchers independently examine the effectiveness of the device to measure what it is intended to measure across a range of activity intensities (Welk, 2005). The calibration of accelerometers and activity monitors has been categorised into unit calibration and value calibration.

2. 8. 1. 1. Unit Calibration

The reliability of an accelerometer is an essential requirement for validity. Essentially, it is critical that each accelerometer measures and processes raw accelerations in the same way. Through completing a unit calibration of a device, researchers can examine the reliability of

a sensor across multiple accelerometers (Welk *et al.*, 2004, Welk, 2005). For accelerometry, the most commonly employed method of examining unit calibration has been the use of mechanical shakers or spinning devices which provides a standardised acceleration (Welk *et al.*, 2004, Welk, 2005). Devices are normally shaken at specific speeds, and the results obtained from the devices are compared with each other and with these fixed accelerations. It has been suggested that newer devices, including the ActiGraph GT1M, which incorporates a direct compression sensor that is integrated into a solid state microelectromechanical system (MEMS) accelerometer with digital filtering, do not require unit calibration checks, as there is very little variance in sensitivity due to tighter manufacturing tolerances (Kozey *et al.*, 2010b, Bassett Jr *et al.*, 2012). However, experts continue to recommend unit calibration for devices, as a manufacturer determined unit calibration (which normally use one acceleration speed and one frequency) may not be sufficient to determine devices reliability across a range of speeds (Welk, 2005, Bassett Jr *et al.*, 2012).

2. 8. 1. 2. Value Calibration

Accelerometers produce a dimensionless output called accelerometer/activity counts (Welk, 2005, Bassett Jr *et al.*, 2012). The output from different makes and models of accelerometers are not directly comparable due to manufacturer specific proprietary algorithms which filter and process the accelerations (Welk, 2005). As a result, researchers have highlighted the importance of employing methods of standardising accelerometer output analysis, which will enable research to compare findings across studies that employ different devices (Freedson *et al.*, 2005). To date, the most commonly used method to translate and interpret accelerometer output is value calibration (Welk, 2005).

Value calibration refers to the procedure used to convert arbitrary count values from accelerometers into a meaningful value, such as an estimate of energy expenditure, and has been described in great detail by experts in the field (Ward *et al.*, 2005, Welk, 2005, Rowlands, 2007a). Briefly, representative samples of a specific population are required to complete a range of free-living activities, including sedentary, non-ambulatory and ambulatory activities. During this time, a criterion measure of energy expenditure - most commonly portable indirect calorimetry - is obtained, while individuals also wear the

specific device which is to be calibrated. The data from both device's is used to predict energy expenditure or to provide activity intensity thresholds which can be used to distinguish between sedentary, light, moderate and vigorous activity intensities (Rowlands, 2007a). A range of methods have been used to calculate these activity intensity thresholds, including linear regression equations (Montoye *et al.*, 1983, Freedson *et al.*, 1998, Trost *et al.*, 1998), two-regression equations (Crouter *et al.*, 2006), random coefficients models (Treuth *et al.*, 2004, Mattocks *et al.*, 2007) and receiver operating characteristics (Esliger *et al.*, 2011). Accelerometer output is then examined for a specific activity variable using the calculated thresholds, such as total time spent in light and/or moderate to vigorous physical activity or time spent in bouts of a specific duration. A detailed description of the methods used in examining physical activity patterns and behaviours is provided in Chapter 4.

2. 9. The Measurement of Sedentary Patterns and Behaviours

To date, the most commonly employed methods of examining sedentary behaviours have been the use of surrogate measures including self-reported TV viewing time and the use of sedentary cut-points or thresholds on accelerometer output (Pate *et al.*, 2008, Reilly *et al.*, 2008, Lubans *et al.*, 2011). However, both of these measures have significant limitations in the examination of sedentary patterns and behaviours (Lubans *et al.*, 2011).

2. 9. 1. Self-Reported TV Viewing Time and Sedentary Time

Self-reported sedentary time and TV viewing time has been the predominant measure of sedentariness in epidemiological research (Marshall *et al.*, 2004, Clark *et al.*, 2009). As reported in Section 2. 3. 3, TV viewing time and self-reported sedentary time and patterns have been associated with health indicators (Chinapaw *et al.*, 2011). Unfortunately, self-reported TV viewing time is susceptible to similar inconsistencies and inaccuracies as self-reported physical activity, due to poor recall of a ubiquitous behaviour and poor reliability and validity (Bryant *et al.*, 2007, Lubans *et al.*, 2011). Contrasting evidence has been presented on the associations between TV viewing time and total sedentary time. Researchers have suggests that TV viewing time is not a good marker of sedentary

behaviours, primarily due to the wide range of additional sedentary activities completed by individuals across the normal day (Biddle *et al.*, 2009). However, conflicting evidence has been presented by Clark and colleagues, whereby a statistically significant relationship was observed between TV viewing time and accelerometer determined sedentary time, but correlations were weak and inconsistent across populations (Clark *et al.*, 2011). Furthermore, the reference sedentary measure in this study was determined using a threshold of <100 counts per minute, which itself has significant limitations (Lubans *et al.*, 2011). Additionally, self-reported sedentary time and TV viewing time does not allow the examination of sedentary patterns and behaviours (Bassett Jr *et al.*, 2010). This type of examination is particularly important, as research has highlighted the potential effect of prolonged sedentary periods on indices of health (Dunstan *et al.*, 2011).

2. 9. 2. Accelerometer Determined Sedentary Time

It has been suggested that objective measures of sedentary time provide the greatest potential in the examination of free-living sedentary patterns and behaviours (Pate *et al.*, 2008, Reilly *et al.*, 2008). The majority of published literature, which has examined sedentary patterns and behaviours using accelerometry, has employed the use of thresholds or cut-points when determining sedentary behaviour (Owen *et al.*, 2010). Unfortunately, the use of sedentary thresholds does not provide researchers with a total description of sedentary activities (Bassett Jr *et al.*, 2010). As highlighted by Hart and colleagues, the use of sedentary thresholds with the most commonly employed accelerometer (the ActiGraph) significantly overestimates the amount of time spent sedentary in a free-living environment when compared with a valid and reliable measure of sitting/lying and standing (Hart *et al.*, 2011). This is primarily due to the inability of the accelerometer cut-points to distinguish between sitting/lying and standing time (Bauman *et al.*, 2011, Lubans *et al.*, 2011). Standing upright is not a sedentary activity (Tremblay *et al.*, 2012), but may produce fewer than 100 counts per minute. Through the use of sedentary thresholds, standing time and light intensity physical activity may be classified as sedentary time (Johnson *et al.*, 2004, Bauman *et al.*, 2011). In addition, the inability of such devices to accurately determine the duration of sedentary periods and/or breaks in sedentary periods limits the detailed examination of sedentary variables (Zderic and Hamilton, 2006, Hamilton *et al.*, 2007). Furthermore, recent research

has highlighted that a sedentary threshold of <150 counts per minute is more accurate at determining sedentary time than the commonly employed <100 counts per minute when compared with direct observation in an adult population (Kozey-Keadle *et al.*, 2011). However, it has recently been highlighted that the use of a sedentary threshold of <100 counts per minute was acceptable when compared to total sitting time determined by a valid objective measure of sitting/lying and standing (Ridgers *et al.*, 2012).

Although total sedentary time is a variable of interest in the study of sedentary behaviours, the accurate examination of the frequency and duration of sedentariness is of great importance (Bassett Jr *et al.*, 2010, Owen *et al.*, 2010, Dunstan *et al.*, 2011). Self-reported sedentary time and TV viewing time are not direct measures of sedentariness (Pate *et al.*, 2008, Lubans *et al.*, 2011). Although more accurate at determining sedentary time, the use of cut-points or thresholds does not allow the direct measurement of posture, but rather relies on estimating sedentary time based on the lack of movement (Lubans *et al.*, 2011). As a result, these measures do not provide researchers with direct and reliable measures of sedentary variables, which are essential in the examination of free-living activity patterns and behaviours (Rowlands, 2007a, Loprinzi and Cardinal, 2011, Intille *et al.*, 2012).

2. 10. The activPAL^TM Professional Physical Activity Monitor

Due to the limitations of objectively measured sedentary time highlighted in Section 2. 9. 2, it has been suggested that valid and reliable measures of posture, which can distinguish between sitting and standing time should be employed when examining sedentary patterns and behaviours (Matthews *et al.*, 2008, Bassett Jr *et al.*, 2010, Kozey-Keadle *et al.*, 2011). One such device is the activPAL^TM Professional Physical Activity Monitor (PAL technologies Ltd., Glasgow, UK). A detailed description of the activPAL and the procedure used when wearing the device is described in Section 3. 2. 2 and Section 4. 2. 1. Briefly, the activPAL is a uniaxial accelerometer which incorporates Intelligent Activity Classification^TM based on information obtained from MicroElectroMechanical System (MEMS). The device is small (53 x 35 x 7 mm) and lightweight (20 grams), and is worn on the midpoint of the anterior aspect of the right thigh, and is attached using a hydro-gel adhesive pad called a PAL*stickie*^TM.

The activPAL has been identified as a valid measure of posture allocation in children (Davies *et al.*, 2011, Ridgers *et al.*, 2012) and static and dynamic activities in adults (Grant *et al.*, 2006, Godfrey *et al.*, 2007, Hart *et al.*, 2011, Kozey-Keadle *et al.*, 2011). Consequently, the use of the activPAL to examine total sedentary time and sedentary patterns and behaviours in free-living environments has been recommended (Matthews *et al.*, 2008, Healy *et al.*, 2011a, Kozey-Keadle *et al.*, 2011). In particular, the use of the activPAL has been encouraged when examining sedentariness for more detailed variables such as breaks in sedentariness and sedentary bout duration (Bassett Jr *et al.*, 2010). The activPAL has also been shown to be a valid measure of stepping and cadence in children (Davies *et al.*, 2011), adolescent females (Harrington *et al.*, 2011b) and in both healthy adults (Grant *et al.*, 2006, Ryan *et al.*, 2006, Maddocks *et al.*, 2010) and older adults (Grant *et al.*, 2008). Although the validity of the step count function of the activPAL has been examined, the activity count function of the activPAL has not been calibrated in any free-living population. This will be discussed and examined in Chapter 3.

Due to the validity and reliability of the activPAL Professional Physical Activity Monitor as a measure of both physical activity and as a measure of sitting/lying and standing, the activPAL has been employed as a measure of activity patterns and behaviours in children (Martin *et al.*, 2011), in adolescent females (Harrington *et al.*, 2011a) and in a range of adult settings (Dall and Kerr, 2010, Grant *et al.*, 2010, Chastin *et al.*, 2012).

2. 11. Summary: Section B

The valid and reliable measurement of physical activity and sedentary behaviour is essential when examining the associations between activity variables and indices of health (Westerterp, 2009, Loprinzi and Cardinal, 2011, Intille *et al.*, 2012). Currently, a wide variety of assessment methods are available for examining physical activity in child and adolescent populations (Trost, 2007, Westerterp, 2009, Warren *et al.*, 2010). Historically epidemiological evidence has assessed activity variables using self-report and questionnaire-based measures due to their low cost, acceptable levels of reliability and validity and the ease with which they can be administered to large cohorts (Kohl *et al.*, 2000, Matthews, 2002, Trost, 2007). Limited information is currently available on the validity of self-reported measures of sedentary behaviours (Lubans *et al.*, 2011). Over the last number of

decades, the objective examination of physical activity using accelerometers has become increasingly popular, primarily due to increased validity and reliability compared to self-reported measures and affordability of available activity monitors (Rowlands, 2007a, Warren *et al.*, 2010). However, their ability to accurately examine sedentary time (and consequently estimated light intensity physical activity) has also been questioned (Hart *et al.*, 2011, Kozey-Keadle *et al.*, 2011). As a result, the use of multi-sensor devices, which can both objectively examine physical activity and directly examine sedentary time, has been encouraged when examining physical activity and sedentary behaviours in free-living populations (Hamilton *et al.*, 2008, Bassett Jr *et al.*, 2010, Owen *et al.*, 2010).

2. 12. Section C: Levels of Physical Activity and Sedentary Behaviour in Childhood and Adolescence

Despite the recommendations for adequate physical activity in adolescence being well documented, national and international data indicates that children and adolescents participate in low levels of physical activity. Furthermore, it is apparent that youths become less physically active between the onset of puberty and age 18 (Schmitz *et al.*, 2005). Irish and international data on these levels and trends of physical activity will be discussed here.

2. 12. 1. National Levels and Trends of Childhood and Adolescent Physical Activity and Sedentary Behaviour

Sedentary patterns and behaviours and physical activity levels have predominantly been examined using subjective measures in the Irish context. However, over the last decade, several examinations of physical activity using objective measures have taken place. The findings from these studies are presented and discussed below.

2. 12. 1. 1. Irish Physical Activity and Sedentary Levels Examined using Subjective Measures

A number of studies have examined the levels of physical activity participation in Irish children and adolescents over the last two decades. The National Health and Lifestyle Surveys (Slán) completed in 1998 and 2003 and the Irish Health Behaviour in School-aged Children (HBSC) Study completed in 2006 and 2010 are collectively the most comprehensive examination of physical activity participation in childhood and adolescence in Ireland (Kelleher *et al.*, 1999, Kelleher *et al.*, 2003, Nic Gabhainn *et al.*, 2007, Kelly *et al.*, 2012). Table 2.2 presents the percentage of individuals that took part in exercise on four or more days per week in each of the three examinations. The findings acknowledge moderate participation in physical activity at early and middle adolescence, but highlight severe fallout in participation during late adolescence, particularly in female populations. Caution should be taken when interpreting these results, however, as participation in physical activity was defined as the frequency with which the individual exercised so much that they would get out of breath, and did not consider duration of activity.

Table 2.2. The percentage of both males and females (all) and females only that reported participating in exercise four or more times per week.

	9-11		12-14		15-17	
	All	**Girls**	**All**	**Girls**	**All**	**Girls**
Slán 1998 (%)	63	59	58	49	40	26
Slán 2003 (%)	59	55	53	44	35	25
HBSC 2006 (%)	64	58	59	51	42	28
HBSC 2010 (%)	62	60	54	42	41	29

Levels of physical inactivity were also examined and presented in each of these studies. Physical inactivity was defined as participating in exercise on less than one day per week. The findings from each of the four examinations are presented in Table 2.3 (Kelleher *et al.*, 1999, Kelleher *et al.*, 2003, Nic Gabhainn *et al.*, 2007, Kelly *et al.*, 2012). It is evident from these findings that inactivity levels remain consistent across teenage years in Irish males.

However, it is also clear that inactivity levels increase dramatically across Irish females, particularly during the latter stages of adolescence, with an 8% increase in 1998, 13% increase in 2003, 14% increase in 2006 and 9% increase in inactivity in 2006 between the ages 12-14 years and 15-17 years.

Table 2.3. The percentage of males and females reporting participation in exercise less than once a week.

	9-11		12-14		15-17	
	Boys	**Girls**	**Boys**	**Girls**	**Boys**	**Girls**
Slán 1998 (%)	4	4	3	5	5	13
Slán 2003 (%)	8	8	7	8	8	21
HBSC 2006 (%)	7	8	4	8	9	22
HBSC 2010 (%)	4	7	4	10	8	19

Hussey and colleagues also completed a large data collection of 6-9 year old children in the Dublin region (n=786) (Hussey *et al.*, 2001). This study reported that 39% of children participated in hard exercise for 20 minutes per day on at least 3 days of the week. Similar to the studies mentioned above, the levels of participation in physical activity were significantly higher in males (53%) than females (28%). This study also highlighted that 60% of participants spend greater than 3 hours per day watching television.

Another study completed on the East coast of Ireland (the Take PART study) examined self-reported levels of physical activity in 1,500 adolescents (Woods et al., 2004). For the purpose of this study, regular activity was defined as participating in > 60 minutes of physical activity on 4 or more days of the week. This study classified 56% of 15-17 year old as not regularly active, highlighting that females (62%) were significantly less active than their male counterparts (52%). When the definition of regular activity was increased to 5 or more days of the week, 82% of participants were identified as not regularly active, while only 4% of participants achieved the recommendations on every day of the week. Figure 2.4 presents information on the number of days individuals participated in the recommended amount of daily physical activity. As discussed in Section 2. 7. 2. 1, these

results should also be interpreted with caution, as all data here was obtained using self-reported measures.
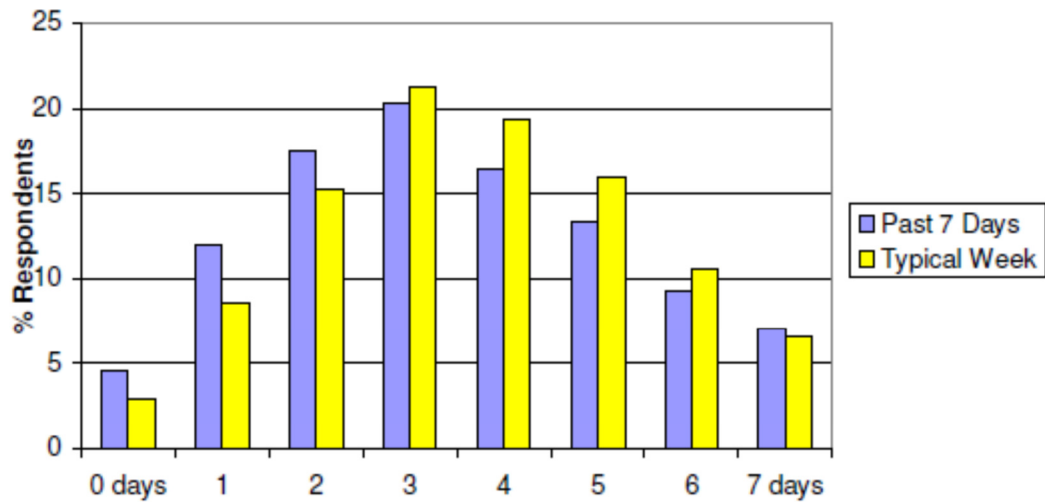
Figure 2.4. The number of days participants achieved the recommended amount (>60 minutes) of physical activity.

(Woods et al. 2004. p 33)

The Children's Sports Participation and Physical Activity study (CSPPA study) is one of the most recent research studies to have examined physical activity participation in a large sample (n=1215) of Irish children and adolescents (Woods *et al.*, 2010). Physical activity levels were examined using self-reported measures. Table 2.4 presents the percentage of children and adolescents that achieved the recommended amount of daily physical activity (>60 minutes of moderate to vigorous physical activity) on all days of the week. Few differences were observed in physical activity participation between this examination and that completed by Woods and colleagues in 2004 (Woods *et al.*, 2010).

Table 2.4. Percentage of children and adolescents achieving 60 minutes or more of moderate to vigorous physical activity on all days of the week.

	Males	Females	All
10-12 years (%)	27	13	19
12-13 years (%)	24	13	18
14-15 years (%)	16	8	12
16-18 years (%)	7	6	6

(Woods et al. 2010, p30)

2. 12. 1. 2. Irish Physical Activity and Sedentary Levels Examined using Objective Measures

Limited objectively measured physical activity information is available in the Irish context. Two studies have examined physical activity levels in child and adolescent populations using heart rate monitoring. Results from a sample of 65 Irish children aged between 7 and 9 years reported that 55% of children accumulated > 60 minutes of light physical activity, 35% achieved > 30 minutes of moderate to vigorous physical activity on every measured day, while 8% achieved > 60 minutes of moderate to vigorous physical activity on all measured days (Belton and MacDonncha, 2007). Findings from heart rate monitoring in 28 Irish adolescents presented low levels of physical activity participation in this population, with no subject meeting the international moderate or vigorous intensity physical activity guidelines (Shiely and MacDonncha, 2009). Interestingly, Shiely and MacDonncha also noted that physical activity levels predicted from heart rate monitoring in this population were significantly lower than those estimated with self-report (Shiely and MacDonncha, 2009).

One Irish study has examined pedometer derived step counts of 7-9 year old Irish children (Belton *et al.*, 2010). Although this study did not present levels of physical activity in terms of physical activity intensities or in terms of reaching the recommendations, this study examined the number of steps accumulated at specific times of the day in both males and females. The findings support the findings observed in much of the other Irish physical

activity research, highlighting that males accumulated significantly more steps than females, while participants were more active on weekend days than on weekdays.

To date, only two studies have employed accelerometry as a measure of physical activity in an Irish cohort (Woods *et al.*, 2010, Harrington *et al.*, 2011a). However, the accelerometer data obtained by Woods and colleagues (2010) was used to validate a self-report measure of physical activity, and accelerometry protocols or detailed accelerometry results have not been reported to date (Woods *et al.*, 2010). As a result, this data cannot be compared to other objective measures of physical activity. One study (Appendix 1) has employed an inclinometer-based accelerometer to examine sedentary patterns and behaviours, and has highlighted that adolescent females spend approximately 19 hours per day sitting/lying, with approximately 79% of their total day (including sleep time) spent in sitting and lying behaviours (Harrington *et al.*, 2011a).

This national information on levels and trends of physical activity in Irish youths has consistently identified that 1) levels of physical activity participation across all ages are low, and are a serious public health concern and 2) levels of physical activity decrease while physical inactivity increases throughout adolescence, with the most severe fallout from participation evident in older adolescent females. Furthermore, the frightening levels and trends that have been observed may be worse than previously thought, with results from objectively assessed physical activity suggesting even lower levels of physical activity participation across children and adolescents (Shiely and MacDonncha, 2009).

2. 12. 2. International Levels and Trends of Childhood and Adolescent Physical Activity and Sedentary Behaviour

A wealth of data on physical activity and sedentary behaviours in childhood and adolescence is now available, particularly from the United States, Australia and European research groups. The levels and trends of physical activity and sedentary behaviour measured using both subjective and objective measures are discussed below.

2. 12. 2. 1. International Levels of Self-Reported Physical Activity and Sedentary Behaviours

Several large-scale studies have examined the levels and trends of physical activity and sedentary behaviours in childhood and adolescence. One of the most notable of these is the Health Behaviour in School-aged Children (HBSC) Study. The most recent report of the HBSC included 43 countries and excess of 200,000 participants (Currie *et al.*, 2012). The findings from the HBSC Study highlighted that physical activity decreased significantly between ages 11 and 15, while males continued to be more active that their female counterparts across all ages (Table 2.5).

Table 2.5. Percentage of children and adolescents that achieved 60 minutes or more of moderate to vigorous physical activity daily.

	11 yrs.			13 yrs.			15 yrs.		
	Boys	Girls	All	Boys	Girls	All	Boys	Girls	All
> 60 mins MVPA daily (%)	28	19	23	24	13	19	19	10	15

(Currie et al., 2012, p 130-131)

The report also highlighted that 15 year olds spent significantly more TV viewing time than 11 year olds, with little or no difference observed between males and females (Table 2.6).

Table 2.6. Percentage of children and adolescents spending 2 hours or more watching TV daily.

	11 yrs.			13 yrs.			15 yrs.		
	Boys	Girls	All	Boys	Girls	All	Boys	Girls	All
> 2 hrs TV viewing daily (%)	58	54	56	65	64	65	64	62	63

(Currie et al., 2012, p 134-135)

58

When compared to another recent large-scale surveillance survey from the United States, similar trends of low levels of physical activity and high sedentary levels were observed. The Youth Risk Behaviour Surveillance Survey (YRBSS) identified that 18.4 % of youths examined were physically active for 60 minutes or more daily, with significantly higher rates of participation observed in males (24.8%) than in females (11.4%) (Eaton *et al.*, 2010). Compliance with physical activity recommendations decreased across each class group, with twice as many males as females achieving the recommendation across all class groups. When the information was examined for participation in at least 60 minutes of physical activity on 5 days of the week, the percentage of children and adolescents achieving the recommendations increased to 37%. Finally, 23.1% of participants did not achieve 60 minutes of physical activity on any of the previous 7 days. Physical activity participation results across class group and sex are described for each of these variables in Table 2.7.

Table 2.7. Percentage of males and females that achieved the recommended daily amount of daily physical activity on 0 days, 5 days and on all 7 days across grades.

> 60 mins MVPA	9th grade		10th grade		11th grade		12th grade	
	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls
0 days (%)	17.4	26.9	15.7	30.3	16.4	29.8	18.5	33
5 days (%)	47.5	30.8	47.4	30.5	46.2	26	40.4	22.4
7 days (%)	28	13.6	25.3	12.7	23.3	10.3	21.9	8.6

(Eaton *et al.* 2010, page 25 & 26)

2. 12. 2. 2. International Levels of Objectively Determined Physical Activity and Sedentary Behaviours

Large-scale studies have incorporated the use of objective measures. One of the most significant of these examinations has been the National Health and Nutrition Examination Survey (NHANES). Findings from the survey completed in 2003-2004 have identified similar physical activity trends to those observed through subjective methods (Troiano *et al.*, 2008). In a sample of 1778 participants aged between 6 and 19 years, levels of physical activity were examined. Troiano and colleagues highlighted that mean accelerometry counts

per minute significantly declined from childhood through adolescence, with females achieving fewer accelerometry counts per minute than their male counterparts. Age specific count thresholds, developed and described by Freedson and colleagues, were employed to determine the amount of time spent in moderate to vigorous physical activity (Insert Reference here: Freedson 1997). The mean total amount of moderate physical activity was above 60 minutes in both males and females at age 6-11 years. However, levels of participation in both total and bouts of moderate and vigorous physical activity severely declined across age, with a particular decline in female participation at 16-19 years of age. These results are presented in Table 2.8.

Table 2.8. Mean total minutes per day in moderate physical activity (MPA) to vigorous physical activity (VPA) and mean total minutes per day in MPA and VPA in bouts of 10 minutes or more. MPA and VPA were examined using age-specific count to activity thresholds (Freedson *et al.*, 2005).

	Males			Females		
(yrs.) (mins)	6-11	12-15	16-19	6-11	12-15	16-19
Total MPA	79.5	39.2	29.8	65.1	21.7	18.5
Total VPA	16.0	6.0	3.0	10.1	2.9	1.1
Bouts of MPA	22.4	11.6	7.7	12.8	4.4	4.2
Bouts of VPA	4.2	1.4	0.9	1.8	0.9	0.4

(Troiano et al. 2008, p 185)

Matthews and colleagues examined the 2003-2004 NHANES accelerometer output for sedentary behaviour in a similar manner to that described in Table 2.9 (Matthews *et al.*, 2008). These findings also highlighted high levels of sedentary time in each population, with females spending significantly more time sedentary than their male counterparts at age 6-11, 12-15 and 16-19 years.

Table 2.9. Mean hours spent in sedentary behaviours for all participants, males and females across the ages of 6 - 19 years.

	Total	Males	Females
6-11 yrs.	6.07	6.00	6.14
12-15 yrs.	7.53	7.37	7.7
16-19 yrs.	8.03	7.91	8.13

(Matthews *et al.* 2008, Page 878)

The NHANES data of 2003-2004 and 2005-2006 has also recently been collectively examined for physical activity levels and sedentary patterns and behaviours in children and adolescents (Carson and Janssen, 2011). Sedentary time was examined using a count-to-activity threshold of <100 counts per minute. Moderate to vigorous physical activity was determined using age specific count to activity thresholds (Freedson *et al.*, 2005). The median values for the accelerometry wear time identified children and adolescents as spending approximately 50.8% of their wear time in sedentary behaviours, 43.8% in light intensity activity and 4.1% in moderate to vigorous physical activity. Interestingly, this population spent 24.5% of their day in prolonged sedentary periods of greater than 30 minutes in duration, which may have specific deleterious effects (Section 2. 4. 4). Unfortunately, the focus of this paper was on the relationship between sedentary patterns and behaviours and cardio-metabolic health in this population. As a result, further breakdown of sedentary results are not provided.

The European Youth Heart Study has provided objectively assessed physical activity trends in a large cohort of 9 and 15 year old children and adolescents in the European context. Count to activity thresholds of 1000 and 1500 counts per minute respectively were employed to determine moderate to vigorous physical activity in these populations (Riddoch *et al.*, 2004). Similar trends to those presented in the NHANES examination were observed here, with the authors concluding that males are more active than females, with a significant reduction in activity over the adolescent years in both males and females (Riddoch *et al.*, 2004). The HELENA study, in which a large-scale objective examination of physical activity was completed across 10 European cities, have provided further data of physical activity and sedentary patterns and behaviours (Martinez-Gomez *et al.*, 2011b).

Findings from this study have concurred with Riddoch and colleagues, stating that adolescent European males have higher levels of MVPA and achieve the recommended amount of daily MVPA more often than females. Additionally, Martinez-Gomez and colleagues noted that adolescent females spent significantly more time in sedentary activities than males.

A recent publication on the largest sample of children and adolescents, which included findings from NHANES and other large-scale objective investigations, has reported physical activity and sedentary time in 20,871 children and adolescents (Ekelund *et al.*, 2012). Sedentary time was identified as time spent below a sedentary count to activity threshold of 100 counts per minute, while a count to activity threshold of <3000 counts per minute identified time spent in moderate to vigorous physical activity. The findings highlight that males achieve significantly higher mean accelerometer counts per minute (642 ± 226 cpm/d^{-1}) than female (540 ± 193 cpm/d^{-1}; p<0.001). Additionally, significantly more time was spent in moderate to vigorous physical activity in males (37 ± 23 min/d^{-1}) than females (24 ± 17 min/d^{-1}; p<0.001), while females accumulated significantly more daily sedentary time (363 ± 96 min/d^{-1}) than males (345 ± 96 min/d^{-1}; p<0.001).

2. 13. Summary: Section C

It is clear from both the objective and subjective findings that physical activity in children and adolescents are lower than expected at baseline. It is also evident that physical activity declines severely across childhood and adolescence. It is also obvious that this fallout is greater in females, with the greatest fallout in physical activity observed in adolescent females aged greater than 15 years. Inverse trends are observed for sedentary time, with all research suggesting that sedentary time increases throughout adolescence, with greater sedentary levels observed in females than males. As highlighted throughout this review, it is important that caution is employed when interpreting sedentary patterns and behaviours, as surrogate measures rather than direct measures have been employed in its examination to date (Kozey-Keadle *et al.*, 2011). Collectively, the information presented here suggests that females adolescents are a particularly at risk population, as tracking of activity behaviours (as discussed in Section 2. 4. 3) would infer that these deleterious behaviours (particularly

sedentary behaviour) will continue through adolescence and into adult life, further increasing the risk of cardiovascular disease and related comorbidities.

2. 14. General Summary

Evidence suggests that associations are evident between levels of moderate to vigorous physical activity in childhood and adolescence and mortality from cardiovascular disease and related disorders in adulthood. Over the last 2 decades, the importance of lower spectrum activity intensities has been emphasised, and research has begun to examine all activity intensities when examining relationships with health. It seems rational that the interaction between the activity profile, rather than specific activity intensities, is the most effective method of associating habitual physical activity with indices of health. In order to effectively examine relationships between indices of health and the activity profile, valid and reliable measures of both activity patterns and behaviours are necessary. To date, no research has examined the relationships between objectively examined physical activities and directly examined sedentary patterns and behaviours and indices of health in any population.

Chapter 3. Criterion and Concurrent Validity of the activPAL™ Professional Physical Activity Monitor in Adolescent Females.

3. 1. Introduction:

3. 1. 1. Prevalence and Effect of Moderate to Vigorous Physical Activity

Increased levels of moderate to vigorous physical activity have the potential to improve cardio-metabolic risk factors, improve bone health, reduce the risk of depression and reduce the risk of becoming overweight/obese in childhood, in adolescence and in adulthood (Warburton *et al.*, 2006, Janssen and LeBlanc, 2010). Despite the widespread publication of the benefits of physical activity, levels remain low in many countries (Troiano *et al.*, 2008, Colley *et al.*, 2011b, Lee *et al.*, 2012). Furthermore, the most significant decrease in levels of physical activity occur in later adolescence, with greater decreases observed in females (Riddoch *et al.*, 2004, Troiano *et al.*, 2008). This is critical, as the processes associated with long term risk of diseases, such as coronary heart disease, begin in childhood and adolescence (Berghöfer *et al.*, 2008).

3. 1. 2. Methods of Assessing Physical Activity

Advancing the field of free-living activity measurement requires the development of methodologies that are practical in habitual settings. These methodologies are crucial when relating levels of physical activity to indices of health (Freedson *et al.*, 1998, Esliger *et al.*, 2011). Over the past two decades, accelerometry has become the preferred method of objectively examining physical activity in free-living populations (Trost *et al.*, 2005, Rowlands, 2007a, Welk *et al.*, 2007). This is primarily due to the rich information obtained from the devices (Rowlands, 2007a, Bassett Jr *et al.*, 2012), coupled with relatively high levels of reliability and validity and the lowering costs of the monitoring devices themselves (Trost *et al.*, 2005). Typically, accelerometers record raw accelerations, and proprietary algorithms calculate arbitrary units known as accelerometer or activity counts over a specified time period or epoch (e.g. 15 seconds). The most frequently employed method of examining these activity counts has been to classify them into physical activity levels (light, moderate, vigorous) using predetermined thresholds (Bassett Jr *et al.*, 2012). Total minutes spent per day at each physical activity intensity, along with the frequency and duration of physical activity can then be calculated (Freedson *et al.*, 1998, Bassett Jr *et al.*, 2012).

3. 1. 3. The Sedentary Behaviour Paradigm

In recent years, the quantification of sedentary behaviour, as well as physical activity, has become extremely topical, as the deleterious effects of sedentariness have been emphasised (Owen *et al.*, 2010). Inactivity physiologists have highlighted the negative effect of sedentary behaviours on indices of health in rats, and have suggested the loss of contractile stimulation of large skeletal muscles as one the major physiological variables which regulates muscle enzyme lipoprotein lipase (LPL) (Bey and Hamilton, 2003, Hamilton *et al.*, 2007, Hamilton *et al.*, 2008). The suggestion that isometric contraction of antigravity muscles produce electromyographic and skeletal muscle LPL change (Hamilton *et al.*, 2007, Hamilton *et al.*, 2008) implies that activities such as standing, which would previously have been considered sedentary, should now be considered as distinct activity behaviours (Owen *et al.*, 2010). Consequently, sedentary behaviour is now characterised by energy expenditure below 1.5 metabolic equivalents (METs) while in a sitting or lying position during waking hours (Marshall and Ramirez, 2011, Tremblay *et al.*, 2012). To date, epidemiological evidence has supported the physiological observations, highlighting the negative effect of sedentary patterns and behaviours in both adolescents (Martinez-Gomez *et al.*, 2010) and adults (Healy *et al.*, 2007, Healy *et al.*, 2008a, Healy *et al.*, 2011b). Unfortunately, the methods used to examine sedentariness in these studies have significant limitations. Surrogate measures of sedentary behaviour, such as self-reported TV viewing time, do not accurately quantify sedentariness, and only examine one aspect of sedentary behaviour (Pate *et al.*, 2008). Furthermore, the use of indirect measures of sedentariness, such as the use of sedentary thresholds from accelerometer counts (e.g. ≤ 100 counts·min^{-1}) rely on the lack of ambulation or movement rather than directly measuring body position (Hart *et al.*, 2011, Kozey-Keadle *et al.*, 2011).

3. 1. 4. Methods of Assessing Sedentary Behaviour

Due to increased interest in sedentary behaviour and the obvious interest in examining levels of physical activity, a device that is both a valid and reliable measure of both domains would be extremely valuable. While the ActiGraph GT1M and GT3X (Manufacturing Technologies Inc. Health Systems, Shalimar, FL), for example, are valid measures of

physical activity, their measurement of sedentary behaviours are dependent on thresholds. It has been suggested that the use of such thresholds to determine sedentary time could lead to errors, as this analysis may include other activities, such as standing (Owen *et al.*, 2010, Hart *et al.*, 2011, Kozey-Keadle *et al.*, 2011). Recent technological developments have provided researchers with the tools to directly examine sedentary behaviours without the use of thresholds. The use of inclinometer-based activity monitor, such as the activPAL Professional Physical Activity Monitor (PAL Technologies Ltd., Glasgow, UK), has enabled researchers to directly identify periods of sitting/lying, standing and stepping, and have been encouraged for studies examining sedentary behaviours in detail (Bassett Jr *et al.*, 2010, Owen *et al.*, 2010). The activPAL is worn on the midline of the anterior aspect of the thigh. Due to this unique positioning, the inbuilt inclinometer is able to distinguish between sitting/lying and standing, while the activity monitoring function of the device allows the examination of ambulation, as with other existing devices. The device has been validated for the measurement of static and dynamic activities in adults (Godfrey *et al.*, 2007), posture during free-living activities (Grant *et al.*, 2006), step and cadence output in females (Harrington *et al.*, 2011b) and in the examination of sedentary time in children (Ridgers *et al.*, 2012) and adults (Kozey-Keadle *et al.*, 2011). While the activPAL has been used as a measure of habitual locomotion using steps (Chastin *et al.*, 2009) and has had a cadence threshold developed for adolescent female populations (Harrington *et al.*, 2012), the activity count function has not been investigated in the same way as with the ActiGraph, and activity counts have not been utilised to examine free-living physical activity in any population. Furthermore, the sit/lie and stand function has not been validated in an adolescent population.

The primary aims of this chapter are to investigate the validity of activPAL activity counts in estimating energy expenditure, to perform a value-calibration of the activPAL and to validate thresholds for defining moderate physical activity and vigorous physical activity for an adolescent female population. This chapter also aims to examine the concurrent validity of the activPAL by comparing activity counts across different activities with the ActiGraph GT3X accelerometer. Finally, the chapter aims to compare the performance of the activPAL with the ActiGraph for estimating time spent sitting, standing and stepping.

3. 2. Methods

3. 2. 1. Participants

Participants for the study were recruited from a community youth group in the West of Ireland. To be considered for inclusion in this study, participants had to be female, aged between 15 and 18 years and have no injury or illness that limited their ability to be physically active. This population were selected for investigation as female adolescents have been highlighted as a particularly inactive population, and as a result are of great interest to physical activity and health practitioners (Riddoch *et al.*, 2004, Troiano *et al.*, 2008, Matthews *et al.*, 2012). A local community youth group was approached to participate in this study. All female members of this group were invited to an information evening, where the study protocols and objectives were clearly outlined. All participants were provided with parental and participant information sheets and consent forms, and invited to return the completed consent forms at their next youth group meeting. All participants that returned completed participant and parental written informed consent were selected for participation (n = 40). Three participants from the original sample of 40 withdrew from the study. From the remaining participants, five data sets were excluded from analysis due to a malfunction of indirect calorimetry measurement. A total of 32 valid sets of VO_2 data were obtained from the participants for statistical analysis. Two sets of activPAL data were not included in the analysis due to equipment malfunction, resulting in 30 full sets of activPAL, ActiGraph GT3X and simultaneous VO_2 data for the current analysis. Each participant was allocated a number, and a randomisation table was used to assign each participant to either an equation development group or a cross-validation group. The study was approved by the Faculty of Education and Health Sciences Research Ethics Committee at the University of Limerick.

3. 2. 2. Physical Activity Measurement Devices

Physical activity was recorded using the activPAL™ Professional Physical Activity Monitor (Firmware: v 0.9.9) which is a single unit uniaxial accelerometer (53 x 35 x 7 mm) that weighs approximately 20 grams. The activPAL responds to gravitational accelerations

resulting from segmental movement (Ryan *et al.*, 2006), and data is recorded at 10 Hz for each 15 second time intervals (epoch). Proprietary algorithms provide outputs including time spent sitting/lying, standing and stepping, step counts and cadence and activity counts. The activPAL communicates with a Windows (Microsoft Corporation, Microsoft Excel 2010, One Microsoft Way, Redmond, WA, USA) compatible PC via a USB interface. The ActiGraph GT3X (Firmware v 4.1.0) (Pensacola, FL 32502, USA) is a small triaxial accelerometer (38 mm × 37 mm × 18 mm) that weighs approximately 27 grams. Throughout the remainder of this document, the term ActiGraph will refer to the ActiGraph GT3X unless otherwise stated. The device assesses acceleration in three individual orthogonal planes using a vertical axis, horizontal axis and a perpendicular axis. The ActiGraph samples accelerations at a rate of 30 Hz and the data can be reprocessed into epochs ranging from 1 to 60 seconds. The ActiGraph also communicates with a Windows compatible PC via a USB interface. For the purpose of this study, the ActiGraph monitor was initialised to record vertical accelerations every 15 seconds.

3. 2. 3. Metabolic Unit:

Oxygen consumption was measured breath-by-breath using a portable metabolic unit (Cosmed $K4B^2$, Rome, Italy). The $K4B^2$ is a lightweight system with a heart rate receiver. The Cosmed $K4B^2$ has been deemed an appropriate criterion measure for minute-by-minute energy expenditure (Bassett Jr *et al.*, 2012). Over the duration of the study, the $K4B^2$ was calibrated following standard manufacturer procedures. Before each testing session, the device was calibrated using known gas concentrations, and environmental conditions were updated. The VO_2 data was downloaded and stored on a PC after each testing session.

3. 2. 4. Testing Protocol

Participants arrived to the testing facility having fasted for two hours, refrained from smoking and drinking caffeine for 2 hours, and having refrained from moderate and vigorous physical activity for 12 hours. Participants wore light shorts, t-shirt or vest, socks

and running shoes. Height was measured without shoes and socks to the nearest 0.25 cm using a portable stadiometer (Seca model 214, Seca Ltd, Birmingham, UK) and weight was measured without shoes and socks to the nearest 0.1 kg using portable electronic scales (Seca model 770, Seca Ltd, Birmingham, UK). Body mass index was then calculated from the height and weight measures (kg/m^2). After participants arrived to the test facility and had their height and weight obtained, participants were fitted with the activPAL, the ActiGraph and the Cosmed K4B^2 metabolic unit. Both accelerometers were initialised prior to participant's arrival and their internal clocks were automatically synchronised with the main investigator computer. To conform to the sampling time used by the activPAL, a 15 s^{-1} epoch was used for the ActiGraph. The activPAL was attached directly on the skin of the midline of the anterior aspect of the right thigh using a PAL*stickie,* (double sided hydrogel adhesive pad) and tube bandages were used as extra security to keep the activity monitor in place. The ActiGraph was worn around the waist on an elasticated band over the right hip bone. The metabolic unit was placed over participants shoulders and a mask fitted over the face.

Participants were then introduced to the protocol of activities. Activities were completed in ascending intensity throughout the testing period. Participants were instructed when to start each activity and when to stop each activity by a single observer. The activity category, the exact start time and the exact finish time of each activity were recorded by the observer. Resting VO_2 was measured for 25 minutes, to ensure the participants were provided an adequate amount of time to return to a rested state. During this time period, participants lay in a reclined position on a physiotherapy plinth in a darkened, quiet room. For the sitting activity, participants sat looking straightforward, placed their feet flat on the floor, placed their hands on their knees and were asked not to speak or take part in any other activities. For the standing activity, participants once again looked straightforward with their feet shoulder width apart, had their hands held by their side and were asked not to take part in any other activity. Participants did not lean against or hold on to any support while completing the seated and standing activities.

Participants then completed the 3 locomotor activities. Participants were asked to complete each activity at a pace that was comfortable to them, but within each speed range: slow walking (2.5-4.5 km.h^{-1}), brisk walking (4.5-6.5 km.h^{-1}) and light jogging (6.5-8.5 km.h^{-1}). Prior to the study beginning, the upper and lower time limits required to complete each section of the track during each speed category were calculated. The time taken to

complete each section of the track was then used to estimate the speed of each participant. During the first minute of measurement, the time it took for each participant to complete each section of the track was recorded. If participants completed each section too slowly or too quickly, they were deemed to be travelling too slow or too fast, and they were asked to adjust their speed accordingly. Once participants were comfortable at travelling within the speed category, the time required to complete each section of the track was recorded, and participants were encouraged to maintain this speed throughout the remainder of the activity. Feedback was provided to each participant throughout the remainder of each speed category in an attempt to maintain a relatively constant speed. This approach was used to simulate real-life activity and to reduce the clustering effect that set speeds may have during statistical analysis. Individual rest periods between each movement activity were used to return participants heart rate below 100 beats·min^{-1}. Once the protocol was completed, the collected data was downloaded to the main investigator's PC.

3. 2. 5. Calibration Activities

The activities included in the protocol were 1) resting VO_2, 2) sitting on a chair, 3) standing upright unaided, 4) slow walking (2.5-4.5 km.h^{-1}), 5) brisk walking (4.5-6.5 km.h^{-1}) and 6) light jogging (6.5-8.5 km.h^{-1}). The activities included in the protocol were informed by a number of past studies which recommended sedentary and locomotor activities (Treuth *et al.*, 2004, Welk, 2005, Bassett Jr *et al.*, 2012). Other core activities which have been recommended for inclusion in validation and calibration studies, such as car driving, cycling and stair ascending/descending have not been included in this protocol (Bassett Jr *et al.*, 2012). Car driving was not included for insurance reasons, cycling was omitted as extremely low levels of participation in cycling have been observed in this population (Department of Transport, 2009) and stair ascending/descending was not included for practicality reasons.

For the sitting and standing activities, data was collected for 5 minutes, while 7 minutes of data was collected for ambulatory activities, with the mean value of the final two minutes of each activity used for data analysis. These durations were selected as VO_2 remains stable (steady state) after 3 minutes for light activity and after 3-5 minutes for more intense activities (Poole *et al.*, 1991). The internal time clocks of the ActiGraph, activPAL and metabolic unit were synchronised The mean value of the final two minutes of each activity

(excluding resting VO_2) was used for data analysis, as participants were deemed to be at steady state energy expenditure during this period (Treuth *et al.*, 2004).

3. 2. 6. Data Processing

Once data from both the activPAL and ActiGraph were downloaded, files were processed using the activPAL (v 5.9.1.1) and ActiGraph (Actilife v4.4.1) software. For the ActiGraph, only accelerations measured in the vertical plane were used for comparative analysis and the low frequency extension was not employed. This created time stamped 15 sec^{-1} epoch-by-epoch information. Using the $K4B^2$ software, the VO_2 information was averaged for every 15 sec^{-1} period, synchronising the start time with the protocol start time. The breath-by-breath VO_2 data from the $K4B^2$ and the resulting epoch-by-epoch data from both the activPAL and the ActiGraph were collated, ensuring that the protocol start time for each individual was synchronised for all three devices. The information recorded by the single observer for the activity categories was synchronised with the VO_2, activPAL and ActiGraph data. The final 2 minutes of each activity performed were selected for analysis, and all data exported to Predictive Analytic Software (PASW) version 18.0 for Windows (SPSS Inc., Chicago, IL, USA).

When preparing data for examining the levels of agreement between sitting/lying, standing and stepping, the inclinometer function of the activPAL was used to examine sitting/lying time and standing time, while the accelerometer function of the activPAL was used to examine stepping time. A sedentary threshold of < 100 counts·min^{-1} has been suggested for use with the ActiGraph in youths from studies which have examined levels of agreement between the activPAL and the ActiGraph (Ridgers *et al.*, 2012). For this reason, a sedentary threshold of < 100 counts·min^{-1} was used to quantify sedentary time using the ActiGraph only. This information was compared with the recorded activity categories from the single observer.

3. 2. 7. Statistical Analysis

The use of conventional 1 MET values is discouraged for use in both children and adults (Butte *et al.*, 2012). To normalise energy cost between participants during different tasks, participant's individual resting metabolic rate (RMR) were used to calculate their resting MET values, with energy cost during activity being expressed in calculated METs (MET score = Activity VO_2 mL·kg^{-1}min^{-1}/Resting VO_2 mL·kg^{-1}min^{-1}). The accelerometer data was plotted to coincide with the steady state VO_2 for each of the performed activities. Spearman's Rho correlation coefficients were calculated between accelerometer output from both the activPAL and the ActiGraph and VO_2 with an r value of > 0.7 considered highly correlated.

A random coefficients statistical model, which accounts for repeated measures taken from the same participants, was used to examine the relationship between MET values (dependant variable) and the activPAL counts using the equation development group only. This has been the predominant statistical method used to examine the relationship between MET values and accelerometer counts (Puyau *et al.*, 2004, Treuth *et al.*, 2004, Pfeiffer *et al.*, 2006). The concordance correlation coefficient (CCC = the mixed model equivalent of R^2 in linear regression) was used to assess the goodness of fit of the equation (Vonesh *et al.*, 1996), and this was presented with the Standard Error Estimate (SEE). Age, height and weight were not found to contribute to the fit of the model. However, linear regression is highly sensitive to outliers, while it also assumes the prediction error is constant across all values of the predictor variables. It has also been highlighted that the relationship between energy expenditure and physical activity is non-linear. The use of decision boundaries and ROC analysis has been proposed as an alternative statistical procedure in this setting as it provides a method of determining accelerometer intensity thresholds with less misclassification than the previously employed regression formulae (Jago *et al.*, 2007). Receiver operating characteristic (ROC) curves were used to calculate an area under the curve (AUC) and to define a threshold which optimises sensitivity and specificity (Zweig and Campbell, 1993). Sensitivity (true positive fraction) refers to the correct identification of an activity intensity (i.e. >3.0 METs) using a specific intensity threshold, and is calculated as Sensitivity = No. of true positive test results/ (No. of true positive test results + No. of false negative test results). Specificity (false positive fraction) refers to the correct identification of different activity intensity (i.e. <3.0 METs) using a specific intensity

threshold, and is calculated as Specificity = No. of false positive test results/ (No. of true negative test results + No. of false positive test results). The advantage of this method is that the sensitivity and specificity can be calculated for each activity intensity threshold, and the threshold with the optimum sensitivity and specificity can then be selected for use within the population. The intensity thresholds were developed using both mixed regression (MR) and ROC analysis. Both sets of thresholds were then cross-validated using ROC analysis on an independent group. Sensitivity, specificity and area under the curve were examined and interpreted (Swets, 1988), and the optimal value for moderate physical activity and vigorous physical activity were identified. All analyses were undertaken using PASW statistics.

A non-parametric Spearman correlation was performed to examine the concurrent validity of the count·15 s^{-1} function of the activPAL with that of the ActiGraph. To examine the validity of the activPAL when classifying sitting, standing and stepping time, data from both the activPAL and the ActiGraph were compared with activity information recorded by the single observer. Agreement between both the activPAL and ActiGraph and direct observation was examined on a minute-by-minute basis. This involved observing the amount of time each participant spent in each activity, and examining how well this time agreed with the observed activity category. Percentage agreement, sensitivity and predictive values were calculated (Grant *et al.*, 2006). Percentage agreement was defined as the agreement between all observed samples and activity monitoring samples ((number of observed samples which were correctly identified by activPAL or ActiGraph * 100)/total number of samples). Sensitivity was defined as the degree to which the activity monitors correctly detected the activity category ((number of observed samples which were correctly identified by activPAL or ActiGraph for each activity category * 100)/total number of samples for each activity category). Predictive Value was defined as the level to which each activity monitor determined category agreed with the observed activity category ((number of matching samples between observed values and activPAL or ActiGraph for activPAL or ActiGraph activity category * 100)/total number of samples for activPAL or ActiGraph activity category).

3. 3. Results

3. 3. 1. Descriptive Information

Participants' mean age was 17.2 yrs. ($\pm$ 0.9), mean height was 1.7 m ($\pm$ 0.1), mean weight was 65.4 kg ($\pm$ 9.2) and the mean body mass index of the population was 23.2 kg·m^{-2} ($\pm$ 2.8). There were no significant differences observed for age, height, weight or BMI between the development group and the cross-validation group.

3. 3. 2. Criterion Validity of the activPAL Activity Monitor

Table 3.1 describes the mean and SD of VO$_2$, MET scores, speeds and both activPAL and ActiGraph activity counts expressed in count·15 s^{-1} from the development group. The chosen activities provided a wide range of accelerometer counts (activPAL Range: 0 to 14198 counts·15 sec^{-1}; ActiGraph Range: 0 to 3378 counts·15 sec^{-1}) and MET scores (Range: 0.74 to 14.95 METs).

Table 3.1 Mean ($\pm$SDs) of VO$_2$ ml·kg^{-1} min^{-1}, MET scores, speed and both activPAL and ActiGraph activity counts.

Activity	VO$_2$ (ml·kg^{-1}·min^{-1})	METs	activPAL counts·15 s^{-1} (n=15)	ActiGraph counts·15 s^{-1} (n=15)	Speed (km/h)
Sitting	4.2 (1.2)	1.1 (0.2)	5 (8)	0 (1)	N/A
Standing	4.3 (1.2)	1.1 (0.2)	15 (22)	1 (2)	N/A
Slow Walk	11.0 (1.9)	3.0 (0.7)	3098 (858)	632 (174)	3.6 (0.4)
Brisk Walk	14.3 (2.1)	3.9 (0.8)	5011 (869)	940 (156)	4.9 (0.4)
Light Jogging	31.1 (4.5)	8.5 (1.9)	11086 (1624)	2368 (406)	7.3 (0.5)

The criterion validity of the activPAL was examined using VO_2 as the criterion measure. The MR equation (N=15) for the activPAL was developed for this population to correspond to activity categories (Moderate = 3-5.99 METs; Vigorous = 6 METs or greater) that have been recommended for examination in previously published literature. The developed equation is:

$$\text{METs} = 0.971011 + 0.000677 * (\text{counts·15 s}^{-1})$$

The concordance correlation coefficient (CCC) for counts·15 s^{-1} was identified as 0.93 (SEE = 1.20). When solving the equation, 2997 counts·15 s^{-1} was the value for a moderate threshold of 3 METs, while 7428 counts·15 s^{-1} was the value for vigorous threshold of 6 METs.

3. 3. 3. Mixed Regression Analysis

The ability of the MR to predict MET values from activity counts in an independent group was examined. The correlation values from this analysis are presented in Table 3.2. The mean absolute difference between actual and predicted MET values for non-locomotor activities, locomotor activities and all activities are also included in Table 3.2.

Table 3.2 Concordance correlation results comparing actual MET values with activPAL counts·15 s^{-1} based predicted MET values for all activities, non-locomotor activities and locomotor activities in the cross-validation group.

	Actual Mean	Predicted Mean	Mean Absolute Difference	SEE	r value
All activities	4.19 (3.16)	4.02 (3.04)	1.32	0.86	0.93[*]
Non-locomotor Activities	1.17 ± 0.21	0.99 ± 0.02	0.92	0.27	0.25
Locomotor Activities	5.92 ± 2.74	5.75 ± 2.5	1.55	1.06	0.87[*]

N=15; [*] p < 0.01.

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3. 3. 4. ROC Analysis

The development group data was examined using ROC analysis, and revealed an AUC of 0.98 for moderate physical activity and 0.99 for vigorous physical activity. For moderate physical activity, a threshold of 3329 counts·15 s^{-1} optimised sensitivity (0.93) and specificity (0.93), while a threshold of 8229 counts·15 s^{-1} optimised sensitivity (0.98) and specificity (0.97) for vigorous physical activity. These values would be considered highly accurate (Swets, 1988).

3. 3. 5. Cross-Validation of Developed Thresholds

The moderate physical activity and vigorous physical activity thresholds from both mixed regression analysis and ROC analysis were cross-validated, and the cross-validation results are presented in Table 3.3. Each threshold demonstrated high levels of sensitivity and specificity when cross-validated. As the AUC for both moderate physical activity thresholds and both vigorous physical activity thresholds were the same, sensitivity and specificity were summed and the threshold with the highest value was selected as the optimal threshold. An optimal threshold of 2997 counts·15 s^{-1} was identified for moderate physical activity, while an optimal threshold of 8229 counts·15 s^{-1} was identified for vigorous physical activity. The moderate physical activity threshold was developed using MR, and optimised sensitivity (95.7%) and specificity (94.5%). The vigorous physical activity threshold was developed using ROC analysis and optimised sensitivity (97.7%) and specificity (100%).

Table 3.3 Cross-validation results for the activPAL for sensitivity and specificity values for activity intensity thresholds developed using both mixed regression analysis and receiver operating characteristic (ROC) analysis.

	Moderate Physical Activity		Vigorous Physical Activity	
	Mixed Regression	ROC	Mixed Regression	ROC
Counts·15 s⁻¹	2997	3329	7428	8229
Sensitivity (%)	95.7	91.3	97.7	97.7
Specificity (%)	94.5	95.9	99.2	100
AUC	0.99	0.99	1.0	1.0

3. 3. 6. Concurrent Validity

There was a strong, positive relationship between the counts function of the activPAL and that of the ActiGraph ($r = 0.96$, $p < 0.01$) demonstrating very high concurrent validity between the two devices. Figure 3.1 presents the relationship between the count function of the activPAL and ActiGraph.
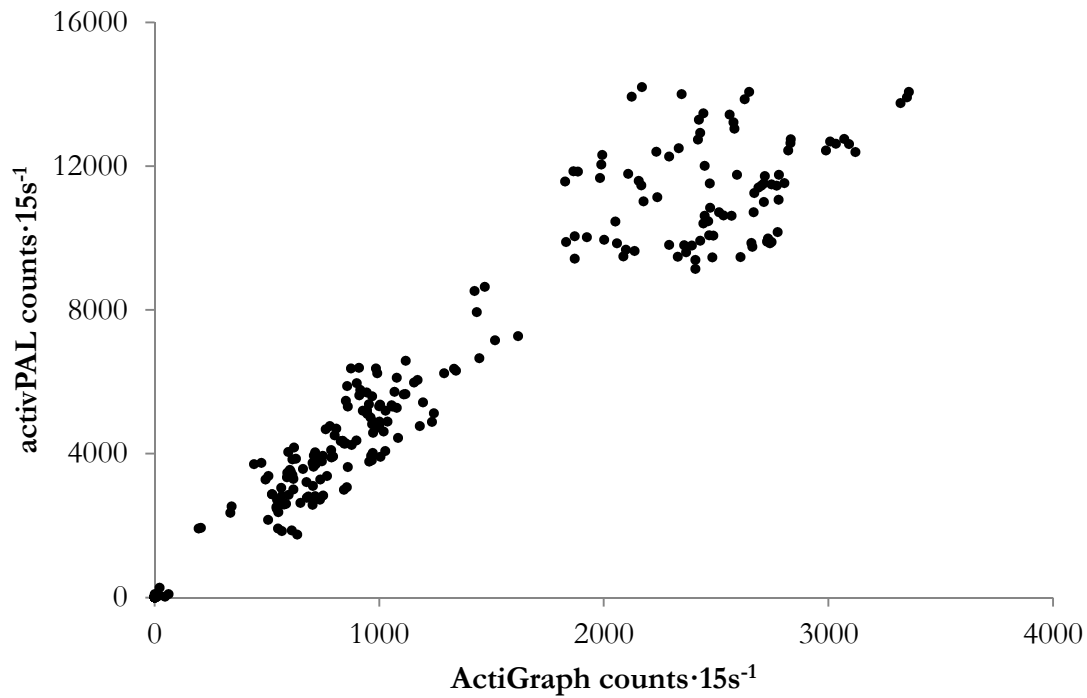
(N=30)

Figure 3.1 Relationship between the activPAL activity monitor count function and the ActiGraph GT3X accelerometer across all activities.

3. 3. 7. activPAL and ActiGraph GT3X Sitting/Standing/Slow Walking Vs. Direct Observation

The results of the minute-by-minute analysis for levels of agreement, sensitivity and predictive values of the activPAL and the ActiGraph with direct observation for sitting, standing upright and slow walking are presented in Table 3.4. The overall levels of agreement between direct observation and activPAL for correct classification of sitting, standing and slow walking was 99.1%, while the overall agreement between direct observation and the ActiGraph was 66.7%. Additionally, a graphical representation of the activity counts·min^{-1} for ActiGraph recorded sitting, standing and light stepping activities is presented and compared with the < 100 counts·min^{-1} sedentary threshold in Figure 3.2.

Table 3.4 Comparison of activPAL and ActiGraph determined sitting, standing and stepping with observed activity category.

	All activities	Sitting		Standing		Slow Walking	
	Agreement	S %	PV %	S %	PV %	S %	PV %
activPAL	99.1 %	100 %	100 %	98.1 %	100 %	99.2 %	100 %
ActiGraph	66.7%	100%	100%	0%	0%	100%	100%

S = Sensitivity; PV = Predictive Value.
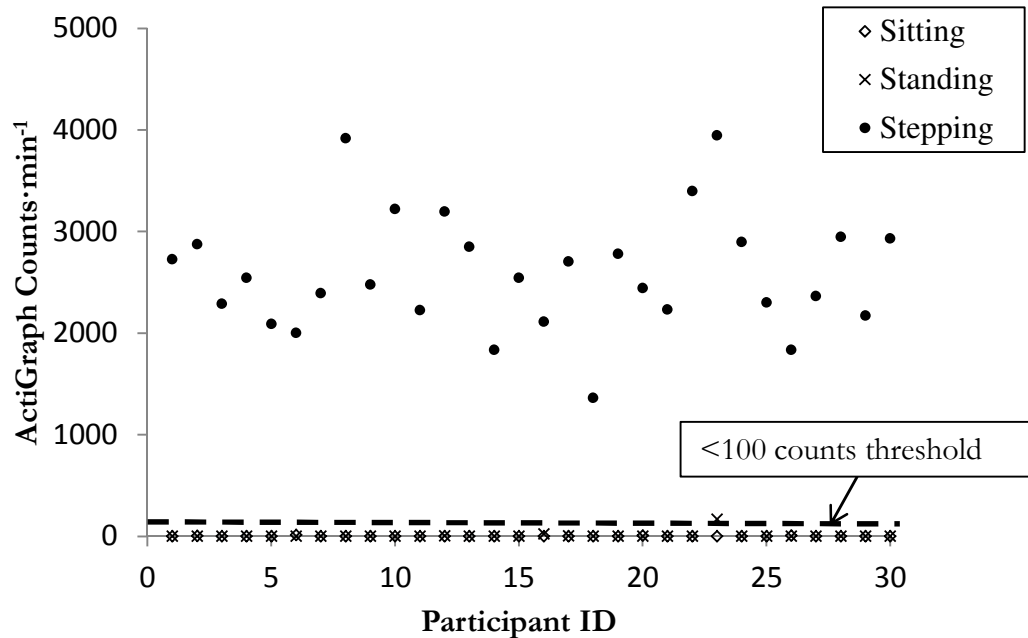
(N=30)

Figure 3.2 ActiGraph counts·min^{-1} directly observed sitting, standing and slow walking compared with the < 100 counts·min^{-1} sedentary threshold.

3. 4. Discussion

The purpose of this chapter is to investigate the validity of the activPAL activity monitor as a measure of physical activity, while also determining a count to activity threshold for moderate to vigorous physical activity. The activPAL demonstrated high levels of criterion validity, identifying a mixed model equivalent to an R^2 of 0.93 (SEE = 1.20) when

compared with METs across 7 different activity intensities. A threshold of 2997 and 8229 counts·15s^{-1} for moderate physical activity and vigorous physical activity respectively identified optimum levels of sensitivity and specificity after cross validation in an independent sample. The activity count function of the activPAL demonstrated high levels of concurrent validity with the ActiGraph accelerometer count function ($r = 0.96$, $p < 0.01$), while the activPAL was more accurate at distinguishing between sitting, standing and stepping than the sedentary thresholds employed when using the ActiGraph.

3. 4. 1. The Identification of the activPAL as a Valid Measure of Physical Activity

This study is the first study to develop count values that correspond to different activity intensities for the activPAL, which are typically used when examining physical activity in both observation and intervention research. Thus far, the literature on the use of the activPAL to examine physical activity is limited to sedentary and step-based measurement in laboratory (Grant *et al.*, 2006, Ryan *et al.*, 2006) and habitual settings (Chastin *et al.*, 2009, Harrington *et al.*, 2012). While the existing activPAL software provides an easy to understand output of steps and cadence, which have been compared to MET estimates, it has been suggested that the use of activity counts in the examination of free-living physical activity may be more applicable than the use of steps (Freedson *et al.*, 1998, Harrington *et al.*, 2011b). To date, only one study has attempted to validate the activPAL with a criterion measure (Harrington *et al.*, 2011b). In this paper, Harrington et al. (2011b) highlighted that the relationship between counts and measured METs was stronger than the relationship between steps and measured METs (Harrington *et al.*, 2011b). Similarly, the results presented in the present chapter indicate that activPAL counts are highly associated with MET scores in an adolescent female population while performing a range of everyday activities (CCC = 0.93; SEE = 1.20). Weak correlations were observed when the MR predicted MET values from activity counts for non-locomotor activities ($r = 0.25$). However, the activPAL separately and accurately distinguishes between sitting and standing using an inbuilt inclinometer, which is more likely to be employed when examining non-locomotor activities in free-living investigations. Although the activPAL employs a separate mechanism to determine sitting/lying and standing activities, non-locomotor activities are

included to comply with recommendations for calibration and validation (Welk, 2005, Bassett Jr *et al.*, 2012). The MR predicted MET values from activity counts within 1.32 METs, while a strong and significant correlation existed between actual and predicted MET values across all activities (r = 0.93; p < 0.01). Similar to findings from other validation studies, these results suggest that the MR appears to be comparable when examining physical activity in this specific population (Freedson *et al.*, 1998, Treuth *et al.*, 2004, Welk *et al.*, 2007).

3. 4. 2. The use of both Mixed Regression Analysis and Receiver Operating Statistics

Methodological differences in estimating intensity thresholds may have a substantial effect on resulting values (Freedson *et al.*, 2005). It has been suggested that the use of linear and non-linear regression equations when developing activity intensity thresholds have significant limitations (Jago *et al.*, 2007). An alternate method for the development of activity intensity thresholds for use in accelerometer-based research has been developed (Jago *et al.*, 2007) and implemented in studies with children and adolescents across a range of accelerometers (Welk *et al.*, 2007, Esliger *et al.*, 2011). Through attempting to maximise the AUC, the ROC method of determining intensity thresholds places an equal emphasis on the importance of both sensitivity and specificity (Welk *et al.*, 2007). The use of ROC analysis and AUC in the development of intensity thresholds maximises the sensitivity and specificity in classifying MET values correctly and reduces the error of estimating the true intensity (Jago *et al.*, 2007). In this chapter, intensity thresholds were developed using both MR and ROC analysis, and a decision on which threshold was recommended for use was based on the sensitivity, specificity and area under the curve after cross-validation. When cross validated with an independent sample, a MR determined threshold of 2997 counts·15 s^{-1} was identified for moderate physical activity (Sens = 95.7; Spec = 94.5; AUC 0.99), while an ROC determined threshold of 8229 counts·15 s^{-1} was identified for vigorous physical activity (Sens = 97.7; Spec = 100; AUC 1.0). The observed high levels of sensitivity, specificity and AUC support the use of the developed threshold values within this specific population.

3. 4. 3. The Concurrent Validity of the activPAL Activity Monitor

To date, only one study has compared the concurrent validity of the step count function of the activPAL and the step count function of the ActiGraph GT1M to video recorded steps (Harrington *et al.*, 2011b), while no study has previously examined the concurrent validity of the activity count function of the activPAL with that of the ActiGraph. The findings of Harrington et al. (2011) identified that the activPAL step function was reasonably accurate at measuring moderate walking speeds, and was more accurate at measuring slow walking speeds when compared to the ActiGraph. The results presented in this chapter have identified that the activity counts·15s⁻¹ function of the activPAL demonstrated very high concurrent validity when compared across all activities with the ActiGraph (r = 0.96; p < 0.01). This would suggest that the activPAL is at least as effective in measuring locomotor activities as the uniaxial function of the ActiGraph.

3. 4. 4. Differences in activPAL and ActiGraph Determined Sitting and Standing Time

Until now, large-scale studies have utilised a sedentary count threshold (e.g. < 100 counts·min⁻¹) when using the ActiGraph to define sedentary or sitting time (Matthews *et al.*, 2008, Healy *et al.*, 2011b, Matthews *et al.*, 2012). Researchers have examined the effectiveness of using a range of count thresholds for the ActiGraph compared with the activPAL (criterion measure) for examining sedentary time in youth, and a sedentary threshold of <100 counts·min⁻¹ has been suggested (Ridgers *et al.*, 2012). Although the use of such sedentary thresholds may be appropriate for specific sedentary variables or research questions - whereby standing is considered a sedentary activity - the ability of such devices to examine sedentary patterns and behaviours is limited. It has been highlighted that standing is a distinct behaviour from sitting and can confer its own physiological benefits (Hamilton *et al.*, 2007, Hamilton *et al.*, 2008, Owen *et al.*, 2010). This chapter has highlighted the accuracy of the < 100 counts·min⁻¹ in estimating sitting/lying time (100%) and stepping time (100%). However, the inability of the ActiGraph to determine standing time has also been demonstrated (accuracy of 0%). These findings suggest that the use of a < 100 ActiGraph counts·min⁻¹ in an adolescent female population will include time spent

standing still, and highlights a limitation to the use of the <100 ActiGraph counts·min^{-1} to determine sitting/lying patterns. This < 100 counts·min^{-1} threshold was applied to the ActiGraph vertical axis only as this threshold was developed using the vertical plane only from an older ActiGraph model. Findings of this study have also identified high levels of agreement between direct observation and the activPAL for sitting/lying (100%), standing (98.1%) and stepping (99.2%). Although the activPAL also records counts that can be examined using sedentary thresholds (similar to the ActiGraph), the activPAL employs an inbuilt inclinometer, which allows inclination of the thigh to be classified into sitting/lying or standing without the user resorting to using thresholds. The inclinometer function of the activPAL has previously been identified as both a valid and reliable measure of posture (Grant *et al.*, 2006). Devices, such as the activPAL, have provided researchers with the capability of directly examining sitting/lying behaviours and standing behaviour, while also examining levels of physical activity. The use of a single activity monitor to distinguish between sitting/lying and standing time, to examine both of these behaviours and to examine physical activity behaviours in a habitual setting has the ability to provide detailed activity profiles in population-based research. The use of inclinometer-based activity monitors has substantial potential in the area of physical activity and health-related research, as results from these monitors enable researchers to make stronger and more accurate associations between activity variables (including sitting/lying, standing and physical activity behaviours) and health variables (Bassett Jr *et al.*, 2010, Owen *et al.*, 2010).

3. 4. 5. The Advantages of using an Inclinometer-Based Activity Monitor as a Measure of Physical Activity

This chapter aims to explore the effectiveness of the commonly employed ActiGraph (used in uniaxial mode) and the newer activPAL in measurement of physical activity and sedentary behaviour. The results provide evidence that the activPAL can be used to examine standing, moderate physical activity and vigorous physical activity, while also as a measure of sedentary behaviour (for which it was originally developed). However, to recommend the activPAL for physical activity measurement alone would be premature, as the present study is only the first to validate the activPAL count function and to create thresholds for moderate physical activity and vigorous physical activity, compared with

over 2 decades of validation and calibration work on the ActiGraph. However, the limitations of the ActiGraph for measuring sedentary behaviour cannot be overlooked. Our findings, particularly data presented in Figure 3.2, highlight the inability of the < 100 counts·min^{-1} sedentary threshold for the ActiGraph to differentiate between sitting and standing. The obvious approach would be to use both ActiGraph for measurement of physical activity and activPAL for the examination of sedentary behaviour. However, the potential cost and burden of wearing two devices on participants, especially children, cannot be overlooked as it may affect compliance. To our knowledge, only one study has examined levels of physical activity and sedentary behaviour using both the activPAL and ActiGraph devices (Martin *et al.*, 2011). Three days of valid measurement, which is below the recommended measurement period (Trost *et al.*, 2005), were required from each participant, and insufficient data was provided by 28% of participants (Martin *et al.*, 2011). Published findings on the measurement of free-living physical activity in adolescents using the activPAL only have identified high levels of compliance (8% of participants providing less than 4 valid days of measurement) (Harrington *et al.*, 2011a). Newer devices, such as the ActiGraph GT3X+, have incorporated the inclinometer functions into existing accelerometers. Although these devices may have the potential to measure inclination, further work needs to determine their validity and reliability. The potential of a device, such as the activPAL, which has now been validated for both activity and posture in an adolescent female population, to objectively examine physical activity, coupled with the objective examination of sedentary patterns and behaviours in free-living populations, is substantial and of great benefit in large-scale health-related research.

3. 4. 6. Strengths and Limitations

This is the first non-treadmill based validation study of the activity count function of the activPAL, which is becoming increasingly popular in physical activity and health-related research. A significant strength of this study is that we employed individualised RMR to normalise energy cost between participants for each activity, rather than the use of standard RMR values (Butte *et al.*, 2012). The use of over ground walking with self-pacing within a particular speed range, which is more effective in simulating real-life activity and reduced the clustering effect that is normally created by using specific speeds, is a significant

strength of this study (Bassett Jr *et al.*, 2012). This study also employs a criterion measures for energy expenditure (indirect calorimetry) while direct observation is used as a measure of posture and activity. The inclusion of sedentary activities and of a range of locomotor activity intensities (light, moderate and vigorous activity) is another strength of this study (Welk, 2005, Bassett Jr *et al.*, 2010). Another important strength of this study is the cross-validation of the equation, which is employed to examine the ability of the MR to estimate MET values from accelerometer counts for the activPAL (Bassett Jr *et al.*, 2012). An additional strength of the study is the development and cross-validation of activity intensity thresholds which optimise sensitivity and specificity using ROC analysis and the AUC.

This study targeted a specific population, adolescent females, and results from this population may not be generalised to younger children, adolescent males or a wider adult population. High levels of physical inactivity have been observed in adolescent female populations (Troiano *et al.*, 2008), making them a population of great importance when examining activity behaviour, particularly when aiming to implement activity interventions to increase activity levels and decrease sedentary time (Harrington *et al.*, 2011a). The validation of the activPAL in larger and more variable samples is necessary. The threshold development protocol does not represent the full range of activities undertaken by a population, since it does not include weight-bearing and upper body activities (Welk, 2005, Bassett Jr *et al.*, 2012). Additionally, during cross validation, the use of different walking speeds over a specified period may be of greater benefit. This methodology may have examined the ability of the thresholds to detect small and quick change in activity intensity. Finally, the use of the low frequency extension may have an effect on the results.

3. 5. Conclusion:

The accurate and objective examination of physical activity and sedentary behaviours is critical when establishing links between activity behaviours and indices of health. The activPAL has been previously identified as a valid and reliable method of directly examining sedentary behaviours. However, the ability of the activPAL to examine physical activity patterns through the accelerometer count function has not been investigated. This chapter has highlighted high levels of criterion and concurrent validity demonstrated by the activPAL count function in an adolescent female population, and has also presented

optimum thresholds for moderate physical activity and vigorous physical activity in this population. The chapter has also highlighted the ability of the activPAL to distinguish between sitting, standing and stepping time, while also identifying the limitation of the <100 counts·min^{-1} sedentary threshold employed by the ActiGraph. The findings of this chapter support the future use of the activPAL not only as a measure of sedentary behaviours, but also as a measure of physical activity in an adolescent female population.

Chapter 4. The Measurement of Sedentary Patterns and Behaviours using the activPAL™ Professional Physical Activity Monitor.

4. 1. Introduction

4. 1. 1. Observed Associations between Sedentary Behaviours and Health

Over the last decade, research has highlighted the independent risk that sedentary behaviours have on health (Bey *et al.*, 2003, Hamilton *et al.*, 2004). There is growing evidence that excessive bouts of prolonged sitting have negative effects on indices of health, which is distinct from the lack of exercise (Hamilton *et al.*, 2004, Owen *et al.*, 2010). According to Hamilton et al. (2007), prolonged periods of sitting may result in a reduced activity of the enzyme lipoprotein lipase (Hamilton *et al.*, 2007). This enzyme regulates muscle triglyceride uptake, and its down-regulation could raise blood lipid levels and decrease high-density lipoprotein synthesis, both of which would have negative consequences for health. Additionally, prolonged sitting reduces the effects of insulin action, even when energy intake is similarly reduced (Stephens *et al.*, 2010). Supporting evidence for the negative health consequences of sedentary time in both children/adolescents and adults has been provided by epidemiological studies such as the AUSDIAB study (Healy *et al.*, 2008c), the NHANES study (Healy *et al.*, 2011b), the EPIC Norfolk study (Jakes *et al.*, 2003), and the AFINOS study (Martinez-Gomez *et al.*, 2010).

4. 1. 2. The Objective Assessment of Sedentary Behaviours

The relationships between activity and inactivity levels and health have been examined throughout history (Pate *et al.*, 2008), and there exists a wealth of evidence on the health benefits of physical activity and the negative effects of inactivity. Consequently, there is a necessity to examine patterns and levels of activity over the whole intensity spectrum, including sedentary, in free-living populations using accurate and reliable measures (Pate *et al.*, 2008). Historically, the accurate and reliable measurement of lifestyle activities has been difficult, with subjective measures, such as self-report, the most commonly employed method of assessment (Ward *et al.*, 2005). Self-reported sedentary time suffers from similar limitations as self-reported physical activity, as individuals across all ages have difficulty recalling such ubiquitous behaviours, primarily due to their intermittent nature (Slootmaker

et al., 2009). Additionally, self-reported sedentary time has predominantly focused on TV viewing time or other surrogate measures, which do not take into consideration all other sedentary patterns that contribute to daily activity (Bassett Jr *et al.*, 2010). Recent technological developments, particularly in the area of wearable motion sensors, have provided reliable, unobtrusive and reasonably affordable methods of examining free-living activity behaviour (Troiano, 2006, Troiano *et al.*, 2008). Such improvements have enabled large-scale objective examinations of free-living populations, such as The Avon Longitudinal Study of Parents and Children (ALSPAC) and the National Health and Nutrition Examination Survey (NHANES) in the United States (Matthews *et al.*, 2008, Troiano *et al.*, 2008).

4. 1. 3. Fundamental Limitations of Assessment of Sedentary Behaviours using an Accelerometer-Based Activity Monitor

Typically, physical activity measurement devices record accelerations, and proprietary algorithms calculate arbitrary units known as accelerometer/activity counts over a specified time period or epoch (e.g. 1 minute). Calibration studies are then completed to determine count-to-activity thresholds. These thresholds enable researchers to categorise specific activity intensities, such as moderate to vigorous physical activity, from the produced accelerometer counts (Welk, 2005). If the number of activity counts produced over a specific epoch exceeds the defined threshold, it is categorised as time spent in that specific activity intensity. Studies have begun to present information on sedentary levels using similar threshold methodologies, whereby time spent below a specified accelerometer count threshold (known as a sedentary threshold) is classified as time spent in a sedentary state. ActiGraph (ActiGraph LCC, Pensacola, FL) is a commonly used measurement device and sedentary behaviour has usually been examined using an accelerometer count thresholds of < 100 counts (Matthews *et al.*, 2008) or < 200 counts (Mitchell *et al.*, 2012), while < 150 counts per minute has recently been proposed as more appropriate threshold (Kozey-Keadle *et al.*, 2011). Conclusions on sedentary time or sedentary patterns from using such thresholds must be interpreted cautiously (Owen *et al.*, 2010, Lubans *et al.*, 2011). The count function of motion sensors estimates sedentary time based on the lack of movement (Ridgers *et al.*, 2012). Consequently, such devices cannot distinguish between

sitting time and standing time (standing time should not be considered a sedentary behaviour, as the term sedentary behaviour refers to activities that do not increase energy expenditure significantly above the resting level while in a sitting or lying position (Owen *et al.*, 2010, Tremblay *et al.*, 2012). Additionally, it has been hypothesised that different sedentary thresholds may be necessary for use in different populations (sex, age, race/ethnicity, body composition) (Owen *et al.*, 2010).

4. 1. 4. The Use of Inclinometer-Based Activity Monitors

The fundamental limitations of examining static behaviour using accelerometer-based motion sensors have highlighted the necessity for alternative accurate and reliable measures of sedentary activities (Bassett Jr *et al.*, 2010). The development of inclinometer-based motion sensors, such as the activPAL™ Professional Physical Activity Monitor (PAL Technologies Ltd., Glasgow, UK), has provided researchers with methods of objectively examining activity behaviours in free-living populations using postural orientation (Chastin and Granat, 2010). The use of such devices has been encouraged, particularly for studies examining sedentary behaviours in more detail (Bassett Jr *et al.*, 2010, Owen *et al.*, 2010). To date, studies have identified the activPAL as a valid measure of posture and motion in adults (Grant *et al.*, 2006, Godfrey *et al.*, 2007), sedentary behaviours in adults (Kozey-Keadle *et al.*, 2011), and step cadence in females (Harrington *et al.*, 2011b).

4. 1. 5. Existing Examinations of Inclinometer-Determined Sedentary Time

The most common method of analysing sedentary behaviour recorded by inclinometer-based activity monitors to date has been the calculation of total sedentary time. An alternative approach is that of Chastin and Granat (2010), who described a generic statistical model to examine sedentary patterns and behaviours (Chastin and Granat, 2010). Though this generic model provides information on total sedentary time and the distribution of the length of sedentary bouts (using the Gini index), it does not aid

researchers in examining detailed information on sedentary behaviours (frequency and duration of sedentary bouts). The rich information provided by inclinometer-based motion sensors, can be examined and analysed to present valuable details of sedentary patterns and behaviours. Due to the benefits of using such a device, it is expected that inclinometer-based activity monitors will become increasingly popular in the examination of sedentary variables. However, to date, limited published information is available on methodologies employed when analysing inclinometer-determined sedentary variables in greater detail.

With the significant increase in efforts to examine sedentary patterns and behaviours in recent years, and the mounting evidence of its relationship with indices of health, there is a need to present practical and descriptive methodologies in the examination of inclinometer-based accelerometer output. Without discussions on standardised methodologies for the examination of sedentary patterns and behaviours, results obtained from different studies may not be comparable, as has been observed with objectively determined physical activity levels over the last number of decades (Westerterp, 1999, Ward *et al.*, 2005). The primary purpose of this chapter is to provide a detailed description of the methodologies used to quantify sedentary periods in a free-living environment using an inclinometer-based physical activity monitor. The secondary purpose of this chapter is to describe the methodologies used to process the resulting sedentary periods and to identify important sedentary patterns and behavioural variables across a measured day. Finally, this chapter will describe the habitual sedentary patterns and behaviours of a group of adolescent females using these methodologies.

4. 2. Methods

4. 2. 1. The activPAL Professional Physical Activity Monitor

A detailed description of the physical characteristics and of the wear protocol of the activPAL has been provided in Section 3. 2. 2. (Additional information only included in this section). The activPAL provides two types of information: 1) steps and activity counts, which can both be used to determine physical activity and 2) inclinometer information, used to determine posture (i.e. whether the wearer's thigh is horizontal, as in sitting or lying, or vertical as in standing or walking). At the end of data collection, activPAL data

was downloaded to a PC via a USB interface. This data was stored in a proprietary data format, and was processed so that sedentary data and accelerometry data was compressed into 15 second epochs.

4. 2. 2. Data from activPAL Output

The activPAL proprietary software (activPAL™ Professional V5.9.1.1) was used to access the recorded data, and the epoch data for the entire week of recording was exported to a Microsoft Excel format file (Microsoft Corporation, Microsoft Excel 2010, One Microsoft Way, Redmond, WA, USA). The spreadsheet displayed the number of seconds that the subjects engaged in sitting/lying, standing and stepping for each 15 second epoch. These values were summed over the entire 24 hour day, and averaged to get the mean time spent sitting/lying, standing and stepping during the monitoring frame.

4. 2. 3. Examination of Sedentary Periods

All recorded activPAL data was examined to ensure that a sufficient number of valid days of accelerometry recording were obtained from each participant. The protocol used for data examination and cleaning has previously been described by the authors (Harrington *et al.*, 2011a). Briefly, only data sets that provided 4 full days of accelerometer recording (including at least one weekend day) were processed for this analysis. For the purpose of this chapter, non-wear time was defined as 60 minutes or more of consecutive zero accelerometer counts between the hours of 7 am and 11 pm. A MATLAB® (The MathsWorks Inc., 3 Apple Drive, Natick, MA, 01760-2098, USA) custom software program was developed to examine the sedentary output of the activPAL Professional physical activity monitor. The developed MATLAB® program examined the sedentary function of the activPAL output file epoch-by-epoch. Firstly, the program binary coded each epoch. A sedentary epoch was categorised as an epoch spent entirely in sedentary activities (i.e. sitting/lying) (code = 1), while a non-sedentary epoch (i.e. an epoch containing more than zero seconds of standing or stepping) was categorised as an epoch with less than 15 seconds spent in sedentary activities (code = 0). The program then

examined sedentary periods, whereby one sedentary epoch identified the start of a sedentary period and the last consecutive sedentary epoch identified the end of a sedentary period. The MATLAB® computer program sequentially examined each daily activPAL file, and for each of the continuous sedentary periods provided the start time, the end time in hh:mm:ss format and the duration in bouts, minutes and seconds. The mean, standard deviation, maximum, minimum and quantity for both the sedentary activity bouts and the dynamic activity bouts were also calculated and presented. An adjustable time of day window (e.g. between 7 am and 11 pm) was also applied to the data to exclude certain out of hours information. This information was then written to a Microsoft Excel file.

4. 2. 4. Examination of Sedentary Variables

1) The Microsoft Excel file containing the non-processed activPAL output by epoch was first examined to provide the total amount of time spent in sitting/lying, standing and stepping behaviour categories. This was achieved by summing all time spent sitting/lying, standing and stepping throughout a measured day.

2) A sedentary analysis Microsoft Excel template was used to categorise sedentary periods by specific duration. For the purpose of this chapter, the selected duration categories for examination were <1 min, 1-5 mins, 6 - 10 mins, 11 - 20 mins, 21 - 40 mins and > 40 mins. These categories were selected to provide a range of shorter sedentary periods, while also identifying longer uninterrupted sedentary periods (e.g. > 20 minutes in duration) to identify daily sedentary patterns. The information obtained from the MATLAB® generated Excel file was exported to the sedentary analysis Microsoft Excel template, where the number of sedentary periods in each category was calculated. Additionally, the total amount of time spent in sedentary periods in each sedentary category was calculated.

3) The number of sit/lie to stand transitions was classified as the number of times an individual moved from a sitting/lying posture to a standing posture throughout the day. This is equivalent to the total number of sedentary periods throughout the waking day, and was calculated by summing the sedentary periods in each category described in (2) above.

4) The identification of percentage non-bed time spent in sedentary activities of specific duration is necessary, as individuals have differing bed/sleep patterns. For these differing bed/sleep patterns, bed hours and waking hours were calculated. The authors first identified 7 am as the start time for each 24 hour measurement day for every participant. This time point was selected as the majority of subjects in our research group would not rise from bed before this time. The first registered non-sedentary epoch after 7 am was identified as rise time. The last registered non-sedentary epoch of the day which was followed by a long, uninterrupted sedentary period (> 2 hours) was identified as the time the subject went to bed. Bed hours were calculated as [time between 7 am and the first non-sedentary epoch] + [time between last non-sedentary epoch and the next 7 am time point]. Waking hours were then calculated by: 24 hours − Bed hours. Particularly short periods of bed hours were manually examined to identify possible breaks in bed hours (e.g. rise to use the toilet or to get a drink), and bed hours were recalculated to present total bed hours.

5) The output produced by the sedentary analysis Microsoft Excel template was examined between the hours of 8 – 9 am (the hour immediately before school) and 3 – 4 pm (the hour immediately after school) to demonstrate the utility of the output produced by an inclinometer-based motion sensor. The purpose of this analysis was to identify potential differences in sedentary patterns and behaviours between the two time periods. The analytical approaches presented here are similar to those presented by Harrington et al. (2011), and the findings supplement those presented (whereby different time periods are analysed). Sedentary variables were processed for these particular time periods, and were examined for normality. As data was identified as non-parametric, Wilcoxon Signed Rank tests were used to compare pre- and post-school findings.

4. 2. 5. Study Outline and Subject Selection

Data for this study was collected from adolescent females who lived in County Limerick in the mid-western region of Ireland. Five urban high schools in were selected to participate in this study. Subjects were eligible to participate in this study if they were female, aged between 15 and 18 years and had no illness or injury that may prevent them from participating in regular physical activity. Consent was obtained from each school principal

prior to study commencement. With the school principal's agreement, a list of all eligible subjects within the school was obtained from the school administrators. A randomisation table was generated, and fifteen subjects from each school were randomly selected for participation in this study. All subjects provided written informed parental and participant consent. Approval for the research study was obtained from the University of Limerick research ethics committee.

4. 2. 6. Subject Procedure

All subjects reported to their school gymnasium with completed parental consent and subject consent forms. Height and weight measures were recorded from each subject, and each was provided with an activPAL Professional physical activity monitor and a detailed demonstration of how to wear the device. Subjects were instructed to wear the accelerometer for 7 full days, 24 hours a day (including when sleeping) and were instructed to only remove the device when bathing, swimming or before any other water based activities. Subjects were asked to attach the activPAL on the midpoint of the anterior aspect of the right thigh using the provided hydro-gel adhesive PAL*stickie*. An elasticised tube grip bandage was also provided, and subjects were asked to wear this over the device to form an envelope for further protection.

4. 3. Results

4. 3. 1. Descriptive Information

From the randomly selected 75 subjects, 51 participated in the study. When accelerometer data was examined for number of valid days of recording, a further 7 subjects were removed due to insufficient data (less than 4 days of accelerometer recording or not including at least 1 weekend day). Data from 44 adolescent females is thus presented in this chapter. The mean age of the subjects that participated in this study was 15.9 ($\pm$ 0.9). Participant descriptive statistics are presented in Table 4.1.

Table 4.1 Mean, standard deviation and range for subject's age, height, weight and body mass index.

N = 44	Mean (SD)	Range
Age (yrs.)	15.9 (0.9)	15 – 17 yrs.
Height (m)	1.6 (0.1)	1.5 - 1.7
Weight (kg)	58.0 (9.0)	42.4 - 80.7
BMI (kg/m^2)	21.7 (2.9)	17.2 – 28.9

4. 3. 2. Sitting/Lying, Standing and Stepping Output

Information for the activPAL output was examined to identify total time spent in specific postural positions and activities. The total number of steps accumulated over the measured day was also summed. The results of each of these variables are presented in Table 4.2.

Table 4.2 Mean (±SD) and range of hours spent sedentary, standing and stepping per day and number of steps achieved per day.

N= 44	Mean (SD)	Range
Sedentary (hrs.)	18.86 (0.96)	16.62 – 20.97
Standing (hrs.)	3.35 (0.74)	1.74 – 4.94
Stepping (hrs.)	1.79 (0.46)	0.78 – 3.12
Steps	9462 (2674)	4483 - 17841

4. 3. 3. Bed Hours, Non-Bed Hours and Percentage of Waking Day Spent in Different Sedentary Categories.

The total sedentary time during waking hours was then examined. Waking hours were defined as "24 hours - Bed Hours". The rise time and bed time (time an individual went to bed) were identified from the MATLAB® computer program output as described in 4. 2. 4 and both bed hours and waking hours identified. As highlighted above, subjects spent an

average of 18.86 hrs. (± 0.96) daily in total sedentary time. The average subject waking hours was 14.77 hrs. (± 0.79), with an average of 9.23 hrs. (± 0.79) in bed. Total waking sedentary time was calculated, identifying that subjects spent 9.63 hrs. (± 1.1) in sedentary activities during waking hours. The total amount of time spent in specific bout durations was then calculated as a percentage of sedentary time during waking hours and as a percentage of total daily sedentary time spent in specific sedentary categories. These results are presented in Table 4.3.

Table 4.3 The percentage of non-bed hours and percentage of waking sedentary hours spent in sedentary categories.

Sedentary bout duration Categories (minutes) (N = 44)	% of non-bed sedentary time	% of total daily sedentary time
< 1	0.86 %	0.44 %
1 – 5	6.29 %	3.21 %
6 – 10	8.5 %	4.34 %
11 – 20	15.67 %	8 %
21 – 40	32.88 %	16.79 %
> 40	35.79 %	67.22 %
Total	100 %	100 %

4. 3. 4. Sedentary Bouts, Sedentary Breaks and Mean Time Spent Daily in Specific Sedentary Categories

The mean number of sit/lie to stand transitions achieved by subjects per waking day was 48.8 (± 9.80). Table 4.4 describes the number of bouts and amount of time spent daily in sedentary periods of specific duration, while Figure 4.1 graphically represents this data.

Table 4.4 Summary of sedentary periods and amount of waking time spent in each specific sedentary period for each sedentary duration presented as Mean (Standard Deviation).

N = 44	Daily Bouts	Daily Minutes
<1 minute	11 (4)	5 (1.6)
1 – 5 minutes	15 (5)	36.3 (11)
6 – 10 minutes	7 (2)	49.1 (12.7)
11 – 20 minutes	6 (2)	90.5 (22.5)
20 – 40 minutes	7 (2)	190 (49.5)
>40 minutes	3 (1)	207.3 (55.8)
Total	49 (10)	578.3 (9.4)
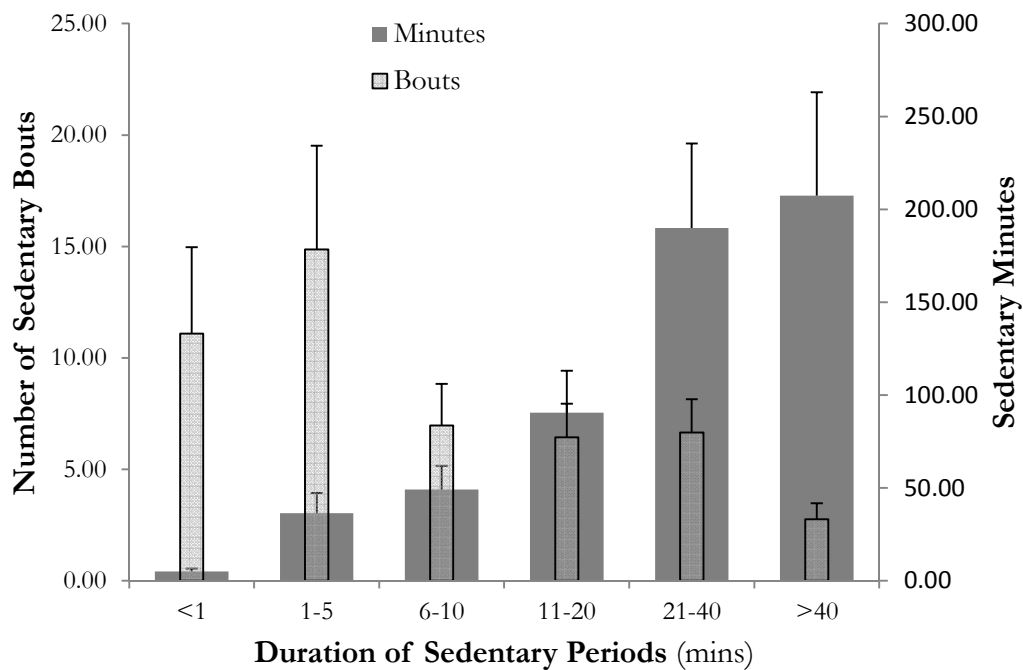
Data presented as mean + standard deviation.

Figure 4.1 Mean number of sedentary periods per day and mean total amount of time spent in each sedentary period per day.

4. 3. 5. Practical Application: A Comparison of Sedentary Patterns and Behaviours during the Hour Immediately Before and Immediately After School

The hours immediately before school and immediately after school were examined for all subjects on school days only. The total amount of time spent sedentary during the hour immediately before school was 30.1 minutes, while total time spent sedentary during the hour immediately after school was 36.47 minutes. The distribution of different sedentary bout durations during the hours immediately before and after school are presented in Figure 4.2.
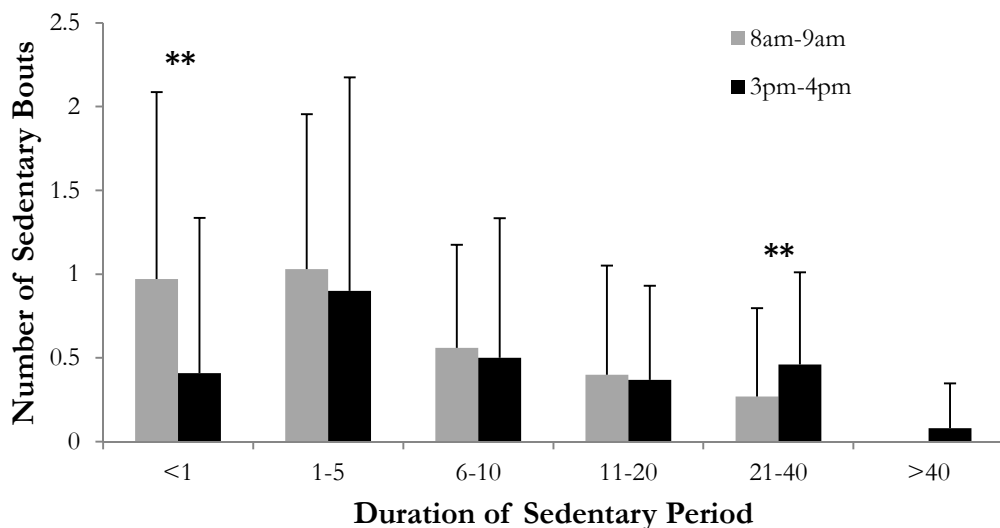
** p <0.01; Wilcoxon Signed Rank Test; N = 44

Figure 4.2 Patterns of sedentary bout categories during the hour immediately before school (8 – 9 am) and the hour immediately after school (3 – 4 pm).

The number of shorter sedentary bouts (< 20 minutes) and the number prolonged sedentary periods (> 20 minutes) were examined for the two time periods. Significantly more bouts of < 20 minutes in duration were accumulated immediately before school (2.75 ± 2.04) than immediately after school (2.3 ± 2.15), while significantly more bouts of > 20 minutes in duration accumulated immediately after school (0.6 ± 0.59) than immediately before school (0.4 ± 0.55). This information is presented in Figure 4.3.
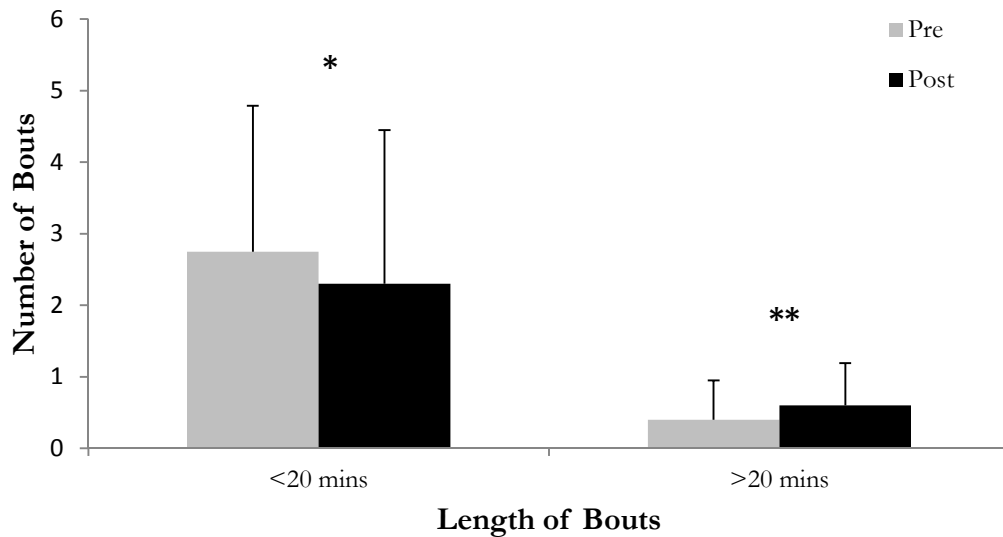
(*p < 0.05; **p < 0.01; Wilcoxon Signed Rank Test; N = 44

Figure 4.3 Sedentary periods of a shorter (< 20 minutes) and longer (> 20 minutes) duration before and after school.

4. 4. Discussion

A recently published *"Sedentary Behaviour Research Strategy"* has identified the precise measurement of prolonged periods of sitting as a key phase when researching the population health science of sedentary behaviour. (Owen *et al.*, 2010). As such, there is a need for researchers to develop methods of analysing sedentary output from inclinometer-based motion sensors. Standardised methods of data analysis have also been identified as one of the greatest difficulties in accelerometry research, as comparability of research findings between studies is extremely difficult (Masse *et al.*, 2005, Ward *et al.*, 2005, Healy *et al.*, 2008c). This chapter has described and presented methodologies that may be employed when examining free-living sedentary patterns and behaviours using an inclinometer-based activity monitor. This information has the potential to enable researchers to examine inclinometer-based activity monitor output in a standardised manner, and to present and compare their findings with similar research studies.

4. 4. 1. The Examination of Sedentary Time

It has been suggested that the examination of sedentary time during waking hours alone may be considered inconsistent, as sleeping periods make up a large proportion of total daily sedentary time (Chastin and Granat, 2010). The majority of large-scale studies, which have reported sedentary time and patterns in this manner, have used accelerometers that were not worn during night/sleep hours, such as the ActiGraph GT1M/GT3X accelerometer (Healy *et al.*, 2007, Matthews *et al.*, 2008, Healy *et al.*, 2011b). A difficulty with not wearing the accelerometer at night is that subjects may potentially fail to re-apply the device immediately after waking or still be awake and sedentary (using laptop or reading for example) for a period of time once the participant is in bed and has removed the device. The use of a device that is an accurate measure of sitting/lying to standing movements that can also be worn throughout the night reduces the uncertainties associated with the assumption of waking hours identified by Chastin and Granat (2009), and allows for a more accurate estimation of waking time. This chapter has examined sedentary patterns and behaviours recorded across an entire 24 hour period using an inclinometer-based activity monitor. The identification of the first rise time and last movements of each individual enables the examination of sedentary patterns including time spent in bed as suggested (Chastin and Granat, 2010), while also allowing researchers to normalise sedentary patterns by presenting results as a percentage of waking sedentary time. The high compliance rates observed in this study (86% of subjects providing sufficient activPAL data) would suggest that wearing the device throughout the night does not deter subjects from wearing the device for recommended measurement period. Similar levels of compliance have been observed in adult studies which have employed the activPAL (Chastin *et al.*, 2009, Dall and Kerr, 2010). Large scale epidemiological studies in children and adolescents that have employed devices that are removed during night hours appear to have provided consistently lower compliance rates (Sardinha *et al.*, 2008, Troiano *et al.*, 2008, Carson and Janssen, 2011). These findings suggest that the activPAL is an acceptable measurement device in an adolescent female population, and should be considered as an acceptable method of monitoring habitual activity in this population. Further examination of the compliance rates of the activPAL is merited to ensure these high levels are apparent across people of different ages, sex and ethnicity.

4. 4. 2. The Frequency of Sedentary Periods

Unsurprisingly, data presented in Figure 4.2 (for waking sedentary patterns and behaviours) resembles a power law distribution (larger number of short periods accounts for a small amount of time, while a small amount of long periods accounts for a large amount of time). Similar observations for the distribution of sedentary patterns and behaviours have been highlighted (Chastin and Granat, 2010), although the distribution included here does not include the sedentary hours spent in bed. Discrepancies with the power law distribution of the < 1 minute category are likely due to the duration of the sedentary category rather than the activity behaviour. Sedentary bouts of less than 1 minute are possibly less likely than sedentary bouts of 1-5 minutes, as few activities of daily living would require a change in postural position from standing to sitting and back to standing within a one minute time period. In future, the authors suggest that this category be pooled with sedentary periods of 1-5 minutes in duration, unless specific shorter bouts are required for analysis.

4. 4. 3. The Importance of a Direct Measure of Sedentary Time

The ability for physical activity and health-related researchers to identify strong associations and relationships between health indices and patterns and behaviours of particular types of activity (such as sedentary, light activity or moderate to vigorous activity) is dependent on accurate measurement methodologies (Reilly *et al.*, 2008, Healy *et al.*, 2011b) and an ability to interrogate our resulting information in the most efficient and effective manner (Troiano, 2005, Welk, 2005). To make associations between free-living sedentary behaviours and the inactivity physiology work completed by Hamilton and colleagues, researchers must 1) examine sedentary behaviour using the correct methods and 2) interpret the findings in the correct manner. Thus far, inactivity physiologists have highlighted the potentially deleterious effect that high levels of sedentary time may have on indices of health (Bey *et al.*, 2003, Hamilton *et al.*, 2004). However, epidemiological studies that have confirmed these observations in large-scale free-living examinations have measured the lack of ambulation rather than sedentary time (Ridgers *et al.*, 2012) or used self-report methods. The term sedentary refers to activities that do not significantly increase energy expenditure above a resting rate while in a sitting or lying position (Owen *et*

al., 2010, Tremblay *et al.*, 2012). Existing objective epidemiological evidence does not distinguish between sedentary time, standing time and low levels of ambulation, and consequently has not directly measured sedentary activities. Furthermore, the presentation of sedentary findings has previously focused on total sedentary time (Healy *et al.*, 2008c, Matthews *et al.*, 2008, Healy *et al.*, 2011b). The presentation of this total sedentary time may allow significant details of sedentary patterns and behaviours to go undetected. Healy et al (2008a) progressed the examination of total sedentary time by providing evidence that more interruptions in sedentary time were positively associated with metabolic risk variables (Healy *et al.*, 2008a), yet the association between prolonged sedentary bouts and health indices has not been examined. The use of a robust statistical method of examination of sedentary behaviours, although adding significantly to the field, may also overlook significant detail of sedentary patterns and behaviours. Through the detailed examination of duration of sedentary periods, such as those presented in this chapter, researchers can examine whether sedentary bouts of differing duration have an effect on health risk factors.

4. 4. 4. The Identification of Sedentary Time

It is important to identify sedentary environments and determinants, which promote uninterrupted sedentary periods, as potential areas for intervention (Owen *et al.*, 2010). The methods of analysis presented in this chapter enable the examination of sedentary patterns and behaviours over the full 24 hour day, which can then be subdivided into particular periods of the day (i.e. work, school or home time). Through applying the methodologies reported here, we highlight that this adolescent female population spent significantly more time sedentary during the hour immediately post school than the hour immediately pre-school, and this sedentary time was accumulated in longer uninterrupted bouts. Researchers have subjectively identified how children and adolescent populations have become increasingly sedentary in their commute to and from school (Jago and Baranowski, 2004, Faulkner *et al.*, 2009), and have suggested that the introduction of initiatives to increase active transportation (such as walking buses) may increase physical activity and subsequently decrease time spent in sedentary behaviours (Tudor-Locke *et al.*, 2001). The findings presented here indicate that the post-school hour may be a potential target for

active transport interventions to reduce sedentary behaviours in this population. Furthermore, we have also recently highlighted the undesirable sedentary profiles of an adolescent female cohort during school hours, with the school setting appearing to promote prolonged sedentary periods. The findings have provided objectively measured sedentary data, which could be used to inform school-based sedentary interventions to decrease prolonged sedentary periods (Harrington *et al.*, 2011a). The measurement of total sedentary time or of sedentary period distribution would not reveal these specific behaviours. Collectively, these findings highlight the value of examining the duration of sedentary periods and how sedentary behaviour changes over the course of the day.

4. 4. 5. Summary

The development of standardised methodologies for examining inclinometer-based sedentary activity at a relatively early stage of the direct measurement of sedentary patterns and behaviours may encourage and enable researchers to collaborate and compare findings from different research studies. The ability of researchers to collate directly examined sedentary time and health indices may result in the identification of statistically stronger associations between risk factors and/or health outcomes and sedentary patterns and behaviours. The methodologies presented herein are an example of a protocol for measuring and analysing sedentary levels and patterns using a particular device. This article adds to the information available on the analysis of the output from the activPAL inclinometer function and provides detailed descriptions of the methodology used to examine a wide range of sedentary variables in free-living environments. The methodologies employed in this chapter are transferable within populations with which the inclinometer function of the activPAL has been validated.

4. 5. Conclusion

This chapter has provided a detailed description of methodologies used to describe and present a wide range of objectively measured sedentary patterns and behaviours using an inclinometer-based motion sensor. The techniques described and presented in this chapter

enable the detailed examination of an individual's sedentary profile across a 24 hour period, across a specific time period during the day and during non-bed hours. Furthermore, the techniques used in this chapter can be applied to all populations in which the inclinometer function of the activPAL Professional Physical Activity Monitor has been validated. The high compliance rates of successful data collection observed in this analysis (86%) would suggest that this device is an acceptable method of examining habitual physical activity and sedentary behaviour in large-scale epidemiological studies. Before large-scale studies are undertaken, it is important to discuss and develop inclinometer-based activity monitor output analysis methods, such as those described in this chapter, which will enable the comparison of sedentary variables from future population-based examinations with each other.

Chapter 5. Associations between Sedentary Time, Light Intensity Physical Activity and Body Composition in Adolescent Females.

5. 1. Introduction:

5. 1. 1. The Significance of Excess Adiposity

Excess adiposity is a physiological state that occurs through an imbalance in energy metabolism, whereby caloric energy intake is increased, energy expenditure is decreased or both occur simultaneously (Katzmarzyk *et al.*, 2003, Reilly, 2005). There is incontrovertible evidence of the associations between obesity and coronary heart disease, type 2 diabetes, hypertension, dyslipidemia, site-specific cancers and all-cause mortality in adults (Malnick and Knobler, 2006, Flegal *et al.*, 2007). Also, high levels of excess adiposity are apparent in many developed nations (Do Carmo *et al.*, 2008, Flegal *et al.*, 2010, Ng *et al.*, 2011, Dalton *et al.*, 2012). The associations between obesity and non-communicable diseases in childhood and adolescence are less well understood, as diseases such as coronary heart disease, type 2 diabetes and cancers tend not to manifest until adulthood (Hallal *et al.*, 2006, Andersen *et al.*, 2011). However, evidence suggests that excess adiposity tracks from childhood and adolescence throughout the lifespan, hence increasing the risk of onset of non-communicable diseases in adulthood (Singh *et al.*, 2008). This has enormous public health significance, as high levels of overweight and obesity have been observed in adolescent populations (Olds *et al.*, 2009, Ogden and Carroll, 2010, Stamatakis *et al.*, 2010, Janssen *et al.*, 2011), while adolescents appear to be particularly susceptible to weight gain (Kimm *et al.*, 2002, Rogol *et al.*, 2002, Kimm *et al.*, 2005).

5. 1. 2. Associations between Light Intensity Physical Activity and Adiposity

A large and consistent body of evidence has shown that higher levels of physical activity protect children and adolescents from the development of overweight and obesity (Jiménez-Pavón *et al.*, 2010), and that moderate to vigorous physical activity is an independent predictor of adiposity in children and adolescents (Strong *et al.*, 2005). To date, the majority of physical activity research has focused on intensities at the higher end of the activity intensity continuum, predominantly moderate to vigorous physical activity (Pate *et al.*, 2008). However, moderate to vigorous physical activity accounts for a very small

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amount of total daily energy expenditure in adolescence (Males: 12-15 yrs.: 45.3 ($\pm$3.4) min·d^{-1}; 16-19 yrs.: 32.7 ($\pm$2.2) min·d^{-1}; Females: 12-15 yrs.: 24.6 ($\pm$1.8) min·d^{-1}; 15-19 yrs.: 19.6 ($\pm$2.4) min·d^{-1}) (Troiano *et al.*, 2008). As a result, it is unlikely that moderate to vigorous physical activity is the dominant determinant of variability in daily energy expenditure (Levine, 2002, Donahoo *et al.*, 2004, Tremblay *et al.*, 2007). This has prompted researchers to examine the relationship between lower intensity activities and indices of health. Non-exercise activity thermogenesis (NEAT) is the energy expended throughout activities of daily living (Levine *et al.*, 2006), and includes all activities of a light intensity. It has been suggested that NEAT is the dominant determinant of variability in total daily energy expenditure, and therefore may have a greater effect on adiposity than moderate to vigorous physical activity (Levine *et al.*, 1999, Levine, 2002, Tremblay *et al.*, 2007). Objective evidence from large-scale adult populations has also identified positive association between increased levels of light intensity physical activity and 2h fasting blood glucose (Healy *et al.*, 2007). Unfortunately, limited objective light intensity physical activity data from epidemiological studies is available due to difficulties in measuring such ubiquitous activities (Shephard, 2003, Bassett Jr *et al.*, 2010).

5. 1. 3. The Sedentary Behaviour Paradigm and Adiposity

The examination of sedentary behaviour has also emerged as a relatively new area in physical activity and health-related research (Owen *et al.*, 2010, Dunstan *et al.*, 2011). Sedentary behaviours refer to waking behaviours spent in a sitting/lying position that require an energy expenditure of <1.5 metabolic equivalents (Dunstan *et al.*, 2011, Marshall and Ramirez, 2011, Tremblay *et al.*, 2012). Recent evidence suggests that sedentary behaviours have a unique negative effect on indices of health including obesity, type 2 diabetes and cardiovascular disease risk factors in adult populations (Hamilton *et al.*, 2007, Owen *et al.*, 2010, Dunstan *et al.*, 2011). Unfortunately, the effect of sedentary behaviour on indices of health in child and adolescent populations is less well understood. Mixed evidence on the effect of sedentary behaviours in childhood and adolescence has been reported. Objectively measured sedentary behaviours have been shown to have a negative effect on insulin resistance, blood pressure and cardiovascular risk in child and adolescent populations, but these studies failed to examine whether the effect was independent of

moderate to vigorous physical activity (Sardinha *et al.*, 2008, Martinez-Gomez *et al.*, 2009, Martinez-Gomez *et al.*, 2010). No associations have been identified between sedentary time and indices of health that are independent of moderate to vigorous physical activity (Mitchell *et al.*, 2009, Carson and Janssen, 2011, Martinez-Gomez *et al.*, 2011a).

5. 1. 4. The Measurement of Sedentary Time and Light Intensity Physical Activity

When examining activity variables, the use of accurate and reliable measures is critical, particularly when making associations with indices of health (Loprinzi and Cardinal, 2011, Intille *et al.*, 2012). To date, the majority of epidemiological studies have examined sedentary behaviours using surrogate measures, such as self-reported TV viewing time (Pate *et al.*, 2008). Significant limitations have been highlighted with this measure (Pate *et al.*, 2008, Bassett Jr *et al.*, 2010, Lubans *et al.*, 2011). The validity of self-reported measures of sedentary behaviour remains largely untested. Such measures are also susceptible to recall and reporting biases (Lubans *et al.*, 2011). Furthermore, surrogate measures such as TV viewing and computer use do not capture all sedentary activities, and provide no information on the sedentary patterns or the time of day that most sedentariness occurs (Bassett Jr *et al.*, 2010, Owen *et al.*, 2010). More recently, studies have employed accelerometers as a measure of sedentary behaviour (Pate *et al.*, 2008, Bassett Jr *et al.*, 2010, Marshall and Ramirez, 2011). Although the use of accelerometers as a measure of sedentary behaviour has greater reliability and validity than self-report (Owen *et al.*, 2010, Lubans *et al.*, 2011), this measure relies on the lack of ambulation to quantify sedentary levels (Ridgers *et al.*, 2012). Typically, physical activity measurement devices record accelerations, and proprietary algorithms compute arbitrary units known as counts over a specified time period or epoch (e.g. 1 minute). A predetermined sedentary threshold is then used to examine sedentary time, whereby time spent below this threshold is included as sedentary time. Consequently, some non-sedentary activities, such as standing and slow walking, can be misclassified as sedentary activities (Kozey *et al.*, 2010a). This misclassification not only results in discrepancies in the quantification of sedentary time, but also in that of light intensity physical activity, as light intensity activities are being included as sedentary activities (Hart *et al.*, 2011). As a result, the use of inclinometer-based activity monitors,

which directly examine the inclination/posture of the body, has been recommended when examining the relationships between specific features of sedentary time (Bassett Jr *et al.*, 2010).

The purpose of this chapter is to examine the associations between low intensity activity variables, such as sedentary time and light intensity physical activity, and body composition in a cohort of adolescent females using an inclinometer-based activity monitor. Any relationships between directly measured sedentary time, standing time, light intensity physical activity, prolonged sedentary periods, and moderate to vigorous physical activity will be explored.

5. 2. Methods:

The aim of this cross-sectional analysis was to examine free-living physical activity and sedentary behaviours, also known as lifestyle physical activities, using an inclinometer-based activity monitor and to compare these findings with measures of adiposity in a population of adolescent females. The sample used in the present analysis was pooled from three studies undertaken in the University of Limerick. Data was collected from 7 urban and 6 rural high schools between 2009 and 2011. Specifically, data from study 1 was collected as part of a cross-sectional analysis of lifestyle physical activities (n=87), data from study 2 was collected as baseline data from a school-based physical activity intervention programme (n=128) and data from study 3 was collected from another cross-sectional analysis of lifestyle physical activities (n=76). The recruitment strategy for study 1 and study 2 have previously been described (Harrington *et al.*, 2011a), while recruitment for study 3 will be described in detail in Chapter 6. Full ethical approval for each study was provided by the institutional research ethics committee.

A total of 291 students were approached to participate in the three different studies. From the three studies, 222 students provided written informed participant and parental consent and participated in the full test days. Due to incomplete information from the inclinometer-based activity monitor (explained in Section 5. 2. 3), 27 sets of data were excluded from this analysis. This resulted in a total of 195 sets of data included in this analysis.

5. 2. 1. Activity Measurement:

The inclinometer-based activity monitor employed in this research was the activPAL™ Professional Physical Activity Monitor (PAL Technologies Ltd., Glasgow, UK). A detailed description of the activPAL and the wear protocol employed in this research has been provided in Section 2. 10 and Section 4. 2. 1.

5. 2. 2. Measurement Protocol:

Participants were brought to the school gymnasium, where anthropometric measures were obtained from each participant. Participants wore light clothing (vest top and tracksuit pants) and removed their shoes and socks before height and weight was measured. Height was measured to the nearest 0.25 cm using a portable wall stadiometer (Seca model 214, Seca Ltd., Birmingham, UK). Body weight was measured to the nearest 0.01 Kg using a portable electronic scale (Seca model 77, Seca Ltd., Birmingham, UK). Body Mass Index (BMI) was calculated by Weight/Height^2. All BMI scores were also converted to BMI percentiles based on their age and sex in accordance with CDC recommendations (Kuczmarski *et al.*, 2002). Once height and weight had been measured, participants were asked to stand in the anatomical position. Skin-fold measurements were then obtained from 4 sites according to the skinfold protocol of the International Society for the Advancement of Kinanthropometry (ISAK) (Marfell-Jones *et al.*, 2006). The 4 sites selected for measurements were the biceps, triceps, subscapular and iliac crest. First, body landmarks were identified and marked using an extensible metric tape and a hypo-allergic pen. Skin-fold thickness was measured to the nearest 0.25cm using a Harpenden skinfold calliper (Cranlea & Co, Birmingham, UK). Each skinfold measure was taken 3 times (but not consecutively) on the right side of the body, and the median value of the three measures was used (Marfell-Jones *et al.*, 2006). The four skinfold measures were then summed.

Participants were then provided with their activPAL activity monitors, and were given a full demonstration of how the activPAL was to be attached, when the device was to be worn and what to do if the device was misplaced. For the purpose of this study, participants were instructed to wear the device on their right thigh only, to ensure uniformity across all data

collection. After 7 days, the main investigator returned to participating schools, and the activPAL activity monitors were collected. The activity information was downloaded to the main investigator's PC using the activPAL interface program, and data files were exported to a Microsoft Excel file format (Microsoft Corporation, Microsoft Excel 2010, One Microsoft Way, Redmond, WA, USA) for further analysis.

5. 2. 3. Data Processing:

Although the optimal wear duration for activity monitors in free living environments remains contentious (Heil *et al.*, 2012), the current and widely used best practise for activity monitoring of free-living physical activity suggests that a minimum of 4 valid days of activity recording (including one weekend day) are obtained from each participant (Trost *et al.*, 2005). It has been recommended that a wear time of 10 hours is necessary for a day to be considered valid when using accelerometer-based devices (Masse *et al.*, 2005). The optimal wear time for the activPAL activity monitor has not yet been identified. For the purpose of this analysis, a valid day was classified as a measured day with ≤ 4 hours non-wear time during waking hours.

5. 2. 3. 1. Identification of Waking Hours:

Daily non-wear time was examined from the produced Excel output files using the following procedures. First, daily waking hours were examined for each participant. The examination of waking hours has been previously described (Section 4. 2. 2). Briefly, the first change in inclination from sitting/lying to standing after 7 am was identified as a participants "rise time". The last change in inclination from standing to sitting/lying which was followed by a prolonged sedentary period (> 2 hours in duration) after 11 pm was identified as "bed time". The time between "rise time" and "bed time" was identified as waking hours. The identified waking hours were then examined for non-wear time.

5. 2. 3. 2. Identification of Non-Wear Time:

A non-wear period was defined as a period with ≥ 60 minutes of consecutive zero activity counts from the Excel output file. This method for identifying periods of non-wear time is consistent with free-living data reduction methodologies (Matthews *et al.*, 2008, Rowlands *et al.*, 2008, Healy *et al.*, 2011b). The non-wear periods for each day were summed, and all measurement days with greater than 4 hours of non-wear time during waking hours were removed from the analysis. Weekly activity information for each participant was then examined. If a participant did not provide 4 valid days of activity recording which included at least 1 weekend day, they were removed from all further analysis. For all remaining participant information, the daily non-wear time was summed, and the 24 hour measured day was adjusted (24 hours – non-wear time).

5. 2. 4. Activity Variables:

The output files provided 1) the time of each epoch, 2) the number of steps taken during each epoch, 3) the number of seconds per epoch spent sitting/lying, the number of seconds per epoch spent standing and the number or seconds per epoch spent stepping and 4) the accrued accelerometer counts per epoch. As highlighted in Section 4. 2. 4, to examine daily activity patterns, a 24 hour measurement period had to be defined. For this analysis, the 24 hour measurement period was defined from 7 am - 7 am of the following day.

The output files were examined to produce daily activity variables which include sedentary time, standing time, light intensity physical activity excluding standing time, light intensity physical activity with standing time included, moderate to vigorous physical activity and prolonged sedentary periods. Sedentary time and standing time was calculated by summing the total number of seconds spent in sitting/lying and standing postures over the 24 hour measurement period. For moderate to vigorous physical activity, a threshold of 2997 counts·15 sec^{-1} was used to estimate metabolic equivalents for each 15 second period (Section 3. 3. 5). Moderate to vigorous physical activity was defined as ≥ 3 metabolic equivalents. This threshold was developed using mixed model regression based on data from a sample of 15-18 year old females. If an epoch with activity counts greater than 2997

counts·15 sec^{-1} was observed, this was identified as time spent in moderate to vigorous physical activity. The amount of time spent in moderate to vigorous physical activity was then summed over the 24 hour measurement period. Light intensity physical activity excluding standing time (excl. standing) was then calculated as; light intensity physical activity = [24 hours – (sedentary time + standing time + moderate to vigorous physical activity)]. Light intensity physical activity including standing time (incl. standing) was calculated by summing both standing time and light intensity physical activity variables.

The Excel output file was then examined using a MATLAB® computer program to identify sedentary bout durations. This program examined each sedentary epoch throughout the measured day. Prolonged sedentary periods were defined as sedentary periods lasting longer than 30 minutes in duration (Carson and Janssen, 2011, Mitchell *et al.*, 2012). The methodological procedures for this program are described in detail in Section 4. 2. 3. Briefly, the start of a sedentary period was identified as an epoch that had a full 15 seconds spent in a sitting/lying position. The end of a sedentary period was identified as the next sedentary epoch that did not have a full 15 seconds spent in a sitting/lying position. The duration between the start and end of the sedentary period was then calculated. The time spent in prolonged sedentary periods was then summed for each measured day.

As the identified non-wear time was categorised as sedentary time in this analysis, sedentary time was adjusted by subtracting the non-wear values from the sedentary time value. Finally, total daily wear time was calculated by subtracted non-wear time from the total measurement period (24 hours), and each variable was then divided by the total daily wear time to derive the percentage of time spent in each activity variable.

5. 2. 5. Statistical Analysis:

Descriptive statistics were calculated, and are presented as mean (±SD), frequencies or percentages where appropriate. All variables were examined for normality using skewness and kurtosis statistics (Kolmogorov-Smirnov test) and through visual inspection of histograms before additional statistical analysis were undertaken. The natural logarithm was applied to BMI, sum of skinfolds, standing time, light intensity physical activity, moderate

to vigorous physical activity and prolonged sedentary periods to account for skewness. The level at which the threshold for p was set was $p < 0.05$ throughout this chapter.

Partial correlations, controlling for age, were used to examine the relationships between sedentary time, standing time, light intensity physical activity (both including and excluding standing time), moderate to vigorous physical activity and prolonged sedentary periods and each of the measures of adiposity (BMI, Σ Skinfolds). Partial correlations, controlling for age and body composition (sum of skinfolds), were also used to examine the relationships between sedentary time, standing time, light intensity physical activity (incl. and excl. standing), moderate to vigorous physical activity and prolonged sedentary periods.

Multiple linear regression models were used to examine the relationships between sedentary time, standing time, light intensity physical activity (excl. standing), light intensity physical activity (incl. standing) and prolonged sedentary periods and body composition measures controlling for age. The two models assessed:

1. Whether activity variables were associated with BMI and Σ Skinfolds after correcting for age only.
2. Whether activity variables were associated with BMI and Σ Skinfolds after correcting for both age and moderate to vigorous physical activity.

Retrospective power estimation calculations were completed on all statistically significant correlations from the multiple linear regression models. This was completed to examine the probability of committing a type 2 statistical error, or not rejecting the null hypothesis when the null hypothesis is false.

Binary logistic regression models were then employed to predict the highest quartile of BMI and the highest quartile of Σ Skinfolds using quartile groups of the activity variables; sedentary time, standing time, light intensity physical activity (incl. and excl. standing time) and prolonged sedentary periods. The first model corrected for age only, while the second model corrected for both age and moderate to vigorous physical activity. Odds ratios with associated 95% confidence intervals are produced by the models. All analyses were undertaken using IBM SPSS Statistics v. 20 (Armonk, New York, USA).

5. 3. Results:

The descriptive characteristics of this sample are presented in Table 5.1.

Table 5.1 Descriptive characteristics of the population. Values presented as Mean (±SD) and Range.

	Mean (±SD)	Range
Age (yrs.)	15.7 (0.9)	13.1 – 18.7
Height (m)	1.64 (0.06)	1.46 – 1.82
Weight (kg)	60.8 (12.0)	40.7 – 115.1
BMI (kg/m^2)	22.7 (4.2)	15.4 – 41.3
Sum of Skinfolds (mm)	68.6 (30.11)	26.0 – 207.1
Sedentary Time (%)	78.8 (4.4)	67.1 – 89.1
Standing Time (%)	14.0 (3.3)	6.8 – 26.0
Light Intensity Physical Activity incl. Stand (%)	17.5 (3.8)	8.8 – 30.1
Light Intensity Physical Activity excl. Stand (%)	3.4 (0.9)	1.4 – 7.3
Moderate to Vigorous Physical Activity (%)	3.7 (1.4)	1.1 – 8.6
Prolonged Sedentary Periods (%)	22.9 (6.2)	5.2 – 45.6

N = 195: All physical activity variables are presented as a percentage of total waking hours.

When the number of valid days of accelerometer data was examined, 14.4 % of the sample provided 4 valid days, 71.8 % provided 5 valid days, while 13.8 % of participants provided 6 full days of accelerometry data Table 5.2.

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Table 5.2 The distribution of the number of valid days of accelerometry data (No. of participants and percentage of participants).

No. of Valid Days	No. of Participants (N = 195)	Percentage (%)
4 days	28	14.4
5 days	140	71.8
6 days	27	13.8

5. 3. 1. Partial Correlations between Activity Variables and Measures of Body Composition and between Activity Variables and Themselves

Partial correlations were also used to initially examine the relationships between activity variables and adiposity measures after correcting for age. A weak but significant negative relationship was observed between light intensity physical activity and BMI and light intensity physical activity and Σ Skinfolds. These correlations are presented in Table 5.3 Table 5.3.

Table 5.3 Partial correlations between physical activity and sedentary variables, body mass index and sum of skinfolds, controlled for age.

	BMI Percentiles	Σ Skinfolds[+]
Sedentary Time	.16 (.03)[*]	.14 (.049)[*]
Standing Time[+]	-.10 (.15)	-.10 (.18)
Light Intensity Physical Activity incl. Standing[+]	-.15 (.04)[*]	-.14 (.06)
Light Intensity Physical Activity excl. Standing[+]	-.25 (.0003)[**]	-.23 (.001)[**]
Moderate to Vigorous Physical Activity[+]	-.09 (.20)	-.12 (.10)
Prolonged Sedentary Periods[+]	.06 (.42)	-.01 (.94)

[+]Values were log transformed before analysis.
BMI = Body Mass Index; Σ Skinfolds = Sum of Skinfolds.
Data are presented as r (p value). [*]$p \leq 0.05$; [**]$p \leq 0.01$; N = 194.

5. 3. 2. Partial Correlations between Activity Variables and Themselves

Partial correlations which controlled for age and body composition were used to examine the relationships between different activity patterns and behaviours. All correlations, except for the correlation between light intensity physical activity (excl. standing) and moderate to vigorous intensity physical activity, were significant at a $p < 0.001$ level. The results of these correlations are presented in Table 5.4.

Table 5.4 Partial correlations between physical activity and sedentary variables, controlled for both age and body composition (Σ Skinfolds).

	SedT	StT	LIPA incl. StT	LIPA excl. StT	MVPA	PSP
SedT	-	-.92**	-.94**	-.68**	-.55**	.47**
StT		-	.98**	.56**	.26**	-.42**
LIPA incl. StT			-	.71**	.27**	-.44**
LIPA excl. StT				-	.22*	-.37**
MVPA					-	-.24**
PSP						-

SedT = Sedentary Time; StT = Standing Time; LIPA incl. StT = Light Intensity Physical Activity including Standing Time; LIPA excl. StT = Light Intensity Physical Activity excluding Standing Time; MVPA = Moderate to Vigorous Physical Activity; PSP = Prolonged Sedentary Periods.
*$p < 0.01$ level; **$p < 0.001$; N = 195.

5. 3. 3. Linear Regression Analysis

Linear regression models were employed to examine the association between activity variables and body composition measures. Model 1 was corrected for age, while model 2 was corrected for age and moderate to vigorous physical activity. Retrospective power (1-β) calculations were also completed on all significant associations. No significant relationships were observed between sedentary time, standing time, light intensity physical activity (incl. standing) or prolonged sedentary periods and body composition. Light intensity physical activity (excl. standing) was significantly associated with BMI in model 1 (β = - 0.231; p =

.003) and in model 2 (β = - 0.222; p = .007). Acceptable statistical power was observed for the associations between BMI and light intensity physical activity (N = 194, r = -0.25, α = 0.01, 1 – β = 0.86). Furthermore, light intensity physical activity (excl. standing) was significantly associated with Σ Skinfold measures in both model 1 (β = - 0.236; p = .005) and model 2 (β = - 0.219; p = .009). Acceptable power was also observed for the associations observed between Σ Skinfold and light intensity physical activity in model 2 (N = 194, r = -0.23, α = 0.01, 1 – β = 0.79). All linear regression results are presented in Table 5.5.

5. 3. 4. Binary Logistic Regression Results

Binary logistic regression models were employed to predict the highest quartile of BMI using quartile groups of the activity variables. The first model corrected for age while the second model corrected for both age and moderate to vigorous physical activity. The results of this analysis identified that the amount of sedentary time, standing time, light intensity physical activity (incl. standing) and prolonged sedentary periods did not predict high BMI after correcting for the selected covariates. However, this analysis did identify that low levels of light intensity physical activity (excl. standing) were a significant predictor of high BMI after correcting for age and moderate to vigorous physical activity. Participants that accumulated the lowest levels of light intensity physical activity (excl. standing) (Quartile 1) were 3.81 (95% CI: 1.31 – 11.11) times more likely to have higher BMI than those who accumulated the highest levels of light intensity physical activity (excl. standing) (Quartile 4). For illustrative purposes, the estimated marginal means for BMI percentiles are presented for each of the quartiles in Figure 5.1, controlling for age and moderate to vigorous physical activity. All data from the binary logistic regression models between all activity variables and BMI are included in Table 5.6. A scatterplot presents the relationship between light intensity physical activity and body mass index in Figure 5.2

Binary logistic regression models were also used to determine whether the different activity variables predicted the highest quartile of skinfold thickness independent of age and moderate to vigorous physical activity. The amount of sedentary time predicted the highest Σ Skinfolds after correction for age and moderate to vigorous physical activity. This data suggests that the highest quartile of sedentary participants were 3.95 (1.25 – 12.47) more

likely to have high Σ Skinfolds than their least sedentary counterparts. The amount of standing time, light intensity physical activity (incl. standing) and prolonged sedentary periods did not predict high Σ Skinfolds after correcting for age and moderate to vigorous physical activity. Low levels of light intensity physical activity (excl. standing) were a significant predictor of high Σ Skinfolds after correcting for age and moderate to vigorous physical activity. Participants that accumulated the lowest levels of this type of light intensity physical activity (Quartile 4) were 2.88 (1.04 – 7.92) times more likely to have high Σ Skinfolds than those who accumulated the highest levels (Quartile 1). All data from the binary logistic regression models between activity variables and Σ Skinfolds are included in Table 5.7. The estimated marginal means for log-transformed sum of skinfold thickness are presented for each of the quartiles of sedentary time and light intensity physical activity in Figure 5.3 and Figure 5.5 respectively. Scatterplots are also provided to identify the relationships between sedentary time, light intensity physical activity and sum of skinfold thickness in Figure 5.4 and Figure 5.6.

Table 5.5 Relationship between sedentary time, standing time, light intensity physical activity (both including and excluding standing time) and prolonged sedentary periods and body composition measures in adolescent females.

	Model 1			Model 2		
Sedentary Time	**β**	**p**	**Adj. R²**	**β**	**p**	**Adj. R²**
BMI	.16	.048*	.02	.15	.11	.01
Σ Skinfold	.14	.14	.01	.11	.22	.01
Standing Time						
BMI	-.10	.19	.01	-.08	.24	.01
Σ Skinfold	-.10	.39	.00	-.07	.29	.00
Light Intensity Physical Activity incl. Standing						
BMI	-.15	.06	.02	-.13	.11	.02
Σ Skinfold	-.12	.23	.01	-.10	.22	.01
Light Intensity Physical Activity excl. Standing						
BMI	**-.25**	**.001**	**.06**	**-.24**	**.003**	**.05**
Σ Skinfold	**-.23**	**.005**	**.05**	**-.22**	**.009**	**.04**
Prolonged Sedentary Periods						
BMI	.06	.36	-.00	.04	.35	.00
Σ Skinfold	.01	.92	-.01	-.02	.40	.00

N = 194; Multiple Linear Regression; *p < 0.05; **p < 0.01;
BMI = Body Mass Index; Σ Skinfold = Sum of four skinfolds;
Model 1 corrected for age; Model 2 corrected for age, and objectively measured MVPA.

Table 5.6 Odds ratios for high body mass index across quartiles of sedentary time, standing time, light intensity physical activity and prolonged sedentary periods.

	Model 1 (95% CI)	Model 2 (95% CI)
Sedentary Time		
Quartile 1	1	1
Quartile 2	1.39 (0.52 – 3.73)	1.49 (0.55 – 4.07)
Quartile 3	1.24 (0.46 – 3.37)	1.53 (0.52 – 4.46)
Quartile 4	2.14 (0.83 – 5.56)	2.85 (0.94 – 8.66)
Standing Time		
Quartile 1	1	1
Quartile 2	1.50 (0.60 – 3.72)	1.49 (0.60 – 3.71)
Quartile 3	0.86 (0.32 – 2.29)	0.87 (0.32 – 2.36)
Quartile 4	1.16 (0.45 – 2.98)	1.15 (0.43 – 3.03)
Light Intensity Physical Activity incl. Standing Time		
Quartile 1	1	1
Quartile 2	0.80 (0.28 – 2.24)	0.77 (0.27 – 2.18)
Quartile 3	2.30 (0.93 – 5.72)	2.51 (0.98 – 6.42)
Quartile 4	1.19 (0.45 – 3.14)	1.22 (0.45 – 3.34)
Light Intensity Physical Activity excl. Standing Time		
Quartile 1	1	1
Quartile 2	2.61 (0.90 – 7.58)	2.85 (0.95 – 8.57)
Quartile 3	2.77 (0.95 – 8.07)	2.91 (0.99 – 8.56)
Quartile 4	**3.52 (1.24 – 10.01)[*]**	**3.81 (1.31 – 11.11)[*]**
Prolonged Sedentary Periods		
Quartile 1	1	1
Quartile 2	0.52 (0.20 – 1.38)	0.53 (0.20 – 1.41)
Quartile 3	0.78 (0.32 – 1.92)	0.81 (0.32 – 2.04)
Quartile 4	0.94 (0.38 – 2.29)	0.96 (0.39 – 2.41)

Model 1 corrected for age;
Model 2 corrected for both age, and objectively measured MVPA;
N = 194; Binary Logistic Regression; [*]$p < 0.05$.
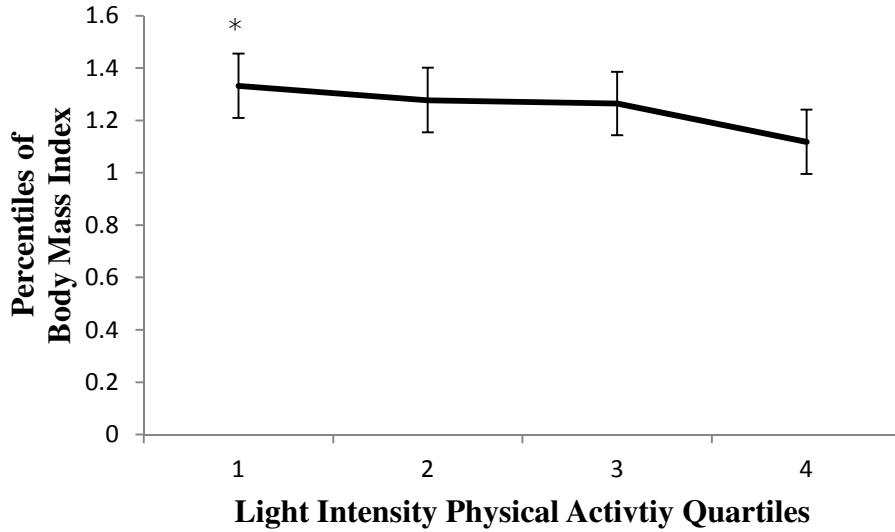
n = 195; Univariate Analysis of Variance; Mean ± 95% CI; *p ≤ 0.01;
Significant differences observed between Quartile 1 and Quartile 4;
Quartile 1 = Lowest levels of light intensity physical activity,
Quartile 4 = Highest levels of light intensity physical activity;

Figure 5.1 Estimated marginal means of high body mass index percentiles stratified by quartiles of light intensity physical activity.
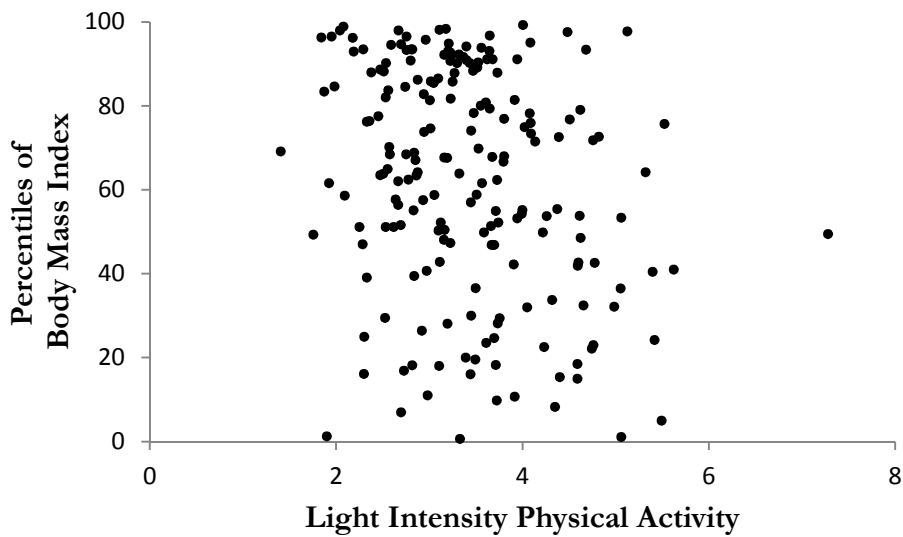
N = 195

Figure 5.2 Scatterplot of the percentage time spent in light intensity physical activity and body mass index percentiles.

Table 5.7 Odds ratios for high sum of skinfold thickness across quartiles of sedentary time, standing time, light intensity physical activity and prolonged sedentary periods.

	Model 1 (95% CI)	Model 2 (95% CI)
Sedentary Time		
Quartile 1	1	1
Quartile 2	1.81 (0.63 – 5.21)	1.78 (0.61 – 5.20)
Quartile 3	2.02 (0.71 – 5.72)	2.00 (0.66 – 6.08)
Quartile 4	**3.79 (1.38 – 10.38)***	**3.95 (1.25 – 12.47)***
Standing Time		
Quartile 1	1	1
Quartile 2	1.66 (0.63 – 4.36)	1.68 (0.63 – 4.45)
Quartile 3	1.35 (0.50 – 3.67)	1.22 (0.44 – 3.38)
Quartile 4	2.16 (0.83 – 5.61)	1.97 (0.73 – 5.27)
Light Intensity Physical Activity + Standing Time		
Quartile 1	1	1
Quartile 2	1.26 (0.44 – 3.62)	1.26 (0.44 – 3.63)
Quartile 3	2.51 (0.94 – 6.65)	2.40 (0.89 – 6.47)
Quartile 4	2.51 (0.94 – 6.71)	2.36 (0.86 – 6.48)
Light Intensity Physical Activity		
Quartile 1	1	1
Quartile 2	1.34 (0.46 – 3.95)	1.23 (0.40 – 3.71)
Quartile 3	**2.79 (1.02 – 7.66)***	2.63 (0.95 – 7.29)
Quartile 4	**3.16 (1.17 – 8.54)***	**2.88 (1.04 – 7.92)***
Prolonged Sedentary Periods		
Quartile 1	1	1
Quartile 2	**0.36 (0.14 – 0.96)***	**0.34 (0.13 – 0.93)***
Quartile 3	**0.34 (0.13 – 0.90)***	**0.29 (0.11 – 0.79)***
Quartile 4	0.85 (0.36 – 1.99)	0.72 (0.30 – 1.75)

Model 1 corrected for age;
Model 2 corrected for both age, and objectively measured MVPA;
N = 194; Binary Logistic Regression; *$p < 0.05$.
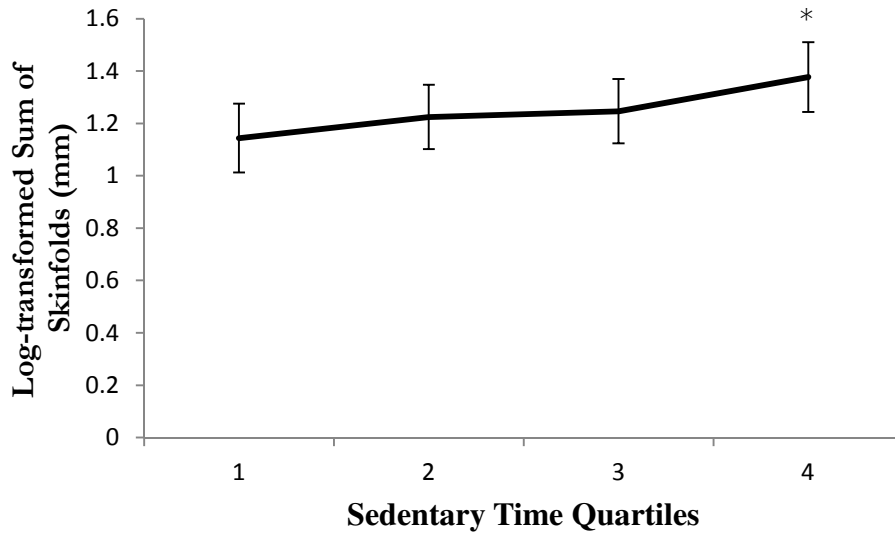
N = 194; Univariate Analysis of Variance; Mean ± 95% CI; *p ≤ 0.01;
Significant difference observed between Quartile 1 and Quartile 4;
Quartile 1 = Lowest levels of sedentary time;
Quartile 4 = highest levels of sedentary time.

Figure 5.3 Estimated marginal means of sum of skinfolds stratified by quartiles of sedentary time.
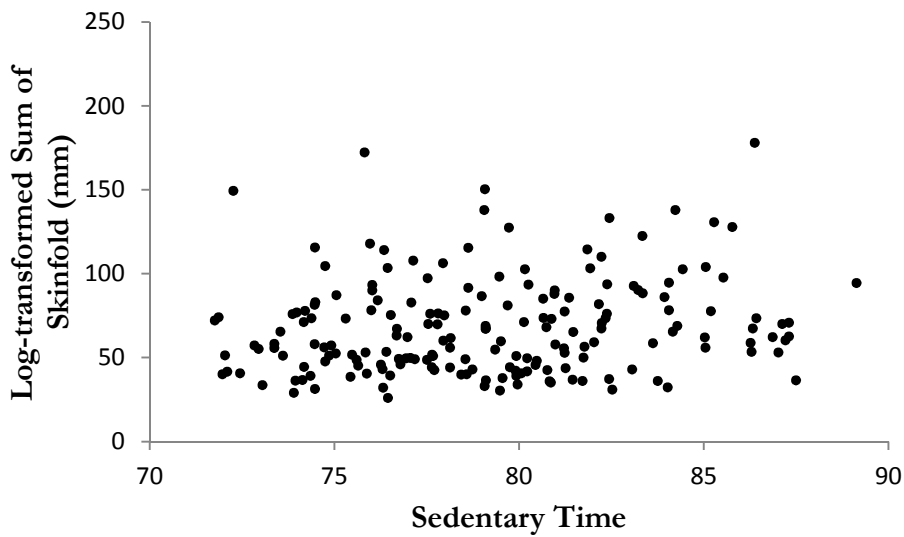
N = 194

Figure 5.4 Scatterplot of the percentage time spent sedentary and the sum of skinfold thickness.
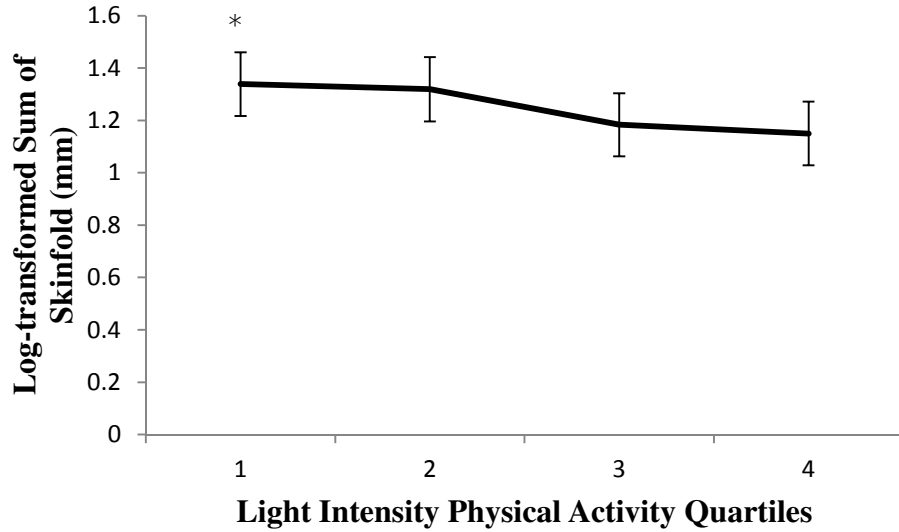
N = 194; Univariate Analysis of Variance; Mean 95% CI; *p ≤ 0.01;
Significant difference observed between Quartile 1 and Quartile 4;
Quartile 1 = Lowest levels of light intensity physical activity;
Quartile 4 = Highest levels of light intensity physical activity.

Figure 5.5 Estimated marginal means of sum of skinfolds stratified by quartiles of light intensity physical activity (excl. standing).
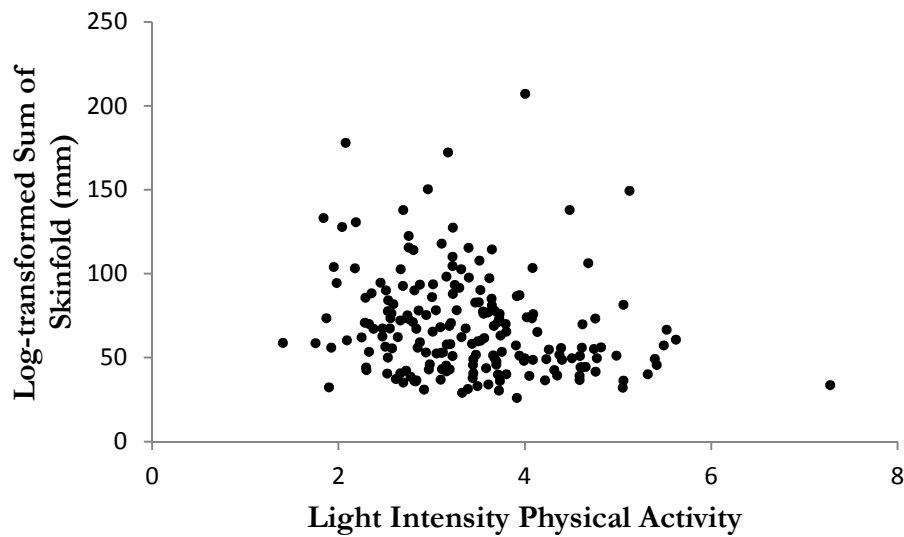
N = 194

Figure 5.6 Scatterplot of the percentage time spent in light intensity physical activity (excl. standing) and the sum of skinfold thickness.

Significant findings were also observed when binary logistic regression was used to examine prolonged sedentary periods. These results unexpectedly suggest that those who spend the lowest amount of time in prolonged sedentary periods have a similar risk for high Σ Skinfolds as those with the highest amount of time in prolonged sedentary periods, while the middle two quartiles have the lowest potential risk for high Σ Skinfolds. A scatterplot was constructed and cross tabulation analysis performed to determine the relationship and explain the unexpected findings. As Figure 5.7 demonstrates, there appears to be no association between the two variables. A large number of participants that have moderate levels of prolonged sedentary periods have relatively low Σ Skinfold values. This causes the quartiles to have conflicting values (Table 5.8). Consequently, the data appears to have spuriously created odds ratios that appear significant.
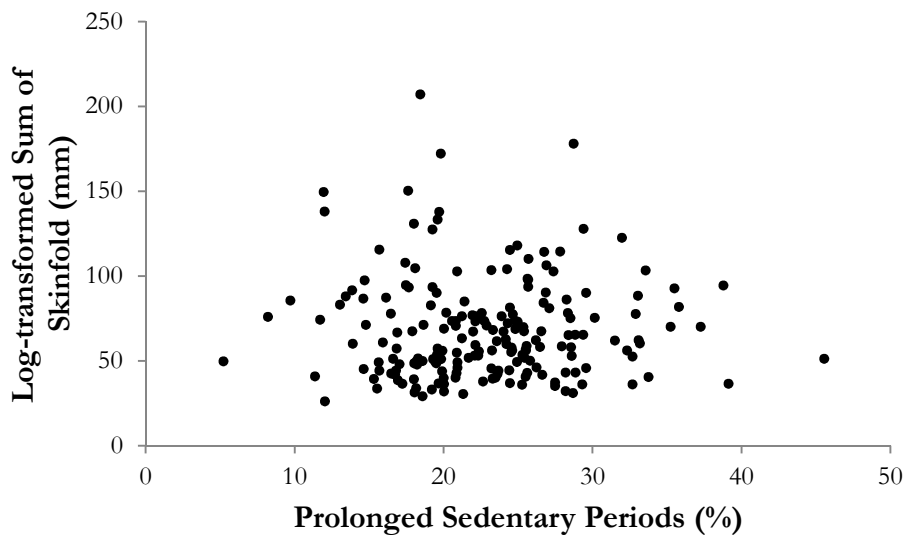
N = 194

Figure 5.7 Scatterplot of the percentage of time spent in prolonged sedentary periods and the sum of four skinfold.

Table 5.8 Cross tabulation table comparing Prolonged Sedentary Periods by quartile with low and high risk sum of skinfold values.

n = 194		Prolonged Sedentary Periods			
		Quartile 1	Quartile 2	Quartile 3	Quartile 4
Sum of	Low Risk (%)	64.6	83.7	84	68.1
Skinfold	High Risk (%)	35.4	16.3	16	31.9

5. 4. Discussion:

This analysis aimed to examine the associations between sedentary time, standing time, light intensity physical activity (incl. standing), light intensity physical activity (excl. standing) and prolonged sedentary periods and body composition measures in a cohort of adolescent females using an inclinometer-based activity monitor. The majority of activity variables were highly or very highly associated with each other. However, weak associations were found between moderate to vigorous physical activity and sedentary variables. The findings of this study indicate that light intensity physical activity (excl. standing) is negatively associated with both BMI and sum of skinfold thickness, independent of age and moderate to vigorous physical activity, while no associations were evident between sedentary time, standing time, light intensity physical activity (incl. standing) or prolonged sedentary periods and body composition measures. Finally, only light intensity physical activity (excl. standing) was identified as a significant predictor of the highest levels of BMI, while sedentary time and light intensity physical activity (excl. standing) were both significant predictors of the highest levels of sum of skinfold thickness, independent of age and moderate to vigorous physical activity.

5. 4. 1. Association between Sedentary Time and Sum of Skinfold Thickness

A novel finding of this study was that female adolescents with the highest objectively measured sedentary time were substantially more likely to have high sum of skinfold thickness compared to their least sedentary counterparts (Figure 5.3). These findings are in contrast with existing objective examinations of sedentary time, which have identified that these associations did not exist or disappeared after correction for moderate to vigorous physical activity (Purslow *et al.*, 2008, Carson and Janssen, 2011). The observed differences between the present findings and the previously published literature may be due to the different methods of quantifying sedentary time. Previous objective examinations have employed accelerometer-based activity monitors, such as the ActiGraph (ActiGraph LCC, Pensacola, FL) as measures of physical activity, and have estimated sedentary time using an activity count threshold (e.g. < 100 counts·min^{-1}). This method estimates sedentary time based on the lack of ambulation (Ridgers *et al.*, 2012). In contrast, the present study has employed the activPAL activity monitor, which directly measures sedentary time using an inbuilt inclinometer. Significant differences have been observed between ActiGraph determined sedentary time and activPAL determined sedentary time, with the activPAL demonstrating increased accuracy at measuring sedentariness (Hart *et al.*, 2011, Kozey-Keadle *et al.*, 2011). Furthermore, the use of the activPAL has been encouraged in studies that aim to examine specific sedentary patterns and behaviours (Bassett Jr *et al.*, 2010), while it has been employed as the reference measure for objective sedentary behaviour when validating accelerometer-based activity monitors (Ridgers *et al.*, 2012).

Our findings are consistent with proposed physiological mechanisms which suggest that the absence or lack of large skeletal muscle contractions may play an important role in the development of obesity, cardiovascular disease and site-specific cancers (Hamilton *et al.*, 2007). These observations have public health significance. It is now widely accepted that sitting/lying is a distinct behaviour to standing with its own set of unique physiologic mechanisms (Hamilton *et al.*, 1998, Bey *et al.*, 2001, Zderic and Hamilton, 2006), while sitting/lying accounts for the majority of an individual's daily activities (Owen *et al.*, 2010). Furthermore, it has been proposed that even though modern humans currently accumulate more sedentary time than at any other period in our history, sedentary levels will continue to increase over the coming years due to further developments in technology (Hamilton *et*

al., 2008, Owen *et al.*, 2010). Collectively, this information should encourage the introduction of sedentary behaviour guidelines in physical activity recommendations, similar to those presented in the Canadian Sedentary Guidelines, which encourage individuals to limit the amount of time spent indoors, in screen-based activities, in prolonged sedentary periods and in sedentary transport (Tremblay *et al.*, 2011). Additionally, the examination of a sedentary time threshold that provides clear and distinct guidelines on the maximum recommended amount of daily sedentary time, as is the case for moderate to vigorous physical activity, should also be investigated. Such guidelines may be clearer, easier to follow and consequently more appropriate as a recommendation for the general population.

5. 4. 2. Association between Light Intensity Physical Activity, Body Mass Index and Sum of Skinfold Thickness.

The predominant reason for the lack of information on the associations between light intensity physical activity and body composition variables is due to difficulties in detecting and assessing this specific activity behaviour (Shephard, 2003). The evidence available on the associations between light intensity physical activity and adiposity in adolescent populations is limited and contrasting in nature. Findings from the European Youth Heart Study have identified no associations between objectively assessed light intensity physical activity (light physical activity defined as 500-1999 counts per minute) and body fatness (BMI and sum of 5 skinfold measures) after correction for sex, maturity and a range of activity variables including moderate to vigorous physical activity (Ekelund *et al.*, 2004). More recently, significant associations have been observed between objectively measured light intensity physical activity (light physical activity defined as 101-1999 counts per minute) and BMI in adolescent females, independent of moderate to vigorous physical activity (Steele *et al.*, 2009). Similar to the contrasting associations identified between sedentary time and adiposity in childhood and adolescence, inconsistencies observed across these studies is likely due to the method that was used to examine sedentariness. Both studies employed accelerometer-based activity monitors, while a broad range of activity thresholds were employed across these two studies (< 100 counts·min^{-1} (Steele *et al.*, 2009) Vs. < 500 counts·min^{-1} (Ekelund *et al.*, 2004)). As identified by Ridgers and colleagues,

significant differences in estimated sedentary time can be observed using sedentary thresholds which differ greatly (Ridgers *et al.*, 2012). Additionally, the accelerometer-based activity monitors (such as the ActiGraph) have been shown to consistently and significantly overestimate sitting and walking activities, primarily due to its inability to examine standing time (Hart *et al.*, 2011). Standing time makes up a large percentage of individuals daily activity, and by definition should be categorised as light intensity physical activity (Owen *et al.*, 2010). Previous publications that have employed non-inclinometer-based accelerometers may have significantly under or overestimated light intensity physical activity through misclassifying standing time as sedentary time or light intensity physical activity (Hart *et al.*, 2011). Through the use of an inclinometer-based activity monitor which accurately and reliably distinguishes between sitting and standing, this study has provided more valid and reliable estimates of sedentary time, standing time and light intensity physical activity compared to previously published literature.

Displacement theory suggests that sedentary time replaces time spent in physical activity (Steele *et al.*, 2009). According to recent objective longitudinal findings, sedentary time increases throughout adolescence at the expense of light intensity physical activity (Mitchell *et al.*, 2012). Findings from this study would appear to agree with these observations, whereby light intensity physical activity (incl. standing) and light intensity physical activity (excl. standing) appears to protect against sedentary time to a greater extent than moderate to vigorous physical activity (Table 5.4). Furthermore, the findings of the current study suggest that light intensity physical activity (excl. standing) is significantly associated with both BMI and sum of skinfold thickness in adolescent females. Lower levels of light intensity physical activity (excl. standing) are a significant predictor of increased adiposity in this population, with those in the lowest quartile of light intensity physical activity (Quartile 1) 2.869 times more likely to have elevated sum of skinfolds than those in the highest light intensity physical activity quartile (Quartile 4). Observations in adult populations have also identified positive associations between participation in light intensity physical activity during breaks in sedentary time and both BMI and waist circumference (Healy *et al.*, 2008a). Collectively, this information would suggest that increasing light intensity physical activity at the expense of sedentary time may be of great benefit in the maintenance of a healthy weight profile. To date, physical activity recommendations have focused on increasing participation in moderate to vigorous physical activity (Physical Activity Guidelines Advisory Committee, 2008). These findings suggest that activity intensities across the

continuum have an influence on health outcomes in both adolescence and adulthood, and that additional recommendations for sedentary time and light intensity physical activity are required. Future physical activity recommendations should encourage the replacement of sedentary time with ambulatory light intensity physical activity alongside existing moderate to vigorous physical activity recommendations.

5. 4. 3. Strengths and Limitations:

There are limitations to this study. This study only focused on adolescent females. These findings are not generalisable to male adolescents, and further research is required to examine the associations between directly measured sedentary behaviours, light intensity physical activity and adiposity in adolescent males. Additionally, our cross sectional design represents a group of adolescent females in one geographical area over a two year period, and may not be representative for all populations. The majority of research studies have included additional covariates, such as stage of pubertal development, nutritional information and parental health status. The use of additional covariates would add more strength to our findings. Significant strengths of this study should also be noted. This is the first study to examine the associations between lifestyle physical activities and adiposity using an inclinometer-based activity monitor in any population. Furthermore, we examined the associations between each activity variables and adiposity independently of time spent in moderate to vigorous physical activity.

5. 5. Conclusions:

In summary, these population-based observations have identified important associations between physical activities at the low end of the activity intensity continuum and body composition measures in an adolescent female population. Firstly, evidence of the positive associations between total sedentary time and adiposity in adolescent females, independent of moderate to vigorous physical activity, has been presented. Secondly, negative associations between light intensity physical activity (excluding standing time) and adiposity, independent of moderate to vigorous physical activity, have been observed. The

results of this study suggest that increasing light intensity physical activity at the expense of sedentary time is a worthwhile initiative that should be promoted along with the well-established regular participation in moderate to vigorous physical activity. Additional cross-sectional research is required to examine whether these associations are evident across all populations, including children, male adolescents and adults of all ages, while longitudinal and interventional evidence is necessary to determine the effects of reduced sedentary time through increased light intensity physical activity on adiposity and additional cardiovascular risk factors in all populations.

Chapter 6. Objectively Determined Light Intensity Physical Activity is Negatively Associated with Skinfold Thickness and Carotid Intima-Media Thickness in Adolescent Females

6. 1. Introduction

6. 1. 1. Cardio-Metabolic Risk Factors in Childhood and Adolescence

Cardiovascular disease continues to be the leading causes of premature death in both industrialised and developing countries (Lloyd-Jones *et al.*, 2009). Risk factors for these pathologies manifest over time, and are predominantly observed in adulthood. Over the last two decades, alarming levels of cardio-metabolic risk factors, which include obesity, hypertension, dyslipidemia, insulin resistance and glucose intolerance have also been detected in children and adolescents (Steinberger *et al.*, 2009). Data from population-based samples have shown that the prevalence of the metabolic syndrome in children and adolescents may range between 3-12% (Steele *et al.*, 2008). A more recent US population-based examination of 2456 participants has estimated that 50% of US children and adolescents possessed one or more cardio-metabolic risk factors (Johnson *et al.*, 2009). These observations are of particular public health concern, as evidence suggests that cardio-metabolic risk factors track from childhood through adolescents and into adulthood, further increasing the risk of early onset cardiovascular disease (Bao *et al.*, 1994, Raitakari *et al.*, 2003). Consequently, the reduced incidence of cardio-metabolic risk factors in children and adolescents has long term implications to quality of life and longevity (Franks *et al.*, 2010b).

6. 1. 2. Associations between Moderate to Vigorous Physical Activity and Cardio-Metabolic Risk Factors

Physical inactivity has been highlighted as a significant contributor to the high prevalence of cardiovascular disease worldwide (Lloyd-Jones *et al.*, 2010). Historically, research has predominantly focused on the effect of moderate to vigorous physical activity, and has emphasised the positive effect that increased levels of moderate to vigorous physical activity has on cardio-metabolic risk factors in children and adolescents. Furthermore, it has been suggested that increased levels of moderate to vigorous physical activity in youth may have a positive effect on cardio-metabolic risk factors in adulthood (Hallal *et al.*, 2006).

6. 1. 3. Light Intensity Physical Activity and Cardio-Metabolic Risk Factors

Moderate to vigorous physical activity accounts for a very small proportion of an individual's daily energy expenditure compared with activities at the lower end of the activity intensity continuum (Troiano *et al.*, 2008). Light intensity physical activity accounts for the majority of our daily energy expenditure, yet these lower intensity activities have received relatively little focus (Levine, 2002, Pate *et al.*, 2008, Owen *et al.*, 2010). Few population-based studies have examined the effect of light intensity physical activity on cardio-metabolic risk factors in adults. These studies have highlighted that objectively measured light intensity physical activity was independently associated with 2 hour fasting glucose (Healy *et al.*, 2007), waist circumference and clustered metabolic risk (Healy *et al.*, 2008c) in adult populations. These relationships have not been addressed using objective measures in a population of children or adolescents. Interestingly, a recent longitudinal study has examined the distribution of sedentary time, light intensity physical activity and moderate to vigorous physical activity throughout adolescence, and has identified that increases in sedentary time from childhood through adolescence are largely due to decreases in light intensity physical activity rather than decreases in moderate to vigorous physical activity (Mitchell *et al.*, 2012). These findings further support the significance of accurately examining light intensity physical activity in adolescent populations.

6. 1. 4. Sedentary Behaviours and Cardio-Metabolic Risk Factors

The mechanisms by which prolonged periods of sedentary time are detrimental to indices of health are not yet fully understood. One potential mechanism, proposed by Bey and Hamilton (2003), is that inactivity reduces the activity of the enzyme lipoprotein lipase in skeletal muscle, thereby altering triglyceride metabolism and presumably increasing the risk of cardiovascular disease (Bey and Hamilton, 2003). Several studies have examined the independent relationship between sedentary time and cardio-metabolic risk factors in adults, highlighting that sedentary time has an effect on cardio-metabolic risk factors in adults, independent of moderate to vigorous physical activity (Healy *et al.*, 2008c, Helmerhorst *et al.*, 2009, Healy *et al.*, 2011b). Additionally, evidence has highlighted that

prolonged sedentary periods are negatively associated with cardiovascular and inflammatory markers in adults (Healy *et al.*, 2011b). The associations of sedentary time on cardio-metabolic risk factors in children and adolescents has been examined using objective activity monitors, yet findings have highlighted that the volume of sedentary time does not have an effect on cardio-metabolic risk factors independent of moderate to vigorous physical activity (Carson and Janssen, 2011, Martinez-Gomez *et al.*, 2011a). Likewise, the amount of time spent in prolonged sedentary periods has not been shown to have an effect on cardio-metabolic risk factors in children and adolescents independent of moderate to vigorous physical activity (Carson and Janssen, 2011).

6. 1. 5. The Assessment of Free-Living Sedentary Time and Light Intensity Physical Activity

The term sedentary refers to a specific behaviour which describes activities that do not substantially increase energy expenditure above resting level (Marshall and Ramirez, 2011, Tremblay *et al.*, 2012). Objectively-measured sedentary time has previously been determined based on a lack of movement using a measure of ambulation rather than a measure of body position (Ridgers *et al.*, 2012). Unfortunately, cut points are unable to distinguish between sitting and standing and may also count time spent in other light intensity activities as sedentary behaviour, hence inaccurately quantifying sedentary time (Hart *et al.*, 2011, Kozey-Keadle *et al.*, 2011). Consequently, if sedentary time is not accurately quantified as a result of the measurement tool being used, the resulting light intensity physical activity, which is calculated as total measurement time minus [sedentary time + moderate to vigorous physical activity], will also be miscalculated. Alternatively, the use of inclinometer-based activity monitors to distinguish standing from sitting, such as the activPAL™ Professional Physical Activity Monitor (PAL technologies Ltd, Glasgow, Scotland, UK), have been encouraged when examining the effects of sedentary behaviour and sedentary time on health outcomes (Bassett Jr *et al.*, 2010, Kozey-Keadle *et al.*, 2011).

To date, no research studies have employed an inclinometer-based activity monitor to examine the relationships between sedentary time and light intensity physical activity and cardio-metabolic risk factors independent of moderate to vigorous physical activity in any

population. The purpose of this chapter is to address this issue by examining the associations between the volume of sedentary time, patterns of sedentary time and the volume of light intensity physical activity with cardio-metabolic risk factors in an adolescent female population using an inclinometer-based activity monitor. Specifically, this chapter aims to determine 1) whether an association exists between the sedentary variables, light intensity physical activity and cardio-metabolic risk factors in female adolescents, 2) to explore whether any observed association between the subcomponents of physical activity and cardio-metabolic risk factors persist after adjustment for moderate to vigorous physical activity and 3) to explore whether any observed association between the subcomponents of physical activity and cardio-metabolic risk factors persist after adjustment for both moderate to vigorous physical activity and adiposity.

6. 2. Methods

A list of all second level schools in the Limerick region was obtained. From this list, a sample of schools was selected. The inclusion criteria for a school to be selected for participation was 1) the school must be public schools and 2) the school must have had a large student base (in excess of 500 students). A list of suitable schools was generated, and four schools were selected for participation using a random numbers table. If a school declined the opportunity to take part in the study the next randomly selected school was approached until 4 high schools had consented to participate. A list of all female students between the ages of 13 and 18 years was obtained from each school, and 40 students per school were randomly selected using a random numbers table. A total of 77 students provided written informed parental and written informed participant consent before the study began. Of these participants, 6 (7.8%) were absent on the initial test days, which automatically removed them from participation in the study. This rate of absence is in line with national absence statistics at post primary level, identifying the average rate of non-attendance at 7.9% (Millar, 2012). A further 7 participants were removed from the analysis due to insufficient accelerometer data (explained in Section 4. 2. 2). This provided a final sample of 64 participants. Recruitment and data collection took place in autumn 2011. Ethical approval was obtained for this study from the Research Ethics Committee of the Mid-Western Regional Hospital, Limerick, Ireland.

6. 2. 1. Physical Examination

All participants arrived to the school gymnasium in groups of three to five. Participants wore light clothing (vest top and tracksuit pants) and removed their shoes and socks before all measures were obtained.

6. 2. 1. 1. Body Composition Measures

Height, weight and 4 sites skinfold measurement was assessed in all participants. Height was measured to the nearest 0.25 cm using a portable stadiometer (Seca model 214, Seca Ltd., Birmingham, UK) and weight was measured to the nearest 0.1 kg using a portable electronic scale (Seca model 770, Seca Ltd., Birmingham, UK) following standard procedures. Body mass index (BMI) was calculated as weight (kg) /height (m)^2. Four sites skinfold measurement was employed as an estimate of general adiposity. All skinfold measures were obtained using a Harpenden skinfold calliper (Assist creative resources Ltd., Wrexham, United Kingdom). The 4 sites included for measurement in this study were the bicep, triceps, subscapular and iliac crest, and the sum of the four skinfold sites were used. All skinfold measures were recorded three times and the median value of the three measures was calculated.

6. 2. 1. 2. Carotid Intima-Media Thickness Measures

Carotid intima-media thickness is the most commonly used and best validated ultrasound measure of early and intermediate stages of atherosclerosis (Knoflach *et al.*, 2003). Atherosclerosis refers to the build-up of plaque on the walls of the arteries and is the most common cause of CVD (Skålén *et al.*, 2002). As atherosclerotic plaque accumulates, the vessel wall undergoes compensatory remodelling in order to avoid luminal narrowing, which results in an increase in the intima-media layer (Silverthorn, 2012). Increments in carotid intima-media thickness are associated with an increased risk for myocardial infarction and stroke (Bots *et al.*, 1997, Lorenz *et al.*, 2007). For an absolute carotid intima-

media difference of 0.1 mm, the future risk of myocardial infarction increases by 10% - 15% (Lorenz *et al.*, 2007).

Thickness of the carotid intima-media was assessed using a 12.0 MHz linear-array transducer (SonoSite, MicroMax). Recordings were obtained with the subject resting in a supine position. The common carotid artery, including the carotid bulb, was visualised and 2 longitudinal β-mode images of the left and the right common carotid arteries at end diastole were recorded and electronically stored. Measurements of CIMT was conducted in the 10-mm linear segment proximal to the carotid bulb at 2 plaque-free sites three times at the near wall and three times at the far wall on both sides and combined as mean CIMT. A combination of readings from both the near and far walls were used as they yield the strongest association with cardiovascular disease (Bots *et al.*, 2003).

6. 2. 1. 3. Large Artery Stiffness

The build-up of atherosclerotic plaques on the interior walls of arteries causes them to stiffen, which in turn causes the pressure at which blood is pumped through the arteries around the body to increase (Silverthorn, 2012). The build-up of these plaques often results in narrowing of the arteries, which in time may lead to clots or aneurysms. Recent technological developments have enabled researchers to examine arterial stiffness more accurately through examining the velocity at which the blood is pumped around the body (pulse wave velocity). Through examining arterial stiffness, researchers can now more accurately estimate the prevalence of fatty streaks and atherosclerotic lesions in the coronary arteries (Dangardt *et al.*, 2008). Until now, the study of pulse wave velocity and arterial stiffness was an expensive and invasive procedure. However, more cost effective devices have been developed that estimate pulse wave velocity.

In this study, large artery stiffness was estimated using a Pulse Trace PCA 2 (Micro Medical Ltd, Rochester, UK). The Pulse Trace PCA 2 estimates stiffness index by recording and analysing the digital volume pulse using a digital photoplethysmographic probe on the fingertip of the participant (Millasseau *et al.*, 2000). Pulse Trace PCA 2 stiffness index has previously been shown to be positively correlated with pulse wave velocity in paediatric populations (Simonetti *et al.*, 2008).

6. 2. 1. 4. Stage of Pubertal Development

Stage of pubertal development Tanner Scale pictures for self-identification of Tanner pubertal status were employed in this research, which precluded the need to examine the participants for pubertal status assignment (Tanner and Whitehouse, 1976). The self-identification of Tanner pubertal status was completed with a paediatrician present in the Mid-Western regional hospital, Limerick, Ireland.

6. 2. 1. 5. Blood Pressure

A detailed description of blood pressure and its relationship with health is discussed in Section 2. 4. 1. 2. Blood Pressure was measured using an automated sphygmomanometer (Omron model M7, Kyoto, Japan), and mean arterial pressure was calculate (Mean Arterial Pressure = Diastolic Pressure + 1/3 * (Systolic Pressure – Diastolic Pressure)).

6. 2. 1. 6. Blood Sampling and Analysis

The importance of examining blood lipids (including HDL-C, LDL-C, total cholesterol and triglycerides) in relation to cardiovascular disease and health have been discussed in Section 2. 4. 1. 1. 1 . Insulin, glucose and high molecular weight (HMW) adiponectin were also examined within this sample. Insulin is a hormone which is secreted by the pancreas. Insulin stimulates increased glucose transport into the cell. However, if skeletal muscle becomes insulin resistant, the pancreas increases its production in an effort to encourage glucose uptake. A high level of insulin in the blood is a precursor of type 2 diabetes. As the insulin resistance grows, the amount of insulin required for glucose homeostasis cannot be produced by the pancreas, resulting in increased blood sugar levels. This is the onset of type 2 diabetes. Adiponectin is also involved in the regulation of glucose levels in the blood, while it is similarly important in the breakdown of fatty acids. Increased levels of HMW adiponectin in the blood is associated with a reduced risk of diabetes (Zhu *et al.*, 2010).

Blood testing was carried out between 9am and midday after each participant was instructed to fast for a minimum of 10 hours. Biochemical analysis was undertaken by the Clinical Chemistry Department at the Mid-Western regional hospital, Limerick, Ireland. Fasting venous blood samples were taken from the cubital vein using a paediatric cannula and were collected in both EDTA and heparin sampling tubes. Cholesterol linked to high-density lipoproteins (HDL-C), cholesterol linked to low-density lipoproteins (LDL-C), total cholesterol (TC), triglycerides (TG) and Glucose (Glu) were measured on a Beckman auto-analyser using standard measurement kits. Insulin and HMW Adiponectin was measured by Enzyme-linked Immunosorbent assay (ELISA) using standard measurement kits. The analytical performance of the clinical laboratory used in this study is continually assessed by the Irish External Quality Assessment Scheme.

6. 2. 2. Clustered Metabolic Risk Score

It has been suggested that a continuous metabolic syndrome score, or clustered metabolic risk score (CMRS), is less prone to error and statistically more sensitive by comparison to standard dichotomous approaches (Brage *et al.*, 2004). Variables included in a CMRS must reflect the adult metabolic syndrome criteria, including obesity, blood lipids, insulin/glucose and hypertension (Eisenmann, 2008). In this study, the CMRS was calculated using sum of skinfolds, HDL-C, TG, Insulin and Mean Arterial Pressure. Each variable was standardised using the linear regression of the results for both age and pubertal developmental stage (Eisenmann, 2008). The standardised results for HDL-C were then multiplied by – 1 due to its inverse relationship with cardiovascular risk (Eisenmann, 2008). The results were then summed to produce a clustered metabolic risk score (CMRS) for each participant. Additionally, the standardised scores were summed excluding the adiposity component to examine whether associations between light intensity physical activity, sedentary variables and clustered metabolic risk were mediated by adiposity (CMRS-Obs).

6. 2. 3. Physical Activity and Sedentary Levels and Patterns

Physical activity and sedentary levels and patterns were examined using the activPAL™ Professional Physical Activity Monitor (PAL Technologies Ltd, Glasgow, UK). A detailed description of the activPAL has been provided in Section 2. 10. The activPAL responds to gravitational accelerations resulting from segmental movement (Ryan *et al.*, 2006), and data is recorded at 10 Hz for each 15 second time intervals (epoch). The activPAL has been identified as a valid and reliable measure of sitting/lying time and standing time in children (Davies *et al.*, 2011) and adults (Kozey-Keadle *et al.*, 2011), and as a measure of light and moderate to vigorous physical activity in an adolescent female population (Section 3. 3. 5).

6. 2. 3. 1. Data Processing

The methods employed in processing the activPAL output have previously been described in Section 4. 2. Briefly, for a day to be categorised as valid, a minimum of 10 hours of daily recording time was required. The activity monitor output was then examined for number of valid days of activity data provided. For a dataset to be included in the examination of habitual activity profiles, 4 valid days of accelerometer data (including one weekend day) are required (Trost *et al.*, 2005). All data sets were examined for non-wear time, where non-wear time was defined as periods of 60 minutes of concurrently recorded sedentary time and continuous 0 accelerometer counts from the activPAL output file. Time identified as non-wear time was removed from the data set, and the 24 hour day was adjusted accordingly.

Data were then examined for time spent sedentary, standing, in light intensity physical activity and in moderate to vigorous physical activity. The start time for each measured day was identified at 6 am, and the following 24 hour period was examined. The total amount of sedentary time and standing time was summed over the entire day. The amount of time spent in moderate to vigorous physical activity was examined using count to activity thresholds. A specific count to activity threshold of 2997 per epoch has been derived for use in this population (Section 3. 3. 5). The amount of time spent in moderate to vigorous physical activity was calculated by summing the time spent in epochs above this threshold. Light intensity physical activity was then calculated as all remaining daily time (light

intensity physical activity = 24 hours – (time spent in sedentary activities + time spent in standing activities + time spent in moderate to vigorous physical activity)). Since participants were encouraged to wear the activPAL device for 24 hours each day, all activities variables are presented as a percentage of waking time to standardise activity scores across all participants. The first change in inclination from sitting/lying to standing after a prolonged sedentary periods (e.g. sleep time) was identified as the "rise time", while the last change in inclination form standing to sitting before a prolonged SP identified the "bed time". From this information, the number of waking hours was the calculated. Each of the activity variables were then presented as percentage of waking time (e.g. (percentage of moderate to vigorous physical activity waking hours = no. of hours spent in moderate to vigorous physical activity/no. of hours spent waking)*100).

The percentage of time spent in prolonged sedentary periods (e.g. sedentary periods greater than 30 minutes in duration) was also examined. A customised MATLAB® computer software program examined the activPAL files for all sedentary periods observed across the entire day. This methodology has been described in great detail in Section 4. 2. 3.

6. 2. 4. Statistical Analysis

Descriptive statistics were calculated and are presented as median and interquartile ranges. All variables were examined for normality of distribution before the analysis. Fasting triglycerides, insulin and adiponectin were identified as not normally distributed. Natural logarithm was applied to these non-normal variables.

Partial correlations, adjusted for age, were used to examine the relationships between these activity variables (sedentary time, light intensity physical activity, moderate to vigorous physical activity and time spent in prolonged sedentary periods) and cardio-metabolic risk factors. Partial correlations were also used to identify relationships between physical activity and sedentary variables while adjusting for age and stage of pubertal development.

Multiple linear regression models were used to examine the independent relationships between percentage sedentary time, percentage of time spent in prolonged sedentary period and the percentage of time spent in a light intensity physical activity (both including and

excluding standing time) and the metabolic risk factors, adjusting for age and stage of pubertal development. The three models employed assessed:

1. Whether activity variables were associated with each cardio-metabolic risk factor after correcting for age and stage of pubertal development;
2. Whether activity variables were associated with each risk factor while adjusting for the original confounding variables in model 1 and moderate to vigorous physical activity;
3. Whether activity variables were associated with each risk factor after adjusting for all earlier confounding variables plus a measure of body composition (when body composition was not the outcome of interest).

The independent associations between activity variables and clustered metabolic risk score (CMRS) were examined in two ways. Firstly, HDL-C, mean arterial pressure, triglycerides, insulin and sum of skinfolds were included in calculating the CMRS and the model was corrected for all confounders identified in model 1 and 2 above. Then the adiposity component (sum of four skinfolds) was removed from the CMRS (CMRS-Obs). The independent associations between activity variables and CMRS-Obs were then examined using models 1, 2 and 3 described above. Retrospective power calculations were completed on all statistically significant correlations from multiple linear regression models. This was completed to examine the probability of committing a type 2 statistical error, or not rejecting the null hypothesis when the null hypothesis is false. All statistical analysis was completed using Predictive Analysis Software version 18.0 for windows (SPSS Inc., Chicago, IL, USA).

6. 3. Results:

6. 3. 1. Descriptive Statistics

Table 6.1 displays the descriptive characteristics for the sample. The median value for percentage of time spent sitting/lying was 70%, percentage of time spent in light intensity physical activity only was 4.8%, the percentage of time spent in light intensity physical

activity including standing time was 24.6% and percentage of time spent in moderate to vigorous physical activity was 5.5%.

Table 6.1 Descriptive characteristics of participants. Values are presented as mean (range).

Variables	Median (Range)
Age (yrs.)	15.1 (14.4 – 16.0)
Height (m)	1.63 (1.59 – 1.68)
Weight (kg)	59.9 (51.2 – 68.1)
BMI (kg/m^2)	22.6 (20.4 – 25.7)
Body Fat (%)	32.3 (28.8 – 34.6)
Σ Skinfolds (mm)	69.7 (53.0 – 82.6)
HDL-C (mmol/l)	1.4 (1.2 – 1.5)
LDL-C (mmol/l)	2.3 (1.9 – 2.6)
Total Cholesterol (mmol/l)	3.9 (3.6 – 4.4)
Triglycerides (mmol/l)	0.54 (0.41 – 0.70)
Insulin (pmol/l)	56.3 (44.1 – 65.2)
Glucose (mmol/l)	4.5 (4.3 – 4.7)
Adiponectin (ug)	2.8 (2.1 – 4.1)
Large Artery Stiffness (m/s^{-1})	5.2 (5.0 – 5.3)
Mean Arterial Pressure (mmHg)	86.3 (80.8 – 90.0)
Carotid Intima-Media Thickness (mm)	0.05 (0.04 – 0.06)
Sitting/Lying (%)	70.0 (63.6 – 74.7)
Standing Time (%)	19.8 (17.1 – 23.7)
Light Intensity Physical Activity (%)	4.8 (3.8 – 5.4)
Light Intensity Physical Activity + Standing (%)	24.6 (20.9 – 29.2)
Moderate to Vigorous Physical Activity (%)	5.4 (3.8 – 7.3)
Sedentary Periods > 30 mins (%)	33.8 (27.1 – 40.0)

All variables, excluding mean arterial pressure (MAP), had a sample of n=64. MAP had a sample size of 48 participants. All activity variables are presented as a percentage of total waking hours.

6. 3. 2. Partial Correlations between Activity Variables and Cardiovascular Risk Factors

The results of the partial correlations between activity variables and cardio-metabolic risk factors, corrected for age, are presented in Table 6.2. The percentage of daily sedentary time demonstrated a moderate but significant positive association with BMI ($r = 0.268$; $p < 0.05$). The percentage of daily time spent in light intensity physical activity demonstrated a moderate but significant association with BMI ($r = .349$; $p = 0.034$). Percentage of daily light intensity physical activity demonstrated a negative but significant association with BMI ($r = -.467$; $p = 0.006$). No other associations were observed between physical activity and sedentary patterns and levels and cardio-metabolic risk factors in this population.

6. 3. 3. Partial Correlations between Activity Variables

The partial correlations between sedentary variables and activity variables adjusted for age and stage of pubertal development are presented in Table 6.3. Moderate to vigorous physical activity was not correlated with standing time ($p = .07$), light intensity physical activity (excl. standing time) ($p = .81$), light intensity physical activity (incl. standing time) ($p = .11$) or with prolonged sedentary periods ($p = .14$). Significant associations at a $p < 0.01$ level existed between all other measured activity variables in this sample.

Table 6.2 Partial correlations between sedentary time, standing time, light intensity physical activity (incl. and excl. standing time), moderate to vigorous intensity physical activity, prolonged sedentary periods and cardio-metabolic risk factors, corrected for age.

	ST	StT	LIPA excl. StT	LIPA incl. StT	MVPA	PSP
BMI	.35*	-.26	-.47**	-.31	-.19	.21
% Body Fat	.25	-.15	-.23	-.16	-.28	.11
Σ Skinfolds	.28	-.19	-.27	-.21	-.25	.13
HDL-C	-.07	.02	.08	.03	.02	-.01
LDL-C	.00	-.14	.04	-.14	.04	-.08
Total Chol.	.01	-.14	.03	-.14	.02	-.05
Triglycerides	.21	-.21	-.09	-.20	-.06	-.04
Insulin	.21	-.19	-.18	-.20	-.02	.05
Glucose	.14	-.04	-.05	-.03	-.18	-.06
Adiponectin	-.29	.22	.34*	.25	.21	-.25
LAS	.03	-.00	.10	.02	-.23	.17
MAP	.12	-.07	-.29	-.12	.13	.14
CIMT	.27	-.23	-.34	-.25	-.09	.31

ST = Sedentary Time; StT = Standing Time; LIPA incl. StT = Light Intensity Physical Activity including Standing Time; LIPA excl. StT = Light Intensity Physical Activity excluding Standing Time; MVPA = Moderate to Vigorous Physical Activity; PSP = Sedentary Periods greater than 30 minutes in duration; BMI = Body Mass Index; HDL-C = High Density Lipoprotein cholesterol; LDL-C = Low Density Lipoprotein cholesterol; Total Chol. = Total Cholesterol; LAS = Large Artery Stiffness; MAP = Mean Arterial Pressure; CIMT = Carotid Intima-Media Thickness; N = 64 (excluding MAP); * p < 0.05; **p < 0.01.

Table 6.3 Partial correlations between sedentary variables and physical activity variables, corrected for age.

	ST	StT	LIPA excl. StT	LIPA incl. StT	MVPA	PSP
SedT	-	-.94**	-.66**	-.96**	-.48**	.69**
StT		-	.56**	.98**	.24	-.71*
LIPA excl. StT			-	.71**	.03	-.45**
LIPA incl. StT				-	.22	-.71**
MVPA					-	-.20
SP > 30 mins						-

ST = Sedentary Time; StT = Standing Time; LIPA excl. StT = Light Intensity Physical Activity excluding Standing Time; LIPA incl. StT = Light Intensity Physical Activity including Standing Time; MVPA = Moderate to Vigorous Physical Activity; PSP = Prolonged Sedentary periods.
All correlations were significant (**$P \le 0.01$) except for the correlations between StT, LIPA incl. StT, LIPA excl. StT and PSP with MVPA.

6. 3. 4. Results of Multiple Linear Regression between Activity Variables and Cardio-Metabolic Risk Factors

As the partial correlations identified no associations between the percentage of waking time spent standing, percentage of time spent in light intensity physical activity (including standing), moderate to vigorous physical activity, prolonged sedentary periods and cardio-metabolic risk factors in Table 6.2, no further results from these variables will be examined using multiple linear regression in this chapter. However, all correlations from these activity variables and cardio-metabolic risk factors are presented in Appendix H.

6. 3. 4. 1. Sedentary Time and Cardio-Metabolic Risk Factors

The associations between sedentary time and cardio-metabolic risk factors using multiple linear regression models, which adjusted for age and stage of pubertal development, are displayed in Table 6.4. All outcomes are displayed using standardised beta scores. The results of the regression analysis highlighted that directly measured sedentary time was not associated with cardio-metabolic risk factors.

6. 3. 4. 2. Light Intensity Physical Activity and Cardio-Metabolic Risk Factors

The results from the multiple linear regression models, which examined the association between the percentage of waking time spent in light intensity physical activity (excl. standing time) and cardio-metabolic risk factors, are displayed in Table 6.5. A significant association was observed between the percentage of waking time spent in light intensity physical activity and body mass index (β = -.332; p = .014). After further adjustment for moderate to vigorous physical activity, this association remained (β = -.333; p = .015). A retrospective power calculation identified power of 0.56 for the association between light intensity physical activity and BMI (N = 64, r = -0.33, α = 0.01, $1 - \beta$ = 0.56). No additional associations were observed.

Table 6.4 Associations between sedentary time and cardio-metabolic risk factors in adolescent females.

	Model 1			Model 2			Model 3		
	β	p	Adj. R²	β	p	Adj. R²	β	p	Adj. R²
BMI	.23	.08	.04	.06	.29	.03	-	-	-
% BF	.20	.13	.06	.21	.17	.04	-	-	-
Σ SF	.22	.10	.05	.25	.11	.04	-	-	-
HDL-C	-.10	.47	.01	-.15	.35	.00	-.09	.57	.02
LDL-C	.09	.50	-.03	.11	.50	-.05	.03	.83	.02
T Chol.	.04	.76	.01	.04	.82	-.01	.02	.92	-.02
TG	.14	.32	-.02	.18	.25	-.03	.11	.50	.05
Insulin	.22	.12	-.00	.29	.07	-.01	.20	.20	.12
Glucose	.19	.15	.10	.15	.32	.09	.12	.44	.09
HMW Apo	-.15	.27	-.02	-.14	.38	-.04	-.15	.37	-.06
LAS	.06	.75	-.06	-.11	.57	-.01	-.69	.50	-.02
MAP	.06	.72	-.04	.15	.43	-.04	.12	.54	-.05
CIMT	.26	.06	.04	.28	.08	.03	.30	.07	.01
CMRS	.26	.11	-.01	.29	.14	-.03	-	-	-
CMRS-Obs	.21	.19	-.03	.28	.15	-.04	.19	.28	.17

BMI = Body Mass Index; % BF= Percentage Body Fat; Σ SF = Sum of Skinfold Thickness; HDL-C = High Density Lipoprotein cholesterol; LDL-C = Low Density Lipoprotein cholesterol; T Chol. = Total Cholesterol; TG = Triglycerides; HMW Apo = High Molecular Weight Adiponectin; LAS = Large Artery Stiffness; MAP = Mean Arterial Pressure; CIMT = Carotid Intima-Media Thickness; CMRS = cardio-metabolic risk score; CMRS-Obs = cardio-metabolic risk score excluding the measure of adiposity. Model 1 adjusted for age and stage of pubertal development; Model 2 adjusted for age, stage of pubertal development and objectively measured MVPA; Model 3 adjusted for age, stage of pubertal development, objectively measured MVPA and adiposity (sum of four skinfolds); N = 64 (excluding MAP); Multiple Linear Regression Analysis; *p < 0.05.

Table 6.5 Associations between light intensity physical activity (excluding standing time) and cardio-metabolic risk factors in adolescent females.

	Model 1			Model 2			Model 3		
	β	p	Adj. R^2	β	p	Adj. R^2	β	p	Adj. R^2
BMI	-.33	.01[*]	.09	-.33	.02[*]	.08	-	-	-
% BF	-.25	.06	.08	-.25	.07	.06	-	-	-
Σ SF	-.27	.05	.07	-.26	.05	.06	-	-	-
HDL-C	.14	.32	.02	.14	.32	-.00	.08	.56	.02
LDL-C	-.14	.33	-.03	-.14	.34	-.04	-.06	.69	.02
T Chol.	-.08	.59	.01	-.07	.60	-.01	-.05	.72	.02
TG	-.19	.18	.00	-.19	.19	-.02	-.10	.46	.06
Insulin	-.07	.63	-.05	-.07	.65	-.07	.06	.68	.12
Glucose	.05	.73	.07	.06	.64	.08	.11	.42	.10
HMW Apo	.19	.18	-.01	.19	.19	-.02	.20	.18	-.04
LAS	.06	.75	-.04	.09	.62	-.02	.12	.53	-.03
MAP	-.20	.21	-.01	-.21	.20	-.03	-.18	.29	-.03
CIMT	-.25	.08	.03	-.24	.09	.02	-.27	.08	.00
CMRS	-.22	.19	-.03	-.20	.23	-.04	-	-	-
CMRS-Obs	-.19	.26	-.03	-.18	.30	-.05	-.08	.60	.20

BMI = Body Mass Index; % BF= Percentage Body Fat; Σ SF = Sum of Skinfold Thickness; HDL-C = High Density Lipoprotein cholesterol; LDL-C = Low Density Lipoprotein cholesterol; T Chol. = Total Cholesterol; TG = Triglycerides; HMW Apo = High Molecular Weight Adiponectin; LAS = Large Artery Stiffness; MAP = Mean Arterial Pressure; CIMT = Carotid Intima-Media Thickness; CMRS = cardio-metabolic risk score; CMRS-Obs = cardio-metabolic risk score excluding the measure of adiposity. Model 1 adjusted for age and stage of pubertal development; Model 2 adjusted for age, stage of pubertal development and objectively measured MVPA; Model 3 adjusted for age, stage of pubertal development, objectively measured MVPA and adiposity (sum of four skinfolds). N = 64 (excluding MAP); Multiple Linear Regression Analysis; [*]$p < 0.05$.

No associations were observed between any of the activity or sedentary variables and the CMRS. The associations between the activity variables independent of adiposity and the CMRS were examined by excluding the sum of four skinfold measurements from the risk score and adjusting for this adiposity measure (CMRS-Obs). No associations were observed between sedentary time, standing time, light intensity physical activity (incl. or excl. standing time) or prolonged sedentary periods and CMRS-Obs.

6. 4. Discussion

The purpose of this analysis was to determine whether associations exist between levels and patterns of sedentary time and light intensity physical activity and cardio-metabolic risk factors in female adolescents, independent of moderate to vigorous physical activity. The key findings of this chapter suggest that light intensity physical activity which does not include standing time is significantly associated with body mass index, independent of moderate to vigorous physical activity. This chapter has also identified that sedentary time is associated with body mass index in this population when controlling for age and stage of pubertal development, but these findings disappear when correcting for moderate to vigorous physical activity. Finally, an association which approaches significance has been observed between light intensity physical activity and carotid intima-media thickness in this adolescent female population. This chapter also indicates that adolescent females spend the majority of their time in sedentary and standing activities.

6. 4. 1. Associations between activPAL Determined Light Intensity Physical Activity and Cardio-Metabolic Risk Factors

The results of this study have highlighted that in this sample, light intensity physical activity is negatively correlated with BMI independent of moderate to vigorous physical activity, while sedentary time, prolonged sedentary periods, standing time and light intensity physical activity including standing time are not significantly associated with any of the cardio-metabolic risk factors when corrected for moderate to vigorous physical activity and adiposity. This suggests that a reduction in the amount of light intensity physical activity is linked to increased body mass index. Furthermore, although sedentary time did not correlate directly with cardio-metabolic risk factors, it may be that sedentary time is a risk when it replaces light intensity physical activity. These findings may have public health and clinical importance. Adverse adiposity is a critical component of metabolic syndrome and an important risk factor for cardiovascular disease (Lloyd-Jones *et al.*, 2010), while large population-based studies in youths have identified alarming trends of increasing levels of obesity, hypertension and type II diabetes mellitus in paediatric populations (Lloyd-Jones *et al.*, 2009).

This is the first study which has examined the independent effect of standing time and light intensity physical activity on cardio-metabolic risk factors using an inclinometer-based activity monitor. Previously, the examination of light intensity physical activity has relied on the use of thresholding for both sedentary time and moderate to vigorous physical activity, which are unable to distinguish between different postural positions such as sitting and standing (Grant *et al.*, 2006), and may also have categorised activities of a lower intensity as sedentary (Davies *et al.*, 2011, Kozey-Keadle *et al.*, 2011). Our findings have identified that light intensity physical activity was inversely associated with BMI independent of moderate to vigorous physical activity, while no associations were observed between standing time or light intensity physical activity including standing time and cardio-metabolic risk factors in this population of adolescent females. Recent physiological evidence has suggested that reduced sedentary time through increased light intensity physical activity (or an increase in the amount of light contractile activity) may have an independent positive effect on an individual's health (Hamilton *et al.*, 2004, Zderic and Hamilton, 2006). It is now accepted that non-exercise activity thermogenesis accounts for the majority of daily energy expenditure, and that increases in the amount of daily light intensity physical activity achieved by an individual can be important in the protection against overweight or obesity (Levine, 2002, Owen *et al.*, 2010). Our findings support these observations, suggesting that light intensity physical activity can protect against sedentary time regardless of participation in moderate to vigorous physical activity, while also having a significant effect on BMI, independent of moderate to vigorous physical activity.

In adults, significant associations have been observed between objectively measured sedentary time and cardio-metabolic risk factors, independent of moderate to vigorous physical activity and other covariates (Ekelund *et al.*, 2007b, Healy *et al.*, 2007, Healy *et al.*, 2008c, Healy *et al.*, 2011b). Researchers have also identified the significant associations of surrogate measures of the duration of sedentary periods, such as breaks in sedentary time and cardio-metabolic risk factors independent of moderate to vigorous physical activity and other covariates in adults (Healy *et al.*, 2008a, Healy *et al.*, 2011b). Studies in youths have observed associations between sedentary time and cardio-metabolic risk factors, yet these associations were not independent of moderate to vigorous physical activity (Ekelund *et al.*, 2007a, Sardinha *et al.*, 2008, Martinez-Gomez *et al.*, 2009). Only two published studies were identified that have examined the associations between sedentary time, prolonged sedentary periods and cardio-metabolic risk factors in child and adolescent populations, independent

of moderate to vigorous physical activity (Carson and Janssen, 2011, Martinez-Gomez *et al.*, 2011a). Similar to the present findings, neither study identified any significant independent associations. As hypothesised by Martinez-Gomez and colleagues (2011), the absence of association between cardio-metabolic risk factors and sedentary variables may be age dependent (Martinez-Gomez *et al.*, 2011a). It is widely acknowledged that weaker associations between activity variables (including moderate to vigorous physical activity) and cardio-metabolic risk factors have been observed in children and adolescents than those observed in adults, as associated diseases do not tend to manifest until adult years (Hallal *et al.*, 2006, Andersen *et al.*, 2011). Additionally, sedentary time has been shown to increase across the lifespan (Janz *et al.*, 2005, Treuth *et al.*, 2005, Matthews *et al.*, 2008), which may further increase the risk of cardiovascular diseases.

6. 4. 2. Potential Areas of Further Research: Associations between Activity Variables and Cardio-Metabolic Risk Factors Approaching Significance

Although no further significant relationships were observed during this analysis, relationships which approached significance were observed between sedentary time and carotid intima-media thickness (Table 6.4; Model 3: $\beta = 0.3$; $p = 0.07$, Adj. $R^2 = 0.01$), independent of moderate to vigorous physical activity. Although insignificant, this relationship may suggest that there is a greater accumulation of atherosclerotic plaques in the large arteries of sedentary adolescents compared to their less sedentary counterparts. This is the first study to examine associations between carotid intima-media thickness and sedentary time, making comparison with existing epidemiological observations difficult. It is well established that initial processes associated with atherosclerosis begin in childhood and develop throughout adolescence and into adulthood, where it is more likely to manifest in the form of myocardial infarction or stroke (Raitakari *et al.*, 2003). If future work identifies a real relationship, it would support the increased use of vascular health measures when examining the relationships between sedentary time, standing time and light intensity physical activity and health in future epidemiological studies. These examinations may present further interesting observations that may provide more evidence on the deleterious effect of sedentary time in childhood and adolescence.

Another relationship which approached significance was observed between standing time and fasting insulin levels (Appendix H; Model 3: β = -0.19; p = 0.15, Adj. R^2 = 0.12), independent of moderate to vigorous physical activity. Epidemiological relationships have been observed between sedentary time and insulin levels in adults, independent of moderate to vigorous physical activity (Healy *et al.*, 2011b). The proposed theory behind these findings supported the work of Hamilton and colleagues, suggesting that fewer skeletal muscle contractions may result in reduced clearance of oral glucose loads from plasma and less glucose-stimulated insulin secretion (Hamilton *et al.*, 2007). The sedentary measure employed by Healy and colleagues (2011) is based on a lack of ambulation rather than postural position (Healy *et al.*, 2011b). Consequently, claims of observing results regarding the contractions of large skeletal muscles in large populations may be premature. Although the independent relationships between standing and insulin presented in this study only approach significance, these findings may be of great importance. The distinction between sitting and standing presented here provides a more accurate measure of large skeletal muscle contraction, resulting in a more accurate insight into the relationship between sedentary time and insulin resistance. Should future studies establish that this trend towards significance for the relationship between sedentary time and insulin is a real effect, then it may be that the increased volume of active skeletal muscle achieved through standing increases plasma glucose clearance and decrease glucose-stimulated insulin secretion (Healy *et al.*, 2008c). Future large-scale epidemiological studies which employ inclinometer-based activity monitors are critical in determining the relationships between activity intensities at the lower end of the spectrum, such as sedentary time, standing time and light intensity physical activity and fasting insulin.

6. 4. 3. Associations between Activity Variables Assessed using the activPAL Activity Monitor

One of the key findings of this analysis is that although moderate to vigorous physical activity is negatively associated with sedentary time, the negative association between standing time, light intensity physical activity (excl. standing time) and light intensity physical activity (including standing time) are stronger. Furthermore, moderate to vigorous physical activity did not correlate significantly with standing time, light intensity physical

activity excluding standing time and light intensity physical activity including standing time. These findings suggest that light intensity physical activity is reduced more than moderate to vigorous physical activity in female adolescents who are more sedentary, and that sedentary behaviour may be replacing light intensity physical activity rather than moderate to vigorous physical activity. This concurs with recent observations from Mitchell and colleagues (2012), who have highlighted decreases in light intensity physical activity and increases in sedentary time (measured using accelerometer counts below 200 counts per minute) from childhood through to adolescence in both males and females (Mitchell *et al.*, 2012). Furthermore, there is a relatively strong negative correlation between long unbroken periods of sedentary time (greater than 30 minutes) and a reduction in light intensity physical activity. It seems that adolescent girls who sit for long periods during the day have significantly reduced light intensity physical activity, suggesting that prolonged sedentary periods may be displacing other activities that include light intensity physical activity.

No relationship between light intensity physical activity and moderate to vigorous physical activity existed after adjusting for age and stage of pubertal development in this population. This contrasts with similar analysis from other studies in children and adolescent populations, which have documented significant associations between objectively measured light intensity physical activity and moderate to vigorous physical activity (Carson and Janssen, 2011). The observed differences can most likely be attributed to measurement differences. The activPAL is a direct measure of sedentariness, and thus can differentiate between standing time and sitting time, while also differentiating between standing time and light intensity physical activity (Section 2. 10). The ActiGraph (ActiGraph LCC, Pensacola, FL), which relies on the measurement of ambulation, has estimated sedentary time through the use of sedentary thresholds, and is unable to accurately distinguish between sedentary time and standing time (Hart *et al.*, 2011, Kozey-Keadle *et al.*, 2011). Studies which have examined and compared both devices as measures of sedentary time have acknowledged the improved accuracy the activPAL physical activity monitor, while also recommending its use as a measure of sedentary behaviour (Davies *et al.*, 2011, Kozey-Keadle *et al.*, 2011, Ridgers *et al.*, 2012). The activPAL has also been identified as a valid and reliable measure of postural allocation (Grant *et al.*, 2006) and as a measure of physical activity intensity within this population (Section 3. 5). These population-based findings suggest that a device which can examine both activities at the low and high end of the

activity intensity continuum should be employed when making associations between free-living activity variables and indices of health.

6. 4. 4. Strengths and Limitations:

A particular strength of this study was the use of an objective measure of ambulation with an inbuilt direct measure of postural position, which enabled the accurate and reliable classification of activities including sedentary, standing, light and moderate to vigorous physical activity. We also measured some novel cardio-metabolic risk factors which have not previously been examined in relation to adolescent sedentary time. However, the limitations of this study must be acknowledged. We are unable to make causal inference regarding the identified relationships due to the cross sectional design of this study. Although the sample was randomly selected, the sample size was small and healthy. Significant large-scale epidemiological studies which employ inclinometer-based activity monitors are necessary to make more powerful and substantial statements regarding the associations between sedentary patterns and behaviours, light intensity physical activity and cardio-metabolic risk factors in adolescent females. This study only focused on female adolescents due to their high levels of physical inactivity. Similar examinations are necessary in children and male adolescents, to inform sedentary and physical activity guidelines in young populations. Only two confounders were included in our statistical analysis, age and stage of pubertal development. The use of further confounder variables such as socio-economic status, smoking status and diet would have strengthened the results obtained from our linear regression models, but may not have been appropriate given the relatively low population numbers.

6. 5. Conclusions

These results are the first to categorise sedentary time, prolonged sedentary periods and light intensity physical activity using an inclinometer-based activity monitor, while also observing an independent association between one of these measured variables and a cardio-metabolic risk factor. A strong negative correlation between prolonged periods of

sitting/lying and light physical activity was observed, suggesting that sitting is displacing light intensity physical activity, irrespective of daily moderate to vigorous physical activity. Additionally, an independent association has been identified between light intensity physical activity (which did not include standing time) and body mass index in an adolescent female population. Taken together, these results suggest that targeting moderate to vigorous physical activity alone may not be a fully effective strategy in changing health risk in this population. Reducing prolonged sitting, which in this population appeared to displace light intensity physical activity, may be an effective target for intervention. These findings add some support to recently published sedentary guidelines, yet further epidemiological evidence from a range of ages, sexes, ethnicities and clinical groups are required to provide more detailed and effective guidelines on the optimum activity profile.

Chapter 7. General Discussion

7. 1. Introduction

The literature review presented in Chapter 2 of this thesis has described existing research on the importance of sedentary patterns and physical activity behaviours to indices of health in all populations. The examination of sedentary patterns and behaviours and physical activities of differing intensity using a range of assessment methodologies was also examined, while the implications of using such measures when making associations between sedentary and light intensity physical activity variables and health were also discussed. The key findings from research studies completed in this thesis, which aimed to address some of the issues raised, have been summarised as:

- The activPAL Professional Physical Activity Monitor (an inclinometer-based activity monitor) is a valid and reliable measure of physical activity intensity in an adolescent female population. As a result, its use within this population as a measure of free-living physical activity is recommended (discussed in Section 7. 2).

- Through determining a threshold for moderate to vigorous physical activity for the activPAL, we have enabled the examination of light intensity physical activity, which can distinguish between sitting time and standing time, for the first time in any population (discussed in Section 7. 3).

- In a cross-sectional examination of physical activity variables and cardio-metabolic risk factors in an adolescent female population, light intensity physical activity (quantified using an inclinometer-based activity monitor) is significantly associated with body composition in an adolescent female population, independent of moderate to vigorous physical activity (discussed in Section 7. 4).

These key findings will be discussed throughout this chapter. Additionally, important areas of future research for physical activity measurement and physical activity and health-related research will be outlined. The limitations of this thesis will be outlined, and potential methods of overcoming these limitations will be suggested. Finally, the conclusion of this thesis will be presented

7. 2. The Importance of examining all Intensities of the Activity Intensity Spectrum

A wealth of research has examined the relationships between moderate to vigorous physical activity and health in childhood, adolescence and adulthood. It is now widely accepted that increased levels of moderate to vigorous physical activity in childhood and adolescence reduce the risk of mortality from cardiovascular disease and related disorders in adulthood (Paffenbarger Jr *et al.*, 1986, Blair *et al.*, 1989b). However, it is plausible that the interaction between the entire activity profile, rather than specific activity intensities, may be the most effective method of associating habitual physical activity with indices of health (Owen *et al.*, 2000, Hamilton *et al.*, 2004, Hamilton *et al.*, 2007). It has been demonstrated that the dominant determinant of variability in total daily energy expenditure is not moderate to vigorous physical activity, but rather light intensity physical activity (Donahoo *et al.*, 2004, Levine *et al.*, 2006, Tremblay *et al.*, 2007), while evidence also suggests that there is a unique physiology of sedentary time, whereby biological processes differ from those experienced during exercise training (Hamilton *et al.*, 2001, Bey and Hamilton, 2003, Zderic and Hamilton, 2006).

7. 2. 1. Limitations of Existing Measures of Sedentary Behaviours

In order to effectively examine relationships between indices of health and physical activity, valid and reliable measures are necessary (Welk, 2005, Bassett Jr *et al.*, 2012, Freedson *et al.*, 2012). Until now, physical activity and sedentary behaviours have predominantly been examined using subjective measures such as self-report or objective measures using accelerometry. Self-report measures of physical activity and sedentary behaviours in child and adolescent populations have inherent limitations, including self-reporting bias and recall difficulty (Trost, 2007, Chinapaw *et al.*, 2010, Marshall and Ramirez, 2011). Additionally, the validity of a large proportion of self-reported sedentary measures has not been examined (Lubans *et al.*, 2011), while self-reported screen-based activities only examine one type of sedentary behaviour (TV viewing or computer use) and fail to capture the complete sedentary profile (Biddle *et al.*, 2009, Bassett Jr *et al.*, 2010, Owen *et al.*, 2010).

Objective measures of physical activity and sedentary behaviours, such as accelerometry, have demonstrated improved validity and reliability compared to self-report (Westerterp, 1999, Trost, 2001, Trost *et al.*, 2005, Warren *et al.*, 2010). However, it is critical that a measurement instrument is effective at measuring what it is intended to measure (Chinapaw *et al.*, 2010). The majority of existing accelerometers, such as the ActiGraph GT1M and GT3X (ActiGraph LCC, Pensacola, FL), examine accelerations of a body relative to free-fall, and have been identified as a valid measure of physical activity (Esliger *et al.*, 2005, Warren *et al.*, 2010). However, such devices estimate sedentary time using activity thresholds, whereby an epoch with activity counts below a predetermined threshold is quantified as sedentary time (Matthews *et al.*, 2008, Matthews *et al.*, 2012). Sedentary behaviour is now defined as energy expenditure below 1.5 METs while in a sitting or lying position during waking hours (Owen *et al.*, 2010, Marshall and Ramirez, 2011, Tremblay *et al.*, 2012). Accelerometer determined estimates of sedentary time are based on a lack of ambulation, and are unable to distinguish between sitting and lying (Hart *et al.*, 2011, Kozey-Keadle *et al.*, 2011, Marshall and Ramirez, 2011). Consequently, conclusions on the relationship between sedentary behaviours and indices of health from surrogate measures of sedentariness, such as self-reported TV viewing (Pate *et al.*, 2008, Owen *et al.*, 2010) and from measures reliant on the lack of ambulation (Kozey-Keadle *et al.*, 2011, Marshall and Ramirez, 2011, Ridgers *et al.*, 2012), must be interpreted with caution.

7. 2. 2. Inclinometer-Based Activity Monitors as a Measure of Physical Activity

Due to the limitations of self-reported and accelerometer determined sedentary time outlined above, the use of valid and reliable inclinometer-based accelerometers has been encouraged (Kozey-Keadle *et al.*, 2011, Bassett Jr *et al.*, 2012). One such device, the activPAL™ Professional Physical Activity Monitor (PAL technologies Ltd., Glasgow, UK), has been validated for the examination of sedentary time in both child (Ridgers *et al.*, 2012) and adult populations (Kozey-Keadle *et al.*, 2011). As identified above, evidence would now advocate that researchers should examine the entire activity profile, including both sedentary and ambulatory activity. Preliminary findings from Harrington and colleagues (2011 b) have identified very strong correlations between the activPAL activity count

function and energy expenditure (Harrington *et al.*, 2011b). However, until now, no study has examined the criterion and concurrent validity of the activPAL activity monitor or has completed a value calibration of the device to enable the valid and reliable examination of both physical activity and sedentary behaviours.

Due to the large amount of available literature on the use of the ActiGraph as a measure of physical activity, it may be suggested that two devices be worn to examine the full activity spectrum, with objective measures of ambulation measuring physical activity (e.g. ActiGraph) and with valid inclinometer-based devices measuring sedentary behaviour (activPAL). However, it would be expected that the increased burden of wearing two activity monitoring devices for prolonged periods would affect compliance rates. To date, only one study has simultaneously employed both the activPAL and the Actigraph as measures of habitual physical activity in a sample of children (Martin *et al.*, 2011). Results from this study identified high levels of non-compliance, with 23 out of 32 children providing at least 3 valid days of accelerometry data (which would not be classified as a stringent minimum wear protocol). Additionally, wear protocols differ significantly among both measures, whereby activPAL can be worn throughout sleep hours while ActiGraph is normally removed during sleep hours. This required collating of data from two separate devices may pose further difficulties with data processing and analysis. Meanwhile, studies which have employed activPAL only (including Chapter 6 of this thesis) have identified high levels of compliance in adolescent populations (Harrington *et al.*, 2011a). The findings presented in Chapter 3 of this thesis have now identified the activPAL as a valid estimate of energy expenditure, while the activPAL also appears to be at least as effective at examining ambulation as the ActiGraph GT3X in an adolescent female population. These findings have provided researchers with the potential to examine both sedentary time and physical activity using a single measurement device. Coupled with the high levels of compliance, this thesis supports the use of the activPAL as a measure of physical activity and sedentary behaviour in future population-based studies in adolescent females.

7. 2. 3. Limitations of the activPAL Activity Monitor

Although the activPAL has previously been identified as a valid and reliable measure of posture in child (Davies *et al.*, 2011) and adult populations (Grant *et al.*, 2006), and as a valid

measure of steps in adolescents (Harrington *et al.*, 2011b) and adults (Ryan *et al.*, 2006, Grant *et al.*, 2008) and now as a measure of physical activity (using accelerometer counts) in adolescent females (Chapter 3), it is important to consider the limitations of using an accelerometer-based device as a measure of physical activity. Similar to existing activity monitors, the activPAL is unable to examine energy expenditure from upper body activities. Devices which examine physical activity using accelerometers are also not accurate at measuring cyclic movements like bicycle riding and rowing. Consequently, such devices will underestimate levels of physical activity in individuals that participate in high levels of such activities. Furthermore, although efforts can be made to waterproof the activPAL, enabling the device to be worn during water-based activities, there is no evidence of its effectiveness at examining water-based activities such as swimming. Each of these limitations must be considered when using the activPAL activity monitor in free-living environments. It is also important for additional activPAL validation studies be completed in child, male adolescent and adult populations before the use of the devices as a measure of physical activity is encouraged in large-scale epidemiological research.

7. 3. The Examination of Light Intensity Physical Activities

As discussed in Section 2. 3, the accurate and reliable examination of light intensity physical activity is desirable, as it has been suggested that activities across the activity intensity spectrum should be considered when examining the associations between habitual activity and health (Levine *et al.*, 2006, Hamilton *et al.*, 2007, Hamilton *et al.*, 2008). Unfortunately, light intensity physical activity is potentially the most difficult activity intensity to quantify in free-living epidemiological research (Healy *et al.*, 2007). The examination of a ubiquitous behaviour such as light intensity physical activity using self-report suffers similar bias and recall limitations experienced when examining sedentary and moderate to vigorous physical activity in child and adolescent populations (Shephard, 2003, Trost, 2007, Chinapaw *et al.*, 2010, Marshall and Ramirez, 2011). Furthermore, objectively determined light intensity physical activity using accelerometer-based devices suffer the same limitations as when examining sedentary time, whereby very light intensity physical activities (below the predetermined sedentary threshold) may be determined as sedentary time, while standing activities are also often miscategorised as sedentary time (Hart *et al.*, 2011, Kozey-Keadle *et*

al., 2011). As a result, the ability to accurately determine associations between light intensity physical activity and health remain difficult.

The identification of the activPAL as a valid measure of physical activity intensities in Chapter 3 has not only enabled the examination of habitual moderate and vigorous physical activity in adolescent females, but also enabled the examination of light intensity physical activity in this population. Light intensity physical activity is characterised as activity behaviours that are not sedentary (< 1.5 METs in a sitting and lying posture) that have an energy expenditure of < 2.9 METs (Owen *et al.*, 2010). The accurate distinction between sitting time, standing time and stepping time of the activPAL allows users to accurately determine sedentary time, while the activity intensity threshold developed in Section 3. 3. 5 enable the determination of time spent in moderate to vigorous physical activity. The remaining waking behaviours can therefore be classified as standing time and light intensity physical activity. This provides a more accurate estimate of light intensity physical activity, which can then be quantified both including and excluding standing time. The resulting variable provides researchers with the opportunity to examine the effect of light intensity physical activity on indices of health in adolescent female populations. The validation of the activPAL as a measure of physical activity intensities in other groups (e.g. adults, adolescent males, children etc.) is necessary prior to the examination of free-living light intensity physical activity in these populations.

7. 4. The Associations between Subcomponents of Habitual Physical Activity and Indices of Health in an Adolescent Female Population

The primary purpose of physical activity assessment in epidemiological research is to examine exposures to specific activity behaviours, examine associations between these behaviours and indices of health and to examine whether changes in these behaviours due to intervention have a significant effect on indices of health (Freedson *et al.*, 2012). A wealth of evidence is available on the validity of examining moderate to vigorous physical activity, on the prevalence and trends of this behaviour across all populations and on the association between this behaviour and health. As described in Section 2. 9, fundamental limitations of existing measures of sedentary time and light intensity physical activity have

provided cause for concern when interpreting identified associations between these variables and indices of health. The use of valid and reliable multi-sensor activity monitors, which combine accelerometry with inclinometry, have been encouraged due to increased functionality in examining sedentary time (Esliger and Tremblay, 2007, Bassett Jr *et al.*, 2010, Kozey-Keadle *et al.*, 2011).

Chapter 5 and Chapter 6 of this thesis have examined free-living physical activity variables, including sedentary time and light intensity physical activity, using a valid and reliable inclinometer-based activity monitor (the activPAL™ Professional Physical Activity Monitor) in an adolescent female population. These chapters have examined the associations between these activity variables and cardio-metabolic risk factors, independent of moderate to vigorous physical activity. This type of analysis is critical when determining the associations between activity intensities at the lower end of the continuum and cardio-metabolic risk factors, as moderate to vigorous physical activity is an independent predictor of cardio-metabolic risk factors (Ekelund *et al.*, 2006).

7. 4. 1. Sedentary Time and Cardio-Metabolic Risk Factors

The overall findings of Chapter 5 and Chapter 6 suggest that sedentary time is not associated with the majority of cardio-metabolic risk factors in adolescent females. However, Chapter 5 does highlight that the most sedentary adolescent females are significantly more likely to have higher levels of adiposity than their least sedentary counterparts. These results are in contrast with previous observations. Carson and Janssen (2011) identified no associations between accelerometer determined sedentary time and cardio-metabolic risk factors, independent of moderate to vigorous physical activity (Carson and Janssen, 2011). As discussed in Chapter 5 a potential cause for this may have been the use of additional confounders during statistical analysis. Another potential cause for observed differences may be the disparity in participant numbers between the two studies (n = 194 Vs. n = 2527). However, the different methods of examining sedentary time must also be considered as a potential cause for the contrasting results, as the device employed by Carson and Janssen (2011) was unable to distinguish between sitting and standing (Kozey-Keadle *et al.*, 2011) and has been shown to overestimate sedentary time (Hart *et al.*, 2011). Additionally, in Chapter 6, associations that approached significance

were also observed between sedentary time and carotid intima-media thickness, which is a high powered measure of arterial health. Although the association was clearly non-significant, it is plausible that the small sample size included in this analysis may be the cause of this "almost" association. These findings are by no means conclusive of the association between sedentary time and indices of health in adolescent female populations. However, they do suggest that this is a worthy area of further research. Further large-scale examinations of adolescent female populations which 1) employ inclinometer-based activity monitors, 2) examine a wide range of high powered health measures and 3) collect information on a broader range of covariates (i.e. smoking status, socio-economic status and dietary information) are required to further examine these associations.

7. 4. 2. Light Intensity Physical Activity and Cardio-Metabolic Risk Factors

Chapter 5 and Chapter 6 provide consistent evidence on the positive associations between light intensity physical activity and indices of health in adolescent females. These chapters have both identified significant associations between adiposity and light intensity physical activity in an adolescent female population, independent of moderate to vigorous physical activity. This association is of great importance, as this is the first examination of light intensity physical activity using an assessment method which can distinguish between sitting time, standing time and stepping time. Although associations between objectively measured light intensity physical activity and 2-hr plasma glucose have been identified in an adult population (Healy *et al.*, 2007), these examinations have not distinguished between sitting time, standing time and stepping time. The use of devices that do not detect sitting time, and do not distinguish between sitting and standing, tend to significantly overestimate sedentary time and light intensity physical activity (Hart *et al.*, 2011). To determine whether these associations are evident in adult populations, further large-scale epidemiological studies, which employ a more accurate and effective inclinometer-based activity monitor are necessary. Additionally, further research studies of a larger scale with a greater range of measures are required in both adolescent females and males to provide more support to the associations identified in this thesis.

7. 5. Potential Translation of Research Findings

The findings presented in this research thesis have significant implications to the health of the general population. For the first time, associations have been observed between objectively assessed light intensity physical activity and sedentary behaviours and indices of health. As highlighted in section 7. 4, light intensity physical activity has a negative association with adiposity, while sedentary time is positively associated with adiposity in this sample of adolescent females. The implications of these findings have the potential to inform future national and international physical activity recommendations. The existing physical activity recommendations, which promote increasing participation in moderate to vigorous physical activity, is based on 5 decades of research, and its continued promotion is essential in the area of physical activity and health. However, the inclusion of an additional recommendation that advocates increasing the amount of time spent in light intensity physical activity at the expense of the amount of time spent in sedentary behaviours may be appropriate. Changes in light intensity physical activity behaviour may be a more achievable than changes in moderate to vigorous physical activity. Consequently, the inclusion of this additional recommendation may be perceived as a more realistic and inviting initiative to the most inactive of our populations.

7. 6. Limitations

- According to best practice and research recommendations for the validation and value calibration of activity monitoring devices, the use of a broad, representative population is necessary. Unfortunately, our validation of the activPAL only included female adolescents between the ages of 15 and 18 years. For this validation study, the use of a broader population, which included females between the age of 13 and 15 and male participants of the same age range, would have made the results of the study more generalisable. Additionally, the activities included in the validation could have included more free-living activities, including household chores, stair ascending/descending and game based activities (e.g. basketball etc.).

- As is the case with all existing devices that measure physical activity using accelerometers, the activPAL was unable to identify non-wear time. As a result, non-wear protocols followed the methodologies employed with other activity monitors (e.g. ActiGraph), whereby 60 minutes of consecutive zero counts were identified as non-wear time. Resulting non-wear time was then deleted. The accuracy of this methodology has not been investigated in the activPAL, and further examination and analysis is required to determine the validity of such estimates of non-wear time in all populations.

- The limitations of the activPAL have already been described in Section 7. 2. 3. However, it is important to reemphasise the inability of this device to examine upper body activities (strength training, carrying loads etc.), water based activity (swimming) and lower body activities which involve a cyclic motion (cycling, rowing). The inability of devices to examine such activities may result in the underestimation of physical activity and energy expenditure, particularly in individuals that perform large amounts of the described activities. The use of an activity log, which encouraged participants to record when they were involved in particular activities may reduce the effect of this limitation. Additionally, the introduction of a physiological variable such as heart rate or heat flux sensor would also eliminate the underestimation of physical activity or energy expenditure when using an accelerometer-based device.

- The small sample size used in Chapter 6 must be acknowledged as a limitation of this work. Due to a relatively low volunteer rate, coupled with absentees on test days, the sample size was reduced to a total of 64 participants. A larger, more representative sample is required to make more statistically powerful associations between activity variables and cardio-metabolic risk factors in an adolescent female population. The results of Chapter 6 should be viewed as pilot work for larger studies, which encourage the further investigation of the effects of sedentary behaviours and physical activity on health in large-scale epidemiological studies.

- The non-examination of additional variables that are significant predictors of non-communicable diseases, including smoking, dietary information and parental health is a significant limitation when examining the associations of activity variables and indices of health, particularly cardio-metabolic biomarkers. Through adjusting for

additional covariates, a more powerful analysis of the associations between different activity variables and health measures is possible.

7. 7. Future Research

The results of this thesis have addressed some important research questions outlined by Owen and colleagues (2010), including 1) the identification of a valid measure of sedentary time and physical activity, 2) the development of methodologies to examine the output from this measure, 3) the identification of the type and intensity of activity that is most protective against sedentary time and 4) the examination of relationships between the observed activity variables and indices of health in a specific population (Owen *et al.*, 2010). However, it is important to acknowledge that there remain many important research questions relating to the sedentary behaviour paradigm that must be addressed. Some of the most pressing of these include:

- The validation of the activPAL (or alternative inclinometer-based activity monitor) as a measure of physical activity in broader populations (e.g. represent different ages, gender and ethnicities). This validation work is necessary before the activPAL can be considered a potential measure of free-living activity in epidemiological research.

- The development of valid and reliable methodologies to determine non-wear time is critical to the future use of the activPAL and all other activity monitoring devices. Without such developments, researchers may continue to under/overestimate specific activity variables, particularly sedentary time, standing time and light intensity physical activity.

- The further examination of associations between sedentary time, standing time, light intensity physical activity and moderate to vigorous intensity physical activity and indices of health in populations of all ages, sexes and ethnicities using inclinometer-based devices is essential. This information will strengthen existing sedentary behaviour/disease findings.

- The development and implementation of longitudinal studies, which will examine the stability of activity variables from childhood and adolescence through to adulthood, are critical. Such studies will provide changes in patterns and trends of activity variables over time, while also highlighting how changes in these patterns and trends affect health over time. In particular, the tracking of variables that have not previously been directly examined, including sedentary time, standing time and light intensity physical activity would be particularly informative.

- The quantification of the relative risk associated with different activity variables is of great public health importance (e.g. does the amount of time spent sedentary have the same importance to health as the amount of time spent in moderate to vigorous physical activity, or how much relative weight does sedentary time have compared to moderate to vigorous physical activity). Such examinations will inform whether 1) additional sedentary and light intensity physical activity recommendations should be included in future public health guidelines and 2) what these sedentary and light intensity physical activity guidelines should include.

- The valid and reliable identification of the determinants of sedentary behaviour is critical for the future of sedentary behaviour research. Such examinations are critical in determining why sedentariness varies between individuals and why sedentariness increases or decreases at specific time points throughout the lifespan. Already, researchers are implementing interventions which aim to reduce sedentary time, while little information is available on the determinants of sedentary behaviours. Over the coming years, a plethora of research will aim to reduce sedentary time through increased light, moderate or vigorous intensity physical activity. The early identification of such determinants will inform future sedentary intervention studies.

- The examination of the effectiveness of a range of different sedentary interventions in representative populations for age, sex and ethnicity are necessary. These interventions will seek to reduce sedentary behaviour through increased standing time, light intensity physical activity or moderate to vigorous physical activity, and will provide further insight into the causation and treatment of risk factors associated with physical activity, physical inactivity and sedentary patterns and

behaviours. It is essential that such intervention studies are informed by solid, strong scientific information.

7. 8. Conclusion

This Ph.D. thesis has identified the activPAL™ Professional Physical Activity Monitor as a valid and reliable measure of physical activity in an adolescent female population, and has recommended its use in the examination of free-living physical activity and sedentary behaviour within this population. For the first time, the associations between subcomponents of physical activity, including sedentary time, standing time and light intensity physical activity, have been determined using an inclinometer-based activity monitor. Additionally, for the first time, the quantified values of sedentary time, standing time and light intensity physical activity (both including and excluding standing time) have been associated with indices of health. The findings of this thesis suggest that light intensity physical activity guards against sedentary time to a greater extent than moderate to vigorous physical activity. Furthermore, light intensity physical activity (that does not include standing time) is significantly associated to adiposity and carotid intima media thickness, while limited associations are evident between sedentary patterns or behaviours and cardio-metabolic risk factors in an adolescent female population. The results of this thesis encourage the reduction of sedentary time through increased participation in light intensity physical activity as a potential method to improve cardio-metabolic risk factors in an adolescent female population.

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Appendices

Prof. Alan Donnelly,

PESS Dept.,

University of Limerick,

Castletroy,

Co. Limerick.

Dear Committee,

I am writing to you today on behalf of our research team in the University of Limerick. We are in the final stages of preparation for a physical activity research project. The project title is *"Predicting Energy Expenditure from activPAL accelerometry counts in Adolescent Females"*. We are enquiring about whether members of your group, the No Name Club, may be interested in participating in the research.

The aim of this study is to develop an accelerometer threshold for adolescent females that can be used to examine energy expenditure and physical activity in free-living activities.

It is expected that a total of 40 female adolescents in will participate in this study. We would hope that approximately 30 of your members would participate, with the remainder of participants from a school in the Limerick region. I have attached a project plan of this study which will explain the full involvement required of your members.

I would ask if you could read the attached information sheet. If you have any questions regarding this research study, please feel free to contact my Ph.D. research student, who is in charge of study planning and preparation, Mr. Kieran Dowd on (061) 234715 or via email at <u>kieran.dowd@ul.ie</u>. Mr. Kieran Dowd will contact you within the next couple of days to arrange a meeting, where you can discuss and examine the advantages and disadvantages of this research project. We have also attached a consent form, in case you do not require a meeting and are happy to consent to participation of your school.

Yours sincerely,

_____

Prof. Alan Donnelly

PESS Dept.,

University of Limerick,

Castletroy,

Co. Limerick.

UNIVERSITY *of* LIMERICK

O L L S C O I L   L U I M N I G H

Committee Information Sheet

Study Title: Predicting Energy Expenditure from activPAL accelerometry counts in Adolescent Females.

Background:

Physical activity has been shown to positively affect a person's current and future health. Currently, all studies that have measured physical activity levels in Ireland have used questionnaires and diaries. These methods of assessing physical activity have limitations, particularly with accuracy. When examining physical activity, it is important to use valid and accurate measures. Currently the most frequently employed measure of physical activity is accelerometers. This study aims to validate a new accelerometer, the activPAL, in female adolescents and to investigate if it is an accurate measure of predicted energy expenditure.

What is required of you, the committee: As adult committee members, we ask for your consent to carry out the proposed research with your members. We ask you to volunteer a member of the committee to be our contact point throughout the research. This will simply involve contacting this person to arrange meetings with the host/hostesses. After this, the only other request we ask is one of support while completing the study.

Participant Selection: We hope to select participants from your members with the help of your host and hostesses. They will be asked to contact members of the club, and to recruit the members to participate in the study.

Parental/Participant consent: We will meet with the selected students at the earliest possible time. We will discuss the study outline, and explain what is involved in the study. We will then provide the students with informed parental and participant consent forms, which are required prior to the study beginning. We will then ask the students to consider participating in the study, and to complete the required forms and return them to the hosts and hostesses of the no name club.

Testing:

All testing will take place in an appropriately sized space (yet to be confirmed) at times that are suitable with all participants. The first type of testing the girls will take part in a simple physiological test of height and weight. This will take place in a private space, and all measurements obtained will be private and confidential. At <u>no time</u> will the information be available to anyone else, <u>except the researcher's names on this document</u>. At no time will the participants be on their own with any researcher, and all efforts will be made to make them as comfortable as possible.

- **Height and Weight:** Height and weight will be measured in stocking feet, light shorts and t-shirt. This information will be used to calculate BMI (Body Mass Index).

The members will be given a heart rate monitor for the main testing. This is simply a watch on the wrist, which picks up a signal from a strap fitted around the chest. Participants will be given a picture of where to place the heart rate monitor, and will fit the monitor behind a private screen. They will also be asked to wear an activPAL accelerometer. This is attached to the midline of the thigh, halfway between the knee and hip, using a *PAL stickie*.

The students will wear a Cosmed Mobile metabolic unit, which records both inspired gas (breathed in gas) and expired gas (breathed out gas). This allows us to collect and analyse the different levels of oxygen and carbon dioxide that is used during specific activities. It is a very light device, which is worn on the back and chest. It is attached to a mask, which is placed over the face, to ensure all gases are measured. A picture of the device in use is provided below.
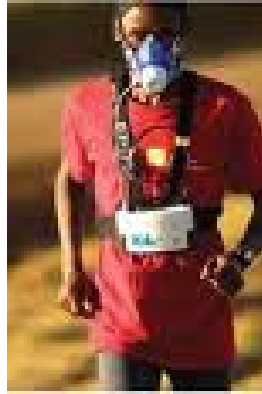
For the main test, the students will be asked to take part in a number of tasks. These will include lying down, sitting down, standing upright, walking and running. The students will complete each of these tasks for between 5 and 10 minutes. They will also be provided with a rest period between each activity. The students will be free to stop the testing whenever they wish.

Benefits of this research: Your members will not be informed directly of the overall results of this research study. However, it is hoped that the results of this study will give us a greater understanding of the uses and accuracy of the activPAL physical activity monitor in a female population. The participants will learn about some of the research methodologies used in a University setting, and may learn some beneficial information about the importance of physical activity for health in adolescents.

What are the risks?

The EHS Research Ethics Committee has assessed all risks associated with each testing procedure. As with all forms of exercise, there is a slight risk of injury to participants. This includes, but is not restricted to, strains, sprains and overuse injuries. To reduce these risks, your members will have a warm up and cool down.

What if the members do not want to take part or change their mind during the study?

We will be delighted with your members taking part in the study. However if they do not wish to take part it is entirely up to them. They can withdraw from the study at any time and we will thank them for their time.

What happens to the information?

The information is completely confidential and will only be used for the purpose of this project. Only the people involved in this project will have access to the results of the testing. Once the project is complete, all personal information will be destroyed. Remaining data will be retained for the recommended period of 7-10 years.

Who else is taking part?

It is hoped that 39 other females in the 15-18 age bracket will be involved in this study.

What if something goes wrong?

In the event of an accident or an emergency, the investigator will follow standard no name club protocol in place to deal with such incidents. The researcher will be informed of all accident and emergency protocol in place for the no name club before the study begins.

Who can I contact for additional information?

If you would like to know more about this study, please do not hesitate to contact any of the investigators listed below.

Name	Title	Contact No.	E-mail
Mr. Kieran Dowd	Postgraduate Student	087-91XXXX	kieran.dowd@ul.ie
Prof. Alan Donnelly	Professor	061-20XXX	alan.donnelly@ul.ie

Also if you have concerns about this study and wish to contact someone independent, you may contact:

Chairman Education and Health Sciences Research Ethics Committee

EHS Faculty Office

University of Limerick

Tel (061) 23XXXX

Email: ehsresearchethics@ul.ie

UNIVERSITY *of* LIMERICK

O L L S C O I L   L U I M N I G H

Committee Consent

We have read and understand the committee information sheet and have had due time to consider it. We now fully understand what this project: *Predicting Energy Expenditure from activPAL accelerometry counts in Adolescent Females* is all about and what the data will be used for. We are fully aware of the procedures that are involved in this project. We are aware that the members of our organisation can pull out of this project at any time, and that their participation is completely voluntary. The members do not have to give any reasons as to why they wish to leave the study if they so choose to. We are aware that the student's results will be completely confidential. We agree to allow the research team to select their sample population from our members.

I_____ understand all that is involved in this study. I hereby agree to our members taking part in this research project.

Signed: _____

Witness: _____

Date: ____/__/____

UNIVERSITY *of* LIMERICK

OLLSCOIL LUIMNIGH

Parent/Carer Information Sheet

Study Title: Predicting Energy Expenditure from activPAL accelerometry counts in Adolescent Females.

What is this study about?

Physical activity has been shown to positively affect a person's current and future health. Currently, all studies that have measured physical activity levels in Ireland have used questionnaires and diaries. These methods of assessing physical activity have limitations, particularly with accuracy. When examining physical activity, it is important to use accurate measures. Currently the most frequently employed measure of physical activity is accelerometry. This study aims to validate a new accelerometer, the activPAL, in female adolescents and to investigate if it is an accurate measure of predicted energy expenditure.

What will my daughter have to do?

Your daughter will be asked to come to the testing venue in Claremorris (yet to be confirmed). She will be asked to bring with her a pair of light shorts, a t-shirt and gel soled runners as opposed to flat soled runners.

Test Day: On arrival at the testing centre, your daughter will be asked to change into the exercise clothing that she will have brought with her. The first type of testing she will take part in is the height and weight measurement. All measurements obtained will be private and confidential, and at <u>no time</u> will information be available to anyone, <u>except the researcher's named on the last page of this document</u>. Height and weight will be measured

in stocking feet, light shorts and t-shirt by the researcher and this will be used to calculate BMI (Body Mass Index).

Your daughter will then be given a Polar heart rate monitor for the main testing. This is simply a watch to be worn on the wrist, which picks up a signal from a strap fitted around the chest. Your daughter will also be asked to wear an activPAL accelerometer. This is attached to the midline of the thigh, halfway between the knee and hip. Finally, your daughter will wear a Cosmed *Mobile* ergospirometry system. This is a device which records inspired (breathed in gas) and expired gas (breathed out gas). This allows us to collect and analyse the different levels of oxygen and carbon dioxide that your daughter uses during specific activities. It is a very light device, which is worn on the shoulder and back. It is attached to a mask, which is placed over the nose and mouth, to ensure all gases are measured (pictured below).

For the main test, your daughter will be asked to take part in a number of tasks. These will include lying down, sitting down, standing upright, walking and a light jog. Your daughter will complete each of these tasks for between 5 and 12 minutes each. A rest period will be provided between each activity.

What are the benefits of this Project?

Your daughter will not be informed directly of the overall results of this research study. However, it is hoped that the results of this study will give us a greater understating of the uses and accuracy of the activPAL physical activity monitor in a female population. Your daughter may obtain some interesting information regarding physical activity and health.

She may also ask the researcher any questions about the research and physical activity, which will be answered to the best of the researcher's capabilities.

What are the risks to my daughter for this study?

The Education and Health Sciences Research Ethics Committee has assessed all risks associated with each testing procedure. As with all forms of exercise there is a risk of injury to participants. This includes, but is not restricted to, strains, sprains and overuse injuries. To reduce these risks you will have a warm up and cool down.

What if my daughter does not want to take part or changes her mind?

We will be delighted with your daughter taking part in the study. However if she does not wish to take part it is entirely up to her. Your daughter can withdraw from the study at any time and we will thank her for her time and help.

What happens to the information obtained?

The information is completely confidential and will only be used for the purpose of this project. Only the people involved in this project will have access to the questionnaires and results of the testing. Once the project is complete, all personal information will be destroyed. Remaining data will be retained for the recommended period of 7-10 years.

Who else is taking part?

It is hoped that 39 other females in the 15-18 age bracket will participate in this study.

What if something goes wrong?

In the event of an accident or an emergency, the investigator will follow standard no name club protocol in place to deal with such incidents. The researcher will be informed of all accident and emergency protocol in place for the no name club before the study begins.

Appendix A: Information Sheet and Consent forms: Study 1

Who can I contact for additional information?

If you would like to know more about this study, please do not hesitate to contact any of the investigators listed below.

Name	Title	Contact No.	E-mail
Mr. Kieran Dowd	Postgraduate Student	087-91XXXX	kieran.dowd@ul.ie
Prof. Alan Donnelly	Professor	061-20XXXX	alan.donnelly@ul.ie

Also if you have concerns about this study and wish to contact someone independent, you may contact:

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Chairman Education and Health Sciences Research Ethics Committee

EHS Faculty Office

University of Limerick

Tel (061) 23XXXX

Email: ehsresearchethics@ul.ie

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UNIVERSITY *of* LIMERICK

OLLSCOIL LUIMNIGH

Parent/Carer Informed Consent Form

I have read and understand the Parent/Carer information sheet and have had due time to consider it. I now fully understand the purposes of the project: *Predicting Energy Expenditure from activPAL™ accelerometry counts in Adolescent Females* and what the data will be used for. I am fully aware of the procedures that will involve my child, and I am aware that she can withdraw from this project at any time, and that her participation is completely voluntary. She will not have to give any reasons as to why she leaves the study if she so chooses to. I am aware that her results will be completely confidential.

I _____, understand all that is involved in this study. I hereby agree to take part in this research project.

Signed: _____

Date: _____

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OLLSCOIL LUIMNIGH

Participant Information Sheet

Study Title: Predicting Energy Expenditure from activPAL^{TM} accelerometry counts in Adolescent Females

What is this study about?

Physical activity has been shown to positively affect a person's current and future health. Currently, all studies that have measured physical activity levels in Ireland have used questionnaires and diaries. These methods of assessing physical activity have limitations, particularly with accuracy. When examining physical activity, it is important to use accurate measures. Currently the most frequently employed measure of physical activity is accelerometers. This study aims to examine a new accelerometer, the activPAL in female adolescents and to investigate if it is an accurate measure of predicted energy expenditure.

What will I have to do?

You are asked to come to the testing venue in Claremorris (yet to be confirmed). You are also asked to bring with you a pair of light shorts, a t-shirt and gel soled runners as opposed to flat soled runners. You will be asked to sign an informed consent form. Your parent/guardian will also be asked to sign a consent form, before you will be allowed to participate.

Test Day: On arrival at the testing area, you will be asked to change into the exercise clothing that you have brought with you. The first type of testing you will take part in is the measurement of height and weight. All measurements obtained will be private and confidential, and at <u>no time</u> will your information be available to anyone, <u>except the</u>

<u>researcher's</u> names on this document. At no time will you be on your own with the researcher, and all efforts will be made to make you as comfortable as possible. Height and weight will be measured in stocking feet, light shorts and t-shirt by the researcher and this will be used to calculate BMI (Body Mass Index).

You will then be given a heart rate monitor for the main testing. This is simply a watch on your wrist which picks up a signal from a strap fitted around your chest. Your will be shown how to attach the monitor using a diagram. You will also be asked to wear an activPAL accelerometer. This is attached to the midline of your thigh, halfway between your knee and hip, using a *PAL stickie.*

You will also wear a *Cosmed Mobile **ergospirometry** system.* This is a device which records the inspired gas (breathed in gas) and expired gas (breathed out gas). This allows us to collect and analyse the different levels of oxygen and carbon dioxide that you use during specific activities. It is a very light device, which is worn on the chest and back. It is attached to a mask, which is placed over the face, to ensure all gases are measured. A picture of the device in use is provided below.

For the main test you will be asked to take part in a number of tasks. These will include lying down, sitting down, standing upright, walking and a light jog. You will complete each of these tasks for between 5 and 10 minutes each. You will also be provided with a rest period between each activity. You will be free to stop the testing whenever you want if you feel too tired, feel unwell or if you get very out of breath.

What are the Benefits of this Project?

You will not be informed directly of the overall results of this research study. However, it is hoped that the results of this study will give us a greater understating of the uses and accuracy of the activPAL physical activity monitor in a female population. You may learn some valuable information about physical activity, or perhaps you may have questions

about physical activity that the researcher may be able to answer. You will also learn about how some things are measured like body composition, energy expenditure or activity.

What are the risks?

The EHS Research Ethics Committee has assessed all risks associated with each testing procedure. As with all forms of exercise there is a slight risk of injury to participants. This includes, but is not restricted to, strains, sprains and overuse injuries. To reduce these risks you will have a warm up and cool down.

What if I do not want to take part or change my mind during the study?

We will be delighted with you taking part in the study. However if you do not wish to take part it is entirely up to you. You can withdraw from the study at any time and we will thank you for your time and help.

What happens to the information?

The information is completely confidential and will only be used for the purpose of this project. Only the people involved in this project will have access to the questionnaires and results of the testing. Once the project is complete, all personal information will be destroyed. Remaining data will be retained for the recommended period of 7-10 years.

Who else is taking part?

It is hoped that 39 other females in the 15-18 age will be involved in this study.

What if something goes wrong?

In the event of an accident or an emergency, the investigator will follow standard no name club protocol in place to deal with such incidents. The researcher will be informed of all accident and emergency protocol in place for the no name club before the study begins.

Appendix A: Information Sheet and Consent forms: Study 1

Who can I contact for additional information?

If you would like to know more about this study, please do not hesitate to contact any of the investigators listed below.

Name	Title	Contact No.	E-mail
Mr. Kieran Dowd	Postgraduate Student	087-91XXXX	kieran.dowd@ul.ie
Prof. Alan Donnelly	Professor	061-20 XXXX	alan.donnelly@ul.ie

Also if you have concerns about this study and wish to contact someone independent, you may contact:

Chairman Education and Health Sciences Research Ethics Committee

EHS Faculty Office

University of Limerick

Tel (061) 23XXXX

Email: ehsresearchethics@ul.ie

UNIVERSITY *of* LIMERICK

O L L S C O I L   L U I M N I G H

Participant Informed Consent Form

I have read and understand the subject information sheet and have had due time to consider it. I now fully understand what this project: *Predicting Energy Expenditure from activPAL accelerometry counts in Adolescent Females* is all about and what the data will be used for. I am fully aware of the procedures that are involved in this project. I am aware that I can pull out of this project at any time, and that my participation is completely voluntary. I do not have to give any reasons as to why I leave the study if I so choose to. I am aware that my results will be completely confidential.

I_____, understand all that is involved in this study. I hereby agree to take part in this research project.

Signed: _____

Date: _____

WITNESS SINATURE:

Signed: _____

Date: _____

UNIVERSITY *of* LIMERICK

O L L S C O I L   L U I M N I G H

Principal [Name],

[Address]

Dear Principal,

I am making contact with you to discuss the possibility of administering a research study in your Secondary School. A key area of research interest in the Department of Physical Education and Sport Sciences at the University of Limerick is physical activity levels of female adolescents. Regular physical activity during childhood and adolescence is associated with improvements in numerous physiological and psychological variables such as reducing risk of obesity, cardiovascular disease, non-insulin-dependant diabetes, osteoporosis, certain cancer and depression. Regular Physical Activity is characterised by taking part in moderate intensity activity for 30 minutes a day 5 times a week but despite recommendations for adequate Physical Activity, data indicates that youths become less physically active between puberty and age 18 .

The purpose of the proposed research is to investigate daily Physical Activity levels of adolescent females in Limerick using accelerometry, and comparing the results with prescribed levels of Physical Activity and with a questionnaire .The study also aims to use anthropometric measurements, along with a 20 meter endurance shuttle run test (bleep test) to compare levels of Physical Activity with physiological fitness and body composition.

The purposes of the proposed study are 1) to establish the Physical Activity rates of 15-17 year old adolescent females using accelerometry and a questionnaire; 2) to examine the weight profiles of students, their blood pressure and their cardiovascular fitness and 3) to examine the interrelationships that exist among the measured variables.

Appendix B: Information Sheet and Consent form: Study 2

The study will be of great benefit to those who participate as it will:

- Provide information on the importance of being physically active,
- Educate participants on physiological measures for body composition
- Inform participants on their weight profiles and cardiovascular fitness.

Another benefit of participating in the study is, upon their full completion of the study, each participant will receive a 20% discount for Lifestyle Sports shops in Limerick. This discount provides a more attractive incentive for participants to complete all aspects of the study.

A random sample of 12-15 students from your school is required. If you agree to participate in the study, a list of all children who fit the inclusion criteria will be required, and from this list, participants will be selected. Participation in the study will be subject to the consent of parents and participants. The study will last for 1 week in your school, and the students will only be asked to miss 4 classes, none of which can be their Physical Education class. (1 double class on the first visit, which must take place in the gym, and 2 further single classes on two separate visits).

Deirdre Harrington, BSc in Sport and Exercise Sciences and Kieran Dowd, BSc in Physical Education, both Ph.D. students in the University of Limerick, will assist in administering the study. They will require some assistance from a class teacher in the administration of the study. Additionally, I will closely monitor the study. If you require more in-depth information about the study and the procedures I would be happy to speak with you or forward you on this information.

This study promises to be of great benefit for the participants. I will be in touch with you shortly to enquire whether you are interested in your schools involvement in this study. Should you agree to your schools participation, or if you have any queries, please contact me via the telephone, fax or e-mail information listed at the bottom of this letter. Thank you very much for taking the time to read this information, and I hope to speak to you soon.

Yours sincerely,

_____

Prof. Alan Donnelly

PESS Department

University of Limerick

Phone: 061-20 XXXX   E-mail: Alan.Donnelly@ul.ie   Fax: + 353 61 20 XXXX

UNIVERSITY *of* LIMERICK

OLLSCOIL LUIMNIGH

Parental Information Sheet

Study Title: The Limerick Physical Activity and Fitness Study of Adolescent Girls

What is the project about?

Regular physical activity during childhood and adolescents is associated with improvements in many physical and psychological health benefits, such as reducing risk of obesity, cardiovascular disease, non-insulin-dependant diabetes, osteoporosis, certain cancers and depression. Regular physical activity is charachterised by taking part in moderate intensity activity for 30 minutes a day 5 times a week. Although these target appear very achieveable, studies show that many Irish adolescents, particularly females, fall short of the prescribed amount of physical activity to maintain a healthy lifestyle.

This study aims to assess participation levels in physical activity in a broad group of female adolescents in the Limerick area. The study will examine these participation levels, and will compare results with prescribed physical activity levels and with other Irish studies findings.

What will your child have to do?

The first set of tests will be physiological testing. These will take place in an appropriately private space with another female observer present at all times to ensure the safety and protection of both the participants and researchers involved.

- Height and weight will be measured in stocking feet, light shorts and t-shirt by a female researcher to calculate BMI (Body Mass Index).
- Measurement of the waist and hip of your daughter will then be taken.

- Skinfolds at four sites will be measured. These are mid-bicep (front of upper arm), mid-triceps (back of the upper arm), sub-scapular (under the shoulder blade) and the iliac crest (side of the body, near the hip bone). All measurements will be taken using a skinfold calliper, and will be performed by an experienced female researcher.

Blood pressure will be measured using a standard procedure. The appropriately sized cuff will be placed around the upper arm and inflated automatically and both systolic and diastolic blood pressures will be recorded.

A 20 meter shuttle run test (Bleep test) will be administered. This is a submaximal test which will involve your daughter running back and forth over a 20 meter distance at specific paces for as long as they can. Your daughter will have the option of dropping out of this test whenever they feel they cannot go any further.

- Physical Activity Levels will be monitored using accelerometry, and is carried out using an accelerometer called an activPAL. The activPAL is a tiny, lightweight box that measures the amount and direction of all the activity that one does. It can tell how long one spends sitting, standing, lying and stepping, and how fast one walks/jogs/runs. The accelerometer is worn on the mid part of the front of the right thigh, and is held onto the skin with a hypoallergenic *stickie*. This *stickie* is both hair and skin friendly. This form of testing is neither invasive, nor will it impede your daughters everyday life. The activPAL only needs to be removed before bathing and any water based activities. The activPAL will be worn for 7 days so we can get any overall picture of her physical activity patterns. Each participant is free to not wear the accelerometer if they feel uncomfortable in any way and can return it before the 7 days are up. This will not affect their future treatment or participation.

- On return of the accelerometers, your daughter will complete a Physical Activity questionnaire. This questionnaire will inform us of your daughters **perceived** activity rates during the same week in which they wore the accelerometer.

What are the benefits to your child?

Your daughter will receive a copy of her results, which can inform them of their body composition and cardiovascular fitness. You or your daughter will not be directly informed of the results of this research study. However, it is hoped that the results of this research

will inform us of the physical activity levels and physical fitness levels of a broad, random group of female adolescent girls in the Limerick region. Your daughter will also receive a letter, which provides her with a **_20% discount_** off purchases at any Limerick based **_Lifestyle Sports_** shop, once the activPAL accelerometer has been returned and all questionnaires and physiological tests have been complete.

What are the risks?

The UL research Ethics Committee has assessed all risks associated with each testing procedure. All researchers will be appropriately qualified for all testing in the study.

What if my child does not want to take part?

We are very appreciative of everyone's time, including your time in reading this consent form. However if your child does not wish to take part in the study, it is entirely their decision. They may withdraw from the study at any time and we will thank them for their time and help.

Who else is taking part in this Research Project?

It is hoped that 15 other participants from your child's school will take part in this study, and 90 other participants from other schools around Limerick will also be tested.

What happens to the information that is gathered?

The information is completely confidential and will only be used for the purpose of this project. Only the people involved in this project will have access to the questionnaires and results of the testing. Once the project is complete, all personal information will be destroyed. Remaining data will be retained for the recommended period of 7-10 years.

Appendix B: Information Sheet and Consent form: Study 2

Who can I contact for additional information?

If you would like to know more about this study, please do not hesitate to contact any of the investigators listed below.

Name	Title	Contact No.	E-mail
Ms. Deirdre Harrington	Postgraduate Student	086-319XXXX	deirdre.harrington@ul.ie
Mr. Kieran Dowd	Postgraduate Student	087-91XXXX	kieran.dowd@ul.ie
Prof. Alan Donnelly	Senior Lecturer	061-20XXXX	alan.donnelly@ul.ie

Also if you have concerns about this study and wish to contact someone independent, you may contact:

The Chairman of the University of Limerick Research Ethics Committee.

C/o Vice President Academic and Registrar's Office

University of Limerick

Limerick

Tel: (061) 20XXXX

UNIVERSITY *of* LIMERICK

OLLSCOIL LUIMNIGH

Parental Consent Form

I have read and understand the parental information sheet and have had due time to consider it. I now fully understand the purposes of the project: *The Limerick Physical Activity and Fitness Study of Adolescent Girls,* and what the data will be used for. I am fully aware of the procedures that will involve my child, and I am aware that she can withdraw from this project at any time, and that her participation is completely voluntary. She will not have to give any reasons as to why she leaves the study if she so chooses to. I am aware that her results will be completely confidential.

I _____, understand all that is involved in this study. I hereby agree to allow my child to take part in this research project.

Signed: _____

Relationship with the participant: _____

Date: _____

UNIVERSITY *of* LIMERICK

OLLSCOIL LUIMNIGH

Participant Information Sheet

Study Title: The Limerick Physical Activity and Fitness Study of Adolescent Girls

What is the project about? Regular physical activity during childhood and adolescents is associated with improvements in many physical and psychological health benefits, such as reducing risk of obesity, cardiovascular disease, non-insulin-dependant diabetes, osteoporosis, colon cancer and depression. Regular physical activity is charachterised by taking part in moderate intensity activity for 30 minutes a day 5 times a week. This study aims to assess participation levels in physical activity in a broad group of female adolescents in the Limerick area. The study will examine these participation levels, and will compare results with prescribed physical activity levels and with other Irish studies findings.

What will you have to do? The first type of testing you will take part in is the physiological testing. This will take place in a private space with a female tester and another female observer will be present at all times. At no point will you be on your own with the people carrying out the tests.

- Height and weight will be measured in stocking feet, light shorts and t-shirt by the female researcher and this will be used to calculate BMI (Body Mass Index).
- Measurement of your waist and hip will then be taken.
- 4 site skinfold test will be administered. The four sites measured are mid-bicep (front of upper arm), mid-triceps (back of the upper arm), sub-scapular (under the shoulder blade) and the iliac crest (side of the body, near the hip bone). All

measurements will be taken using a skinfold calliper, and will be performed by an experienced female researcher.

- Blood pressure will be measured using a standard procedure. The appropriately sized cuff will be placed around the upper arm and inflated automatically. The pressure will be slowly reduced, and both systolic and diastolic blood pressures will be recorded.

- You will participate in a 20 meter shuttle run test (Bleep test). This is a standardised test to measure cardio respiratory fitness in large groups. This is a submaximal test which involves running back and forth a 20 meter distance at specific paces for as long as you can (Many P.E teachers use this as a test in schools, and you may have already completed a bleep test in your current school). You will have the option of dropping out of this test whenever you feel that you cannot go any further..

- Physical Activity levels will be calculated for a week using accelerometry, and is carried out using an accelerometer called an activPAL. The activPAL is a tiny, lightweight box that measures the amount and direction of all the activity that one does. It can tell how long one spends sitting, standing, lying and walking, and how fast one walks. The accelerometer is worn on the mid part of the front of the right thigh, and is held onto the skin with a hypoallergenic stickie. <u>This stickie is both hair and skin friendly</u>. This form of testing is neither invasive, nor will it impede your everyday life. The activPAL only needs to be removed before bathing and any water based activities. The activPAL will be worn for 7 days, including 2 weekend days so we can get any overall picture of your physical activity patterns. Each participant is free to not wear the accelerometer if they feel uncomfortable in any way and can return it before the 7 days are up. This will not affect your future treatment or participation.

- On return of the accelerometers, you will complete a self-report questionnaire. This questionnaire will inform us of your **perceived** activity rates during the same week in which you wore the accelerometer.

What are the benefits to you?

You will receive a copy of your results, which can inform you of your body composition and cardiovascular fitness. You will not be directly informed of the results of this research study. However, it is hoped that the results of this research will inform us of the physical activity levels and physical fitness levels of a broad, random group of female adolescent

girls in the Limerick region. You will also receive a letter, which provides you with a **_20%_** **_discount_** off purchases at any Limerick based _Lifestyle Sports_ shop, once the activPAL accelerometer has been returned and all questionnaires and physiological tests have been complete.

What are the risks?

The UL Research Ethics Committee has assessed all risks associated with each testing procedure.

What if I do not want to take part?

We will be delighted with you taking part in the study. However if you do not wish to take part it is entirely up to you. You can withdraw from the study at any time and we will thank you for your time and help.

Who else is taking part in this Research Project?

It is hoped that 15 other participants from your school will take part in this study, and that 90 other transition year students from schools around Limerick will also participate.

What happens to the information that is gathered?

The information is completely confidential and will only be used for the purpose of this project. Only the people involved in this project will have access to the questionnaires and results of the testing. Once the project is complete, all personal information will be destroyed. Remaining data will be retained for the recommended period of 7-10 years.

What if something goes wrong?

In the event of an emergency we have protocol in place to deal with such an emergency.

Appendix B: Information Sheet and Consent form: Study 2

Who can I contact for additional information?

If you would like to know more about this study, please do not hesitate to contact any of the investigators listed below.

Name	Title	Contact No.	E-mail
Ms. Deirdre Harrington	Postgraduate Student	086-31XXXX	Deirdre.harrington@ul.ie
Mr. Kieran Dowd	Postgraduate Student	087-91XXXX	Kieran.dowd@ul.ie
Mr. Alan Donnelly	Senior Lecturer	061-20XXXX	Alan.donnelly@ul.ie

Also if you have concerns about this study and wish to contact someone independent, you may contact:

The Chairman of the University of Limerick Research Ethics Committee.

C/o Vice President Academic and Registrar's Office

University of Limerick

Limerick

Tel: (061) 20XXXX

UNIVERSITY *of* LIMERICK

OLLSCOIL LUIMNIGH

Participant Consent Form

I have read and understand the subject information sheet and have had due time to consider it. I now fully understand what this project: *The Limerick Physical Activity and Fitness Study of Adolescent Girls* is all about and what the data will be used for. I am fully aware of the procedures involving myself that are involved in this project. I am aware that I can pull out of this project at any time, and that my participation is completely voluntary. I do not have to give any reasons as to why I leave the study if I so choose to. I am aware that my results will be completely confidential.

I_____, understand all that is involved in this study. I hereby agree to take part in this research project.

Signed: _____

Date: _____

WITNESS SINATURE:

Signed: _____

Date: _____

UNIVERSITY *of* LIMERICK

OLLSCOIL LUIMNIGH

Parental Information Sheet

Study Title: Post Primary Girls Physical Activity Research Programme

What is the project about?

Regular physical activity during childhood and adolescents is associated with improvements in health benefits, such as reducing risk of obesity, improving the fitness of the heart and lungs, along with developing fitness and strength. Regular physical activity is described as accumulating moderate intensity activity, such as brisk walking, for 30 minutes a day on 5 days of the week.

Female adolescents are recognised as being particularly at risk of being inactive, with large numbers not participating in enough activity to improve health and fitness. Previous studies have identified that non-team, non-competative activities are a more attractive and successful method of improving activity levels. This study will introduce a physical activity intervention lasting 6-8 weeks to a group of female adolescents in 4 schools across the Limerick county region. The school your daughter attends has been selected as a control school. She will have all the same measurements taken, but will not be involved in the intervention. Her involvement in the study is extremely important, as results from her school will be used as a comparison against results from the intervention schools. This study will be very beneficial to your daughter, as she will have the opportunity to get her level of Physical Activity accurately measured using the accelerometers. Your daughter will also learn about her fitness and body composition levels in a private and confidential manner.

What will my daughter have to do?

All testing will take place in the Physical Education and Sports Science (PESS) building in the University of Limerick. The first type of testing she will take part in is the physiological testing. This will take place in a private space with a female research student, and another female observer will be present at all times. All measurements obtained will be private and confidential, and at <u>no time</u> will your daughter's information be available to anyone, <u>except the researcher's</u> names on the last page of this document.

- Height and weight will be measured in stocking feet, light shorts and t-shirt by a female researcher and this will be used to calculate BMI (Body Mass Index).

- Measurement of waist and hip circumference will then be taken.

- 4 site skinfold test will be administered. The four sites measured are mid-bicep (front of upper arm), mid-triceps (back of the upper arm), sub-scapular (under the shoulder blade) and the iliac crest (side of the body, near the hip bone). All measurements will be taken using a skinfold calliper, and will be performed by an experienced female researcher.

- Blood pressure will be measured using a standard procedure. The appropriately sized cuff will be placed around the upper arm and inflated automatically. The pressure will be slowly reduced, and both systolic and diastolic blood pressures will be recorded.

- Your daughter will participate in a treadmill test. This measures the difference in breathing as someone exercises, and examines how fit your daughters heart and lungs are. This will involve walking and jogging on a treadmill while breathing through a piece of equipment called a gas analyser. She will breathe through a snorkel type mouthpiece while wearing a nose clip, to ensure all breathing is collected by the analyser. Your daughter will be given a familiarization period, to get used to walking and jogging on the treadmill. She will also be asked to wear a heart rate monitor, which will record her heart rate throughout the exercise. This monitor is attached around the chest under clothing. It emits a signal which is read from a watch worn on the wrist. Once the test begins, your daughter will complete several stages or speeds lasting 3 minutes. The test begins at a slow walk (5 kilometres per hour). After three minutes, heart rate will be recorded and your daughter will be asked to point at a scale identifying how hard she believes she is working. At the end of every three minutes, the speed will be increased by 1 kilometre per hour. The treadmill test will finish when your daughter reaches 85%

of her maximum heart rate, when she points to 17 on the Borg RPE (rate of perceived exertion) scale, or when she decides to stop herself.

- Physical Activity levels will be calculated for a week using accelerometry, which is carried out using an accelerometer called an activPAL. The activPAL is a tiny, lightweight box that measures the amount and direction of all the activity that one does. It can tell how long one spends sitting, standing, lying and walking, and how fast one walks. The accelerometer is worn on the mid part of the front of the right thigh, and is held onto the skin with a hypoallergenic stickie. <u>This stickie is both hair and skin friendly</u>. This form of testing is neither invasive, nor will it impede your daughters everyday life. The activPAL only needs to be removed before bathing and any water based activities. The activPAL will be worn for 7 days, including 2 weekend days so we can get an overall picture of your daughter's physical activity patterns. Each participant is free to not wear the accelerometer if they feel uncomfortable in any way and can return it before the 7 days are up. This will not affect their future treatment or participation.

- On return of the accelerometers, your daughter will complete a physical activity and lifestyle questionnaire. This questionnaire will inform us of why she does/does not choose to take part in physical activity, and of her own perceived level of physical activity

Eight weeks after your daughter completes the accelerometer data, she, along with 19 of her classmates, will be asked to return to the University of Limerick to complete the tests listed above for a second time. All transport to and from the university will be provided, and all groups will be supervised at all times.

What are the benefits for my daughter?

Your daughter will receive a copy of your results, which may inform her of her body composition and cardiovascular fitness. She will not be directly informed of the results of this research study. However, it is hoped that the results of this study will inform us of the impact an individual based intervention has on adolescent females in the Limerick region.

What are the risks?

The UL Research Ethics Committee has assessed all risks associated with each testing procedure. The treadmill test carries all risks associated with participating in any exercise. An example of these risks may be soreness, stiffness or possible injury to muscles. All researchers will be appropriately qualified and have First Aid certificates in case of any emergencies.

What if my daughter does not want to take part?

We will be delighted with her taking part in the study. However if she does not wish to take part it is entirely up to her. Your daughter can withdraw from the study at any point, and we will thank her for her time and help.

Who else is taking part in this Research Project?

It is hoped that 19 other participants from your daughter's school will take part in this study, and that a total of 79 other students from schools around Limerick County will also participate.

What happens to the information that is gathered?

The information is completely confidential and will only be used for the purpose of this project. Only the people involved in this project will have access to the questionnaires and results of the testing. Once the project is complete, all personal information will be destroyed. Remaining data will be retained for the recommended period of 7-10 years.

What if something goes wrong?

In the event of an accident, the department first aid officer will be available to assist in any way possible. In the case of an emergency, the department protocol, in place to deal with such incidents, will be set in motion.

Appendix C: Information Sheet and Consent forms Study 3

Who can I contact for additional information?

If you would like to know more about this study, please do not hesitate to contact any of the investigators listed below.

Name	Title	Contact No.	E-mail
Mr. Kieran Dowd	Postgraduate Student	087-91XXXX	Kieran.dowd@ul.ie
Miss. Sarah Breen	Postgraduate Student	061-23XXXX	sarahbreen@ul.ie
Mr. Phelim Macken.	Coordinator, County Limerick Sports Partnership	087-20XXXX	pmacken@limerickcoco.ie
Prof. Alan Donnelly	Professor	061-20XXXX	Alan.donnelly@ul.ie

Also if you have concerns about this study and wish to contact someone independent, you may contact:

The Chairman of the University of Limerick Research Ethics Committee.

C/o Vice President Academic and Registrar's Office

University of Limerick

Limerick

Tel: (061) 20XXXX

UNIVERSITY *of* LIMERICK

O L L S C O I L   L U I M N I G H

Parent/Carer Informed Consent

I have read and understand the parental information sheet and have had due time to consider it. I now fully understand the purposes of the project: *Post Primary Girls Physical Activity Research Programme*, and what the data will be used for. I am fully aware of the procedures that will involve my child, and I am aware that she can withdraw from this project at any time, and that her participation is completely voluntary. She will not have to give any reasons as to why she leaves the study if she so chooses to. I am aware that her results will be completely confidential.

I_____, understand all that is involved in this study. I hereby agree to allow my child to take part in this research project.

Signed: _____

Relationship with the participant: _____

Date: _____

UNIVERSITY *of* LIMERICK

OLLSCOIL LUIMNIGH

Participant Information Sheet

Study Title: Post Primary Girls Physical Activity Research Programme

What is the project about?

Regular physical activity during childhood and adolescents is associated with improvements in health benefits, such as reducing risk of obesity, improving the fitness of the heart and lungs, along with developing fitness and strengyh. Regular physical activity is described as accumulating moderate intensity activity, such as brisk walking, for 30 minutes a day on 5 days of the week.

Female adolescents are recognised as being particularly at risk of being inactive, with large numbers not participating in enough activity to improve health and fitness. Previous studies have identified that non-team, non-competative activities are a more attractive and successful method of improving activity levels. This study will introduce a physical activity intervention lasting 6-8 weeks to a group of female adolescents in 4 schools across the Limerick county region. Your school has been selected as a control school. You will have all the same measurements taken, but will not be involved in the intervention. Your involvement in the study is extremely important, as results from your school will be used as a comparison against results from the intervention schools. This study will be very beneficial to you, as you will have the opportunity to get your level of Physical Activity accurately measured using the accelerometers. You will also learn about you own fitness and body composition levels in a private and confidential manner.

What will you have to do?

All testing will take place in the Physical Education and Sports Science building in the University of Limerick. The first type of testing you will take part in is the physiological testing. This will take place in a private space with a female research student, and another female observer will be present at all times. All measurements obtained will be private and confidential, and at <u>no time</u> will your information be available to anyone, <u>except the researcher's</u> names on the last page of this document.

- Height and weight will be measured in stocking feet, light shorts and t-shirt by the female researcher and this will be used to calculate BMI (Body Mass Index).

- Measurement of your waist and hip circumference will then be taken.

- 4 site skinfold test will be administered. The four sites measured are mid-bicep (front of upper arm), mid-triceps (back of the upper arm), sub-scapular (under the shoulder blade) and the iliac crest (side of the body, near the hip bone). All measurements will be taken using a skinfold calliper, and will be performed by an experienced female researcher.

- Blood pressure will be measured using a standard procedure. The appropriately sized cuff will be placed around the upper arm and inflated automatically. The pressure will be slowly reduced, and both systolic and diastolic blood pressures will be recorded.

- You will participate in a treadmill test. This measures the differences in your breathing as you exercise, and will examine how fit your heart and lungs are. This will involve walking and jogging on a treadmill while breathing through a piece of equipment called a gas analyser. You will breathe through a snorkel type mouthpiece while wearing a nose clip, to ensure all breathing is collected by the analyser. You will be given a familiarization period, to get used to walking and jogging on the treadmill. You will also be asked to wear a heart rate monitor, which will record your heart rate throughout the exercise. This monitor is attached around your chest under whatever clothing you wear for exercise. It emits a signal which is read from a watch worn on your wrist. Once the test begins, you will complete several stages or speeds lasting 3 minutes. The test begins at a slow walk (5 kilometres per hour). After three minutes, your heart rate will be recorded and you will be asked to point at a scale identifying how hard you believe you are working. At the end of every three minutes, the speed will be increased by 1 kilometre per hour. The treadmill test will finish when you reach 85% of your maximum heart

rate, when you point to 17 on the Borg RPE (rate of perceived exertion) scale, or when you decide to stop yourself.

- Physical Activity levels will be calculated for a week using accelerometry, which is carried out using an accelerometer called an activPAL. The activPAL is a tiny, lightweight box that measures the amount and direction of all the activity that one does. It can tell how long one spends sitting, standing, lying and walking, and how fast one walks. The accelerometer is worn on the mid part of the front of the right thigh, and is held onto the skin with a hypoallergenic stickie. <u>This stickie is both hair and skin friendly</u>. This form of testing is neither invasive, nor will it impede your everyday life. The activPAL only needs to be removed before bathing and any water based activities. The activPAL will be worn for 7 days, including 2 weekend days so we can get any overall picture of your physical activity patterns. You are free to not wear the accelerometer if you feel uncomfortable in any way and can return it before the 7 days are up. This will not affect your future treatment or participation.

- On return of the accelerometers, you will complete a physical activity and lifestyle questionnaire. This questionnaire will inform us of why you do/do not choose to take part in physical activity, and of your own perceived level of physical activity

Eight weeks after you complete the accelerometer data, you will be asked to return to the University of Limerick to complete the tests listed above for a second time. All transport to and from the university will be provided, and all groups will be supervised.

What are the benefits to you?

You will receive a copy of your results, which can inform you of your body composition and cardiovascular fitness. You will not be directly informed of the results of this research study. However, it is hoped that the results of this research will inform us of the impact a physical activity intervention, directed at improving participation in individual activities, has on a group of female adolescents.

What are the risks?

The UL Research Ethics Committee has assessed all risks associated with each testing procedure. Normal risk of muscle soreness and stiffness associated with any form of physical activity may be experienced by completing the Vo2 sub-maximal test.

What if I do not want to take part?

We will be delighted with you taking part in the study. However if you do not wish to take part it is entirely up to you. You can withdraw from the study at any time and we will thank you for your time and help.

Who else is taking part in this Research Project?

It is hoped that 19 other participants from your school will take part in this study, and that a total of 79 other students from schools around Limerick County will also participate.

What happens to the information that is gathered?

The information is completely confidential and will only be used for the purpose of this project. Only the people involved in this project will have access to the questionnaires and results of the testing. Once the project is complete, all personal information will be destroyed. Remaining data will be retained for the recommended period of 7-10 years.

What if something goes wrong?

In the event of an accident, the department first aid officer will be available to assist in any way possible. In the case of an emergency, the department protocol, in place to deal with such incidents, will be set in motion.

Appendix C: Information Sheet and Consent forms Study 3

Who can I contact for additional information?

If you would like to know more about this study, please do not hesitate to contact any of the investigators listed below.

Name	Title	Contact No.	E-mail
Mr. Kieran Dowd	Postgraduate Student	087-91XXXX	kieran.dowd@ul.ie
Mr. Phelim Macken.	Coordinator, County Limerick Sports Partnership	087-20XXXX	pmacken@limerickcoco.ie
Miss. Sarah Breen	Postgraduate Student	061-2XXXX	sarahbreen@ul.ie
Prof. Alan Donnelly	Professor	061-20XXXX	alan.donnelly@ul.ie

Also if you have concerns about this study and wish to contact someone independent, you may contact:

The Chairman of the University of Limerick Research Ethics Committee.

C/o Vice President Academic and Registrar's Office

University of Limerick

Limerick

Tel: (061) 20XXXX

UNIVERSITY *of* LIMERICK

OLLSCOIL LUIMNIGH

Participant Consent

I have read and understand the subject information sheet and have had due time to consider it. I now fully understand what this project: *Post Primary Girls Physical Activity Research Programme* is all about and what the data will be used for. I am fully aware of the procedures that are involved in this project. I am aware that I can pull out of this project at any time, and that my participation is completely voluntary. I do not have to give any reasons as to why I leave the study if I so choose to. I am aware that my results will be completely confidential.

I_____, understand all that is involved in this study. I hereby agree to take part in this research project.

Signed: _____

Date: _____

WITNESS SINATURE:

Signed: _____

Date: _____

Prof. Alan Donnelly,

PESS Dept.,

University of Limerick,

Castletroy,

Co. Limerick.

Dear Principal,

I am writing to you today on behalf of our research team at the University of Limerick, Dublin City University, the Mid-Western Regional Hospital and both the Limerick City and County Limerick Local Sports Partnerships. We are currently planning a large-scale physical activity research project in the Limerick region. The project title is *"Sedentary behaviours, physical activity and health in adolescent females"*. We have recently selected four schools, including your school, which we would hope to participate in this study.

The aim of this study is to investigate and examine physical activity levels and sedentary behaviours in adolescent females aged between 12 and 18 years. We hope to examine how health indices vary across adolescents, and how these behaviours correspond with the measured health indices.

It is expected that a total of 120 female adolescents will participate in this study, with potentially 30 students from your school participating. I have attached a project plan of this study which will explain the full involvement required of you and your students, and how it will affect your school throughout the next 12 months.

I would ask if you could read the attached information sheet. If you have any questions regarding this research study, please feel free to contact my Ph.D. research student, who is in charge of study planning and preparation, Mr Kieran Dowd on (061) 234781 or via email at kieran.dowd@ul.ie. Mr Kieran Dowd will contact you within the next couple of days to arrange a meeting, where you can discuss and examine the advantages and disadvantages of this research project. We look forward to speaking with you, and hope to assist you with any queries or questions you may have.

Yours sincerely,

_____

Prof. Alan Donnelly,

Email: alan.donnelly@ul.ie

Phone: (061) 20 XXXX

UNIVERSITY *of* LIMERICK

OLLSCOIL LUIMNIGH

Principal's Information Sheet

Study Title: Sedentary behaviours, physical activity and health in adolescent females

Background: Regular physical activity during childhood and adolescents is associated with health benefits such as reducing the risk of obesity, improving the fitness of the heart and lungs, along with developing fitness and strength. Regular physical activity for adolescents is described as taking part in moderately intense activity, such as brisk walking, for 60 minutes a day on all days of the week. Female adolescents are recognised as being particularly at risk of being inactive, with large numbers not participating in enough activity to improve health and fitness. This study aims to examine the levels of physical activity in a large group of female adolescents in 4 schools, including your school, across the Limerick region. We also wish to investigate how these levels of physical activity affect different aspects of health, such as cholesterol, blood pressure, body composition and fitness. The study will identify levels in physical activity at three different time points throughout one full year, and will also examine the different aspescts of health at each of these time points. This study also hopes to examine why each person participates in different levels of physical activtiy, and how we may best improve these levels of participation.

What is required of you, the principal: As principal of the school, we ask for your consent for the proposed research to take place in your school. Initially, we ask for your consent to obtain a copy of the names and dates of birth of <u>all female students that are aged between 12 and 18 years</u> in your school. This information is required for one reason only, to randomly select our participants. Once this list of names is obtained, 30 students will be randomly selected to participate in the study. <u>The names and dates of birth information will be destroyed once potential participants have been identified</u>. We also ask

you to volunteer a member of the teaching staff to be our contact in the school. This teacher will be asked to assist in arranging meetings and organise test days with the students. Finally, we ask for your support while completing the study in your school. All testing protocol and procedures involved in the research will be explained in detail below.

Parental/Participant consent: We will meet with the selected students at the earliest possible convenience. We will discuss the study outline, and explain what is involved in the research. Students will then be provided with parental and participant information sheets and consent forms, which are required to be completed prior to the study beginning. Both of these forms include PAR-Qs (Physical Activity Readiness Questionnaires). Upon return of the completed forms, we will examine the results of the PAR-Q's. If discrepancies are found between the parental and participant PAR-Q's, we will contact the participants GP, to ensure that it is safe for the selected students to take part in the study. We have requested for parents to grant us permission to make this contact with the GP's in the parental information sheet, and all information will be dealt with privately and confidentially. T*hese precautions are necessary to conform to ethical best practice. We would like to emphasise that this study is not extremely dangerous and does not require additional precautions compared to other research of this kind.*

Four test periods are involved in this study, with each test period explained below.

Test Period 1 (to take place in September/October 2011):
Test Day 1
9:00-2:00 Girls that have volunteered to participate in the research will be called to the school gym in pairs. Each participant will be asked to rest on a physiotherapy plinth for 10-15 minutes. Once rested, her blood pressure, pulse wave velocity and carotid intima-media thickness will be obtained. Pulse wave velocity is measured by simply attaching a clip onto the index finger. The clip is much less painless than attaching a cloths peg onto the top of your finger. Carotid intima-media thickness measures the thickness of a large artery in the neck. This is measured using an ultrasound machine. None of these measures are invasive, and all measurements can be obtained without causing any pain, discomfort or embarrassment. These measures will take a total of 20 minutes to complete on each participant.

Test Day 2 (will take place the day after test day 1)

9:00-11:30 Students will be transported from your school to the Mid-Western Regional Hospital, Limerick, where a qualified medical professional will take a blood sample from the student's arm, as may happen at a regular GP visit. The student's will then be briefly asked some questions by the doctor on their current stage of development. This will involve asking the girls if they have had their first menstrual period, showing them standard female puberty diagrams and asking them to self-select their pubertal status. This will be performed by a Specialist Registrar in Paediatrics, working in the Mid-Western Regional Hospital, Limerick. Permission from their parents will be requested before the girls are shown pictures or asked pubertal questions. All of this testing will be done in private, and will be dealt with the greatest confidentiality.

11:30-1:00 Students will be provided with breakfast/lunch and will be transported back to your school, where they will complete a physical activity and lifestyle questionnaire.

1:00-4:00 Back in the school sports hall, students will then complete some physiological tests, which will include the measurement of height and weight, waist and hip circumference, skinfold measurements and cardiovascular fitness. All of these tests are easy to complete, are not painful and should not cause any embarrassment.

Finally, the students will be provided with an activPAL accelerometer, which will be used to record physical activity over a one week period. The activPAL is a small, lightweight accelerometer, which is used to examine physical activity levels and sedentary behaviour. The accelerometer is a non-invasive, comfortable device which can be worn for long periods of time unnoticed. The activPAL is shown attached to a leg in the picture below.

Test Period 2 (March/April 2012): *One Day Only*

9:00-12:00 Participants will complete physiological tests: Height and Weight, Waist and Hip circumference, Skinfold measurements, Pulse Wave Velocity, Blood Pressure and Cardiovascular fitness. Participants will once again be provided with an activPAL accelerometer.

12:00-01:00 Participants will be asked to complete a Physical Activity and Lifestyle Questionnaire, as they did on the first test day.

All testing in test period 2 and 3 will take place in the school, as no trip to the hospital will be required (no blood sampling).

Test Period 3 (September/October 2012):

All protocol and procedures in test period 3 will be the exact same as test period 1 (two days testing).

There may be other meetings required with the participants when organising these test days, but disruptions to class time and activities within the school will be kept to a minimum at all times. We also hope to provide the participating students with a voucher (approximately €20-€40) to a local Limerick sports shop as an incentive for the safe return and care of the activPAL devices. This is consistent with the ethos of the study, and may promote further physical activity participation of the participants.

Benefits to Participants: There are several benefits to your students for participating in this study. They will learn of the other types of work which are carried out in the hospital, particularly academic research and education. They will also get the experience of observing this work when they are in the hospital. They will learn about physiological testing which takes place in the Physical Education and Sport Sciences department in the University of Limerick. If your students wish, the results of their test will be returned to their GP, and they will be able to obtained and receive an explanation of the results on their next GP visit. Finally, we will inform your students of their levels of participation in physical activity and sedentary behaviour, which may inform them of whether they receive enough activity in their everyday life, or whether they need to participate in more activity.

Risks: The Mid-Western Regional Hospital Research Ethics Committee and the University of Limerick Research Ethics Committee have both assessed all risks associated with each testing procedure. Limited risks are associated with this type of research. All measurements are commonly used in both hospital and school settings, and all procedures will be completed by trained and experienced examiners. During the case of accident or emergency in the hospital, trained medical practitioners will be on hand to assist at all times. During the case of accident or emergency in the school, the school first aid procedure will be implemented, and all precautions possible will be taken.

Exclusion from participation: This research will include healthy female adolescents between the ages of 12 and 18 years. No leaving certificate students will participate in this study. The only other exclusion criterion from this research is health. A number of measures have been included in this study plan to ensure that only health participants can take part in this study. These measures are outlined above.

Confidentiality: The information is completely confidential and will only be used for the purpose of this project. Only the people involved in this project will have access to the questionnaires and results of the testing. Once the project is complete, all personal information will be destroyed. Remaining data will be retained for the recommended period of 7-10 years.

Voluntary Participation: We will be delighted with your students taking part in this study. However if they do not wish to take part it is entirely up to them. If they do not wish to participate, they simply return this form <u>unsigned</u> and inform the cooperating teacher that they do not wish to take part in the study. If your students do return the form, and then realise that they do not wish to continue participating in the study, they can withdraw from the study at any time and we will thank them for their time and help.

Who can I contact for additional information? If you would like to know more about this study, please do not hesitate to contact any of the investigators listed below.

Name	Title	Contact No.	E-mail
Mr. Kieran Dowd	Postgraduate Student	087-91 XXXX	kieran.dowd@ul.ie
Prof. Alan Donnelly	Professor	061-20 XXXX	alan.donnelly@ul.ie

Also if you have concerns about this study and wish to contact someone independent, you may contact:

Chairman Education and Health Sciences Research Ethics Committee,

EHS Faculty office,

University of Limerick,

Co. Limerick,

Tel: (061) 23 XXXX

UNIVERSITY *of* LIMERICK

OLLSCOIL LUIMNIGH

Principal Consent

I have read and understand the principal information sheet and have had due time to consider it. I now fully understand what this project: "*Sedentary behaviours, physical activity and health in adolescent females"* is all about and what the data will be used for. I am fully aware of the procedures that are involved in this project. I am aware that the students in my school can pull out of this project at any time, and that their participation is completely voluntary. The students do not have to give any reasons as to why they wish to leave the study if they so choose to. I am aware that the student's results will be completely confidential. I agree to provide the research team with the names and ages of all eligible students in my school, to allow them to select their sample population. I also give permission to the research group to use the facilities in the school on their test days, and to transport the students to the Mid-Western Regional Hospital, Limerick, on the first and fourth test period.

I_____ understand all that is involved in this study. I hereby agree to the students taking part in this research project, pending parental consent, participant consent and relevant GP information.

Signed: _____

Date: _____/___/_____

UNIVERSITY *of* LIMERICK

O L L S C O I L   L U I M N I G H

Parental/Guardian Information Sheet:

Study Title: Sedentary behaviours, physical activity and health in adolescent females.

Background and aims of the study: Regular physical activity during childhood and adolescents is associated with health benefits such as reducing the risk of obesity, improving the fitness of the heart and lungs, along with developing fitness and strength. Regular physical activity for adolescents is described as taking part in moderately intense activity, such as brisk walking, for 60 minutes a day on all days of the week.

Female adolescents are recognised as being particularly at risk of being inactive, with large numbers not participating in enough activity to improve health and fitness. This study aims to examine the levels of physical activity achieved in a large group of female adolescents in 4 schools, including your daughters school, across the Limerick region. We wish to investigate how these levels of physical activity affect different aspects of health, such as cholesterol, blood pressure, body composition and fitness. The study will examine participation levels in physical activity at four different time points throughout one full year, and will also examine the different aspescts of health at each of these time points. This study also hopes to highlight why young people participate in different levels of activtiy, and how these levels of physical activity and sedentary behaviour can be best improved.

Study outline:

This study will begin in November/December 2010. The study will involve approximately 30 female adolescents from four different schools across the Limerick city region. One of the schools selected to participate in this study was your daughter's school. It is expected that

between 100 and 120 girls in total will take part in the study. The study will involve 4 different test periods. Each of these test periods will be described in detail below.

Test period 1 (September/October 2011):

Day 1:

9:00-2:00 Your daughter, accompanied by another girl who is participating in this research, will be asked to go to the school gym. Both girls will be asked to rest on a physiotherapy plinth for 10-15 minutes. Once rested, your daughter's blood pressure, pulse wave velocity and carotid intima-media thickness will be obtained. Pulse wave velocity is measured by simply attaching a clip onto the index finger. The clip is much less painless than attaching a cloths peg onto the top of your finger. Carotid intima-media thickness measures the thickness of a large artery in the neck. This is measured using an ultrasound machine. None of these measures are invasive, and all measurements can be obtained without causing any pain, discomfort or embarrassment. These measures will take 20 minutes to complete on each participant.

Day 2:

9:00-11:30 On the second test day, your daughter will not be allowed to eat on the morning of the testing, as she must be in a fasted state. Your daughter, along with the 29 other students from her school, will be transported to the Mid-Western Regional Hospital, Limerick. She will be brought to the paediatric day ward, where a doctor will take a small blood sample (10ml) from her arm, as might happen at a regular GP visit. Your daughter will then be briefly asked some questions by the doctor on her stage of development. This means that a paediatrician who works in the hospital will ask your daughter some questions about puberty. Firstly, they will ask if her if she has had her first menstrual period. If she has not yet had her first period, the doctor will then show her a picture scale (which is attached to this form), and ask her to choose which of the pubertal categories she believes she is in. There will be a female assistant (final year sport sciences students) in the room with your daughter at all times.

11:30-1:00 Your daughter will then be provided with breakfast/lunch and transported back to her school, where she will complete a physical activity and lifestyle questionnaire. This is a simple questionnaire that will take approximately 30-40 minutes for her to complete.

1:00-3:30 Back in the school sports hall, she will then complete some physiological tests, which will include the measurement of her height and weight, waist and hip circumference, skinfold measurements and cardiovascular fitness. All of these tests are easy to complete, are not painful and should not cause her any embarrassment. All of these tests will be completed in an appropriately quiet and private area, and will be completed by a female examiner. At no time will she be on her own with any examiner, and all information obtained is private and confidential.

Finally, she will be provided with an ActivPAL accelerometer. The ActivPAL is a small, lightweight accelerometer (20 grams), which is used to assess physical activity levels and sedentary behaviour. It is affixed to your daughter's leg using adhesive strips, which attach the ActivPAL onto the midline of her right thigh (demonstrated in the picture below). A standard demonstration will be completed by one of the investigators on how to fix the ActivPAL to the leg. The ActivPAL is worn at all times for 7 days, except when bathing, swimming or in any contact with water. It is a non-invasive device, which can be comfortably worn throughout the day and night.

activPAL accelerometer

Test Period 2 (to be held in March/April 2012): *One Test Day only:*

9:00-11:30 Your daughter will complete each of the physiological tests that were completed on the first test day, including height and weight, waist and hip circumference, skinfold measurements, pulse wave velocity, blood pressure and cardiovascular fitness. She will once again be provided with an ActivPAL™ accelerometer. There will be no visit to the hospital, as blood sampling is not to be measured.

11:45-12:30 Your daughter will be asked to complete a Physical Activity and Lifestyle Questionnaire, as she did during the first period of testing.

Test Day 3 (to be held in September/October 2012):
All protocols and procedures on test day 3 will be the exact same as test period 1.

Upon full completion of the study, your daughter will receive a small valued sports voucher for a local Limerick sports store (approx. €20-€40). This voucher will be provided to show our appreciation for the return of the ActivPAL devices in full working order. This has worked in previous studies of this kind, and promotes taking care and monitoring the devices when they are worn. The sports vouchers are also very much in accordance with the ethos of this study and may promote further participation in physical activity.

Benefits: There are several benefits to your daughter for participating in this study. She will learn of the other types of work which are carried out in the hospital, particularly academic research and education. She will also get the experience of observing this work while she is in the hospital. Your daughter will learn about physiological testing which takes place in the Physical Education and Sport Sciences department in the University of Limerick. If your daughter wishes, the results of her tests will be returned to her GP, and she will be able to obtained and receive an explanation of the results on her next GP visit. Finally, we will inform your daughter of her levels of participation in physical activity and sedentary behaviour, which may be able to inform her of whether she receives enough activity already in her everyday life, or whether she needs to participate in more activity.

Risks: The Mid-Western Regional Hospital Research Ethics Committee and the University of Limerick Research Ethics Committee have both assessed all risks associated with each testing procedure. Limited risks are associated with this type of research. All measurements are commonly used in both hospital and school settings, and all procedures will be completed by trained and experienced examiners. During the case of accident or emergency in the hospital, trained medical practitioners will be on hand to assist at all times. During the case of accident or emergency in the school, the school first aid procedure will be implemented, and all precautions possible will be taken.

Exclusion from participation: This research will include healthy female adolescents between the ages of 12 and 18 years only. Once you and your daughter have consented to participate in the research, and have both consistently completed the Physical Activity Readiness Questionnaire (PAR-Q), your daughter will be able to participate in the study.

However, if there are discrepancies between the PAR-Q that you complete, and the one your daughter completes, then a letter must be sent to your daughters GP. This letter will inform your daughters GP that she will be participating in this study, and will ask him/her to contact the principal investigator if he/she feels your daughter should not take part in the study. With this, we will require the <u>name and address of your daughters GP</u> if you consent to participation in this study. Once each of these precautions has been completed, we can proceed with the research.

Confidentiality: The information is completely confidential and will only be used for the purpose of this project. Only the investigators involved in this project will have access to the questionnaires and results of the testing. Once the project is complete, all personal information will be destroyed. Remaining data will be retained for the recommended period of 7-10 years.

Voluntary Participation: We will be delighted with your daughter taking part in the study. However if she do not wish to take part in the project, it is entirely up to her. If your daughter does not wish to participate, she simply needs to return this form <u>unsigned</u> and inform the cooperating teacher that she does not wish to take part in the study. If your daughter does return the form, and then realises that she does not wish to continue participating in the study, she can withdraw from the study at any time and we will thank her for her time and help.

Who can I contact for additional information? If you would like to know more about this study, please do not hesitate to contact any of the investigators listed below.

Name	Title	Contact No.	E-mail
Mr Kieran Dowd	Postgraduate Student	087-91 XXXX	kieran.dowd@ul.ie
Prof. Alan Donnelly	Professor	061-20 XXXX	alan.donnelly@ul.ie

Also if you have concerns about this study and wish to contact someone independent, you may contact:

Chairman Education and Health Sciences Research Ethics Committee,

EHS Faculty office,

University of Limerick,

Tel: (061) 23 XXXX

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OLLSCOIL LUIMNIGH

Parent/Guardian Consent Form

I have read and understand the parental/carer information sheet and have had due time to consider it. I now fully understand what this project: *"Sedentary behaviours, physical activity and health in adolescent females"* is all about and what the data will be used for. I am fully aware of the procedures that are involved in this project. I am aware that my daughter can pull out of this project at any time, and that her participation is completely voluntary. I am aware that my daughter's results will be completely confidential. I am also providing the name and address of my daughters GP in accordance with this research. I am giving permission to the investigators involved to contact my daughters GP. I am also giving permission to my daughters GP to provide the research team with any reason why my daughter should not participate in this study.

I_____ understand all that is involved in this study. I hereby agree to my daughter taking part in this research project, pending relevant GP information.

Name of GP: _____

Address of GP: _____

_____

_____

Parent/ Carer Signature: _____

Relationship with participant: _____

Date: ___/___/____

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OLLSCOIL LUIMNIGH

As your daughter is to be a subject in this project, would you please complete the following questionnaire about your daughter? Your cooperation in this is greatly appreciated.

PRE-TEST QUESTIONNAIRE

Study Title: Sedentary behaviours, physical activity and health in adolescent females

Name: _____   **Age:** _____

Date of Birth: _____   **School:** _____

PAR-Q FORM   Please mark YES or No to the following: YES   NO

1) Has your doctor ever said that your daughter has a heart condition and that She should only do physical activity recommended by a doctor?   ____   ____

2) Does your daughter feel pain in her chest when she does physical activity?   ____   ____

3) In the past month, has your daughter had chest pain when she was not doing physical activity?   ____   ____

4) Does your daughter lose her balance because of dizziness or does she ever lose consciousness?   ____   ____

5) Does your daughter have a bone, joint or any other health problem that could be made worse by a change in her physical activity? ____ ____

6) Is your doctor currently prescribing drugs for your daughters blood pressure or heart condition? ____ ____

7) Do you know of any other reason why your daughter should not undergo physical activity? This might include severe asthma, diabetes, a recent sports injury or a serious illness. ____ ____

8) Is your daughter pregnant now or has she given birth within the last 6 months? ____ ____

9) Has your daughter recently had surgery? ____ ____

10) Has your daughter any blood disorders or infectious diseases that may prevent her from providing blood for experimental procedures? ____ ____

If you have marked YES to any of the above, please elaborate below:

_____

_____

- ✓ If you answered no honestly to <u>all</u> questions then you can be reasonably sure that you can take part in the physical activity requirement of the test procedures involved in this study.
- ✓ If you have answered yes to <u>any</u> of the questions above, please ensure that you have provided additional information in the area provided above.

I _____ declare that the above information for my daughter is correct at the time of completing this questionnaire

Date:__/__/____

Scale of Pubertal Development:

This scale will be shown to your daughter by a specialist registrar Paediatrician during her visit to the hospital. This information is important, as it is very likely that hormonal differences at different developmental stages can affect our examination of the blood sample.
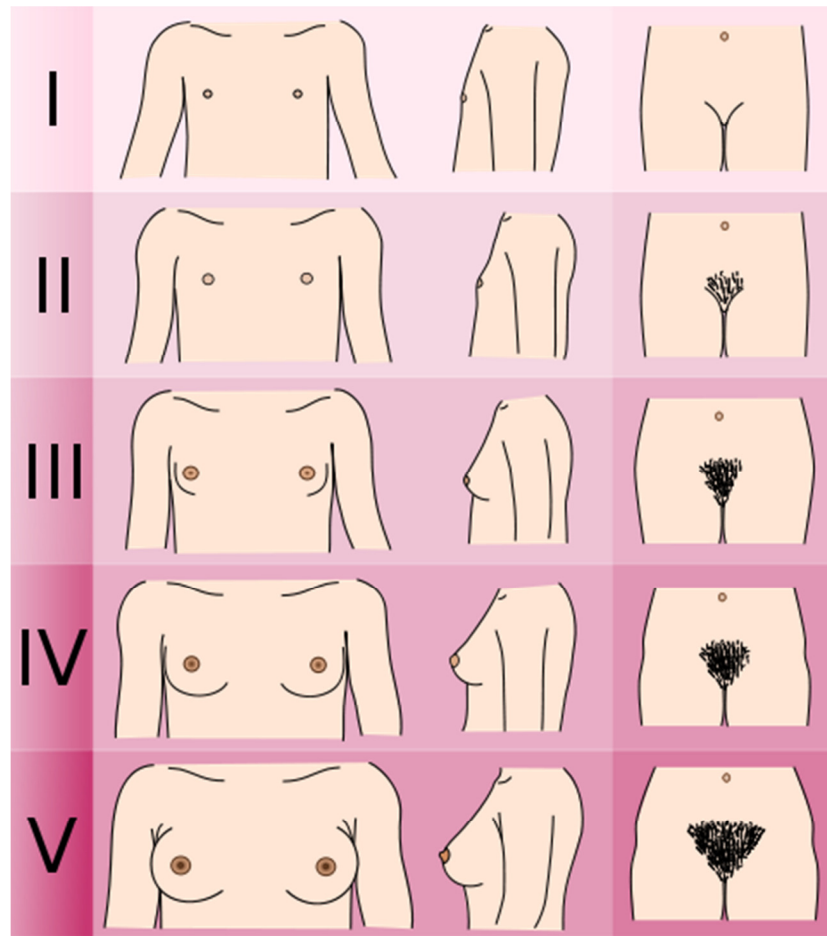
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OLLSCOIL LUIMNIGH

Subject Information Sheet

Study Title: Sedentary behaviours, physical activity and health in adolescent females.

Background and aims of the study: Regular physical activity during childhood and adolescents is associated with health benefits such as reducing the risk of obesity, improving the fitness of the heart and lungs, along with developing fitness and strength. Regular physical activity for adolescents is described as taking part in moderately intense activity, such as brisk walking, for 60 minutes a day on all days of the week.

Female adolescents are recognised as being particularly at risk of being inactive, with large numbers not participating in enough activity to improve health and fitness. This study aims to examine the levels of physical activity achieved in a large group of female adolescents in 4 schools, including your school, across the Limerick region. We wish to investigate how these levels of physical activity affect different aspects of health, such as cholesterol, blood pressure, body composition and fitness. The study will examine participation levels in physical activity at four different time points throughout one full year, and will also examine the different aspescts of health at each of these time points. This study also hopes to highlight why each person participates in different levels of activtiy, and how we may best improve these levels of participation.

Study outline:

This study will begin in November/December 2010. The study will involve approximately 30 female adolescents from four different schools across the Limerick city region. It is expected that between 100 and 120 participants in total will take part in the study. The study will involve 4 different test days. Each of these test days will be described in detail below.

Test period 1 (September/October 2011): *Day 1:*

9:00-2:00 In pairs, each of you will be asked to make their way to the school gym. You will be asked to rest on a physiotherapy plinth for 10-15 minutes. Once rested, your blood pressure, pulse wave velocity and carotid intima-media thickness will be obtained. Pulse wave velocity is measured by simply attaching a clip onto the index finger. The clip is much less painless than attaching a cloths peg onto the top of your finger. Carotid intima-media thickness measures the thickness of a large artery in the neck. This is measured by using an ultrasound machine. None of these measures are invasive, and all measurements can be obtained without causing any pain, discomfort or embarrassment.

Day 2:

9:00-11:30 You will not be allowed to eat on the morning of the testing, as you must be in a fasted state. You will be transported from your school to the Mid-Western Regional Hospital, Limerick. You will be brought to the paediatric day ward, where a doctor will take a small blood sample (10ml) from her arm. You will then be briefly asked some questions by the doctor on your stage of development. This means that a paediatrician who works in the hospital will ask you some questions about puberty. Firstly, they will ask you if you have had your first menstrual period. If you have not yet had your first period, the doctor will then show you a picture scale, and ask you to choose which of the pubertal categories you believe you are in. There will be a female assistant present at all times. However, your privacy will be maintained, and no person will have knowledge of anything you say during this testing period.

11:30-1:00 You will then be provided with breakfast/lunch and transported back to the school, where you will complete a physical activity and lifestyle questionnaire. This is a simple questionnaire that will take approximately 30-40 minutes to complete.

1:00-3:30 Back in the school sports hall, you will then complete some physiological tests, which will include the measurement of height and weight, waist and hip circumference, skinfold measurements and cardiovascular fitness. All of these tests are easy to complete, are not painful and should not cause you any pain or embarrassment. All of these tests will be completed in an appropriately quiet and private area, and will be completed by a female examiner.

Finally, you will be provided with an ActivPAL accelerometer, which will be used to record physical activity over a 7 day period. The ActivPAL is a small, lightweight

accelerometer (20 grams), which is used to examine physical activity levels and sedentary behaviour. The activPAL is worn at all times for 7 days, except when bathing, swimming or in any contact with water. It is a non-invasive device, which can be comfortably worn throughout the day and night.

activPAL accelerometer

Test Period 2 (to be held in March/April 2012):

One Test Day only:

9:00-11:30 You will complete each of the physiological tests that were completed on the first test day, including height and weight, waist and hip circumference, skinfold measurements, pulse wave velocity, blood pressure and cardiovascular fitness. You will once again be provided with an ActivPAL™ accelerometer. There will be no visit to the hospital as blood sampling will not be measured.

11:45-12:30 You will be asked to complete a Physical Activity and Lifestyle Questionnaire, as she did during the first period of testing.

Test Period 4 (to be held in September/October 2012):

All protocols and procedures on test day 3 will be the exact same as test period 1.

Upon full completion of the study, you will receive a small valued sports voucher for a local Limerick sports store. This voucher will be provided to show our appreciation for the return of the ActivPAL devices in full working order.

Benefits: There are several benefits to you for participating in this study. You will learn of the other types of work which are carried out in the hospital, particularly academic research and education. You will also get the experience of observing this work when you are in the hospital. You will also learn about all other physiological testing which takes place in the

Physical Education and Sport Sciences department in the University of Limerick. If you wish, the results of your testing will be returned to your general practitioner (GP) and you will be able to obtained and receive an explanation of the results on your next GP visit. Finally, we will inform you of your levels of participation in physical activity and sedentary behaviour.

Risks: The Mid-Western Regional Hospital Research Ethics Committee and the University of Limerick Research Ethics Committee have assessed risks associated with each testing procedure. Limited risks are associated with this type of research. All measurements are commonly used in both hospital and school settings, and all procedures will be completed by trained and experienced examiners. During the case of any accident or emergency in the hospital, trained medical practitioners will be on hand to assist at all times. During the case of accident or emergency in the school, the school first aid procedure will be implemented, and all precautions possible will be taken.

Exclusion from participation: This research will include healthy female adolescents between the ages of 12 and 18 years. Both you and your parent will be asked to consent to participation in the research, and asked to complete a short Physical Activity Readiness Questionnaire (PAR-Q). Once each of these precautions has been completed, we can proceed with the research.

Confidentiality: The information is completely confidential and will only be used for the purpose of this project. Only the people involved in this project will have access to the questionnaires and results of the testing. Once the project is complete, all personal information will be destroyed. Remaining data will be retained for the recommended period of 7-10 years.

Voluntary Participation: We will be delighted with you taking part in the study. However if you do not wish to take part it is entirely up to you. If you do not wish to participate, simply return this form <u>unsigned</u> and inform your teacher that you do not wish to take part in the study. If you do return the form, and then realise that you do not wish to continue participating in the study, you can withdraw from the study at any time and we will thank you for your time and help.

Who can I contact for additional information? If you would like to know more about this study, please do not hesitate to contact any of the investigators listed below.

Name	Title	Contact No.	E-mail
Mr. Kieran Dowd	Postgraduate Student	087-91 XXXX	kieran.dowd@ul.ie
Prof. Alan Donnelly	Professor	061-20 XXXX	alan.donnelly@ul.ie

Also if you have concerns about this study and wish to contact someone independent, you may contact:

Chairman Education and Health Sciences Research Ethics Committee,

EHS Faculty office,

University of Limerick,

Co. Limerick,

Tel: (061) 23 XXXX

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Subject Consent Form

I have read and understand the subject information sheet and have had due time to consider it. I now fully understand what this project: *Sedentary behaviours, physical activity and health in adolescent females* is all about and what the data will be used for. I am fully aware of the procedures that are involved in this project. I am aware that I can pull out of this project at any time, and that my participation is completely voluntary. I do not have to give any reasons as to why I leave the study if I so choose to. I am aware that my results will be completely confidential.

I _____ understand all that is involved in this study. I hereby agree to take part in this research project.

Signed: _____

Date: _____

WITNESSES SIGNATURE:

Signed: _____

Date: ___ / __ / ___

activPAL Accelerometer

Instructions

Information sheets and Protocol

What Do I Do?

<u>When you get the device</u>

1. You will be given a full demonstration on how to use the activPAL and you will be given help with putting it on for the first time.
2. The accelerometer will be attached to your thigh using a stickie and a standard tube support bandage. Be sure that the little man on the front of the device is facing the right way up.
3. **Applying the Stickie:** Remove the plastic layer from the stickie and attach the open side firmly to the back of the activPAL. Then, remove the butterfly tabs and apply straight onto the skin, pressing firmly on the activPAL. Try not to use any moisturiser or other creams on the area where the activPAL will be attached, as this can make the *stickie* less sticky!

1. **Applying the Tube grip:** Pull the bandage on over your leg and up over your thigh. Envelope the activPAL so it is covered by the bandage at all sides.

2. When wearing the activPAL, you can partake in all activities (except water-based activities) as normal, as it is secure and should not impede your normal activity. Please live your life as you always do.

3. Wear the activPAL all day and night, even when you take a nap and go to bed. Remove the activPAL when you are bathing, swimming or doing any other water-based activities. <u>Remember; do not let the device get wet.</u>

4. When bathing, remove the fabric, ActivPAL and stickie and leave in a flat, dry, safe place. Once you are dried off, reattach the ActivPAL using the same stickie. It is skin and hair friendly.

5. Record on the ActivPAL diary sheet the time and day when you took off and put back on the ActivPAL. Otherwise when you are not wearing the ActivPAL, we will think you were lying down!!

Every Morning and Night:

Leave the device on all day and all night except when bathing. Please reattach the device as soon as you can afterwards once you have dried off.

FAQs

Where should I apply the activPAL?

It is most comfortable to wear the ActivPAL on the mid line of the thigh, about one third of the way down between the hip and the knee. However, it will work correctly anywhere on the front of the thigh as indicated on the front panel of the device.

What if it is not secure?

Ensure that you have the correct side sticking to your leg. The butterfly tab side will stick to your leg while the clear plastic side will stick to the activPAL. The *stickie* will not work as well if any lotions (moisturiser or fake tan for example) are on the leg.

Often the *stickie* on its own is not secure enough especially during some more vigorous activities. Add the tube grip bandage over the activPAL making sure to create an envelope with the fabric all around the activPAL.

When should I remove the activPAL?

The activPAL can be worn comfortably all day and all night and should not impede your everyday activities. It must be removed before bathing and swimming or before any other activities which may result in the activPAL coming in contact with water.

How do I know the activPAL is working?

The activPAL is a continuous recorder so will never stop recording. But you can be sure by checking the little light in the front panel-it will flash green every six seconds. If it is not flashing green please call us on the number below!

Are there any safety issues or warnings?

Ensure to dry off thoroughly after bathing before reapplying the activPAL. If it drops or falls from the leg don't worry-just check the front panel to see if the green light flashes every 6 seconds. Please do not leave the activPAL lying around in school or public toilets or showers in case it gets lost or stolen. While the activPAL is of no value to you, it is precious to us so please take care of the device at all times!

What if I'm in trouble or have a question?

At any stage, day or night if you are having a problem with the device or have a question please give me a call. No matter how small or silly you think the question is, it could turn out to be very important later on.

Name: Kieran Dowd

Email Address: kieran.dowd@ul.ie

Home Phone Number: 087-91XXXXX

Office Phone Number: 061-23XXXX

Appendix F: Publications and Conference Proceedings

Deirdre Harrington was the principal author of the paper appended below. I, Kieran Dowd, contributed to study design, aided in data collection, contributed to the writing of each section and proof read the final manuscript for submission. Full text included on additional CD.

Cross-Sectional analysis of levels and patterns of objectively measured sedentary time in adolescent females

Deirdre M Harrington[1,2*], Kieran P Dowd[2], Alan K Bourke[3] and Alan E Donnelly[2]

Abstract

Background: Adolescent females have been highlighted as a particularly sedentary population and the possible negative effects of a sedentary lifestyle are being uncovered. However, much of the past sedentary research is based on self-report or uses indirect methods to quantity sedentary time. Total time spent sedentary and the possible intricate sedentary patterns of adolescent females have not been described using objective and direct measure of body inclination. The objectives of this article are to examine the sedentary levels and patterns of a group of adolescent females using the ActivPAL™ and to highlight possible differences in sedentary levels and patterns across the week and within the school day. A full methodological description of how the data was analyzed is also presented.

Methods: One hundred and eleven adolescent females, age 15-18 yrs, were recruited from urban and rural areas in the Republic of Ireland. Participants wore an ActivPAL physical activity monitor for a 7.5 day period. The ActivPAL directly reports total time spent sitting/lying every 15 seconds and accumulation (frequency and duration) of sedentary activity was examined using a customized MATLAB® computer software programme.

Results: While no significant difference was found in the total time spent sitting/lying over the full 24 hour day between weekday and weekend day (18.8 vs. 18.9 hours; $p = .911$), significantly more sedentary bouts of 1 to 5 minutes and 21 to 40 minutes in duration were accumulated on weekdays compared to weekend days ($p < .001$). The mean length of each sedentary bout was also longer (9.8 vs. 8.8 minutes; $p < .001$). When school hours (9 am-3 pm) and after school hours (4 pm-10 pm) were compared, there was no difference in total time spent sedentary (3.9 hours; $p = .796$) but the pattern of accumulation of the sedentary time differed. There were a greater number of bouts of > 20 minutes duration during school hours than after school hours (4.7 vs. 3.5 bouts; $p < .001$) while after school time consisted of shorter bouts < 20 minutes.

Conclusions: School is highlighted as a particularly sedentary setting for adolescent females. Interventions to decrease sedentary time at school and the use of wearable devices which distinguish posture should be encouraged when examining sedentary patterns and behaviors in this population.

Keywords: Sedentary, adolescent females, ActivPAL, sitting, school, methodology

Deirdre Harrington was the principal author of the paper appended below. I, Kieran Dowd, contributed to study design, aided in data collection, contributed to the writing of each section and proof read the final manuscript for submission. Full text included on additional CD.

A Steps/Minute Value for Moderate Intensity Physical Activity in Adolescent Females

Deirdre M. Harrington
Pennington Biomedical Research Center

Kieran P. Dowd
University of Limerick

Catrine Tudor-Locke
Pennington Biomedical Research Center

Alan E. Donnelly
University of Limerick

The number of steps/minute (i.e., cadence) that equates to moderate intensity in adolescents is not known. To that end, 31 adolescent females walked on a treadmill at 5 different speeds while wearing an ActivPAL accelerometer and oxygen uptake was recorded by indirect calorimetry. The relationship between metabolic equivalents (METs) and cadence was explored using 3 different analytical approaches. Cadence was a significant predictor of METs ($r = .70; p < .001$). Moderate intensity (3 METs) corresponded to 94 or 114 steps/minute based on the mixed model and ROC analysis, respectively. These two values, and a practical value of 100 steps/minute, were cross-validated on an independent sample of 33 adolescent females during over-ground walking at 3 speeds. The sensitivity and specificity of each value correctly identifying 3 METs were 98.5% and 87.2% for 94 steps/minute, 72.9% and 98.8 for 114 steps/minute and 96.5% and 95.7% for 100 steps/minute. Compromising on a single cadence of 100 steps/minute would be a practical value that approximates moderate intensity in adolescent females and can be used for physical activity interpretation and promotion.

The objective assessment of physical activity using step counts is gaining momentum in both descriptive (27,28) and interventional (4) research. Total steps/day can be measured by pedometer or accelerometer and serve as a practical approximation of daily ambulatory physical activity volume. Physical activity

Abstract submitted and presented at the American College of Sports Medicine, Baltimore 2010. Poster included on additional CD.

Abstract Title: The Examination of Accelerometer Output: Age/Non-age specific Thresholding and Bout Duration.

Kieran P. Dowd, Deirdre M. Harrington, Alan E. Donnelly.

University of Limerick, Limerick, Ireland.

The ability to relate physical activity (PA) to health improvements relies on accurate and precise measurements; often made using accelerometers. The most common method of analysing accelerometer output is classifying activity counts into physical activity levels (PAL's) or energy expenditure (using count-activity thresholds) and summing the results as total minutes per day at each level. Significant differences in PAL's have been noted when analysing accelerometry data using different thresholds. **Purpose:** To present differences in physical activity levels (PAL's) of female adolescents, using two different methods: total accumulated moderate to vigorous physical activity (MVPA) and bouts of MVPA $\geq$ 10 minutes in duration. Data were analysed using age specific (AS) and non-age specific (NAS) thresholds developed using the same methodologies. Results were then compared with the American College of Sports Medicine (ACSM 2007) PA guidelines (60 minutes of MVPA on at least 5 days of the week). **Methods:** Participants were randomly selected from 6 schools across the mid-western region of Ireland (N=51). Four to six days of PA was recorded using accelerometry (ActivPAL™, PAL technologies Ltd, Glasgow, Scotland) placed on the mid-thigh of the volunteer's right leg. Data was examined using both AS and NAS thresholds. The resulting data was then processed to identify total daily MVPA and bouts of MVPA $\geq$ 10 minutes in duration. **Results:** Mean AS and NAS total MVPA differed significantly (p<0.001, t-test). Mean AS (20.2 $\pm$ 14.5 min d^{-1}) and NAS (18.5 $\pm$ 13.8 min d^{-1}) bouts of MVPA also differed significantly (p<0.01, t-test). Participants did not achieve the recommended levels of PA using either AS (45.3 $\pm$ 19.2 min d^{-1}; mean $\pm$ SD) or NAS (37.9 $\pm$ 18.1 min d^{-1}) thresholds. When the output was analysed using more stringent guidelines (bouts of MVPA $\geq$ 10 min), recommended PAL's were not achieved. **Conclusion:** These results illustrate that care must be taken when 1) selecting thresholds, as the lack of threshold specificity may significantly under/overestimate PAL's and 2) analysing duration using either total or bouts of MVPA, as significant differences of estimated PAL's can be observed.

Abstract submitted and presented at the American College of Sports Medicine, San Francisco 2012. Poster included on additional CD.

Abstract Title: Relation between Physical Activity, Sedentary Behaviour and Selected Cardiovascular Disease Risk Factors in Adolescent Females

[1]Kieran P. Dowd, [2, 3] Sarah M. Hughes, [4]Steven Gastinger, [1]Grainne Hayes, [5]Michael Harrison, [6, 8] Alan P. Macken, [7, 8]Clodagh S. O'Gorman, [2, 3]Niall M. Moyna FACSM, [1]Alan E. Donnelly.

[1]Centre of Physical Activity and Health Research, University of Limerick, Limerick, Ireland,[2]CLARITY: Centre for Sensor Web Technology and [3]The Centre for Preventative Medicine, Dublin City University, Dublin, Ireland, [4]Movement, Sport and Health Sciences, University of Rennes 2, France, [5]Centre for Health Behaviour Research, Waterford Institute of Technology, Waterford, Ireland, [6]National Children's Research Centre, Dublin, Ireland, [7]4i The Children's Ark, University Hospital, Limerick, Ireland, [8]4i Centre, Graduate Entry Medical School, University of Limerick, Limerick, Ireland.

Background: Cardiovascular disease risk factor (CVRF) levels for an individual tend to track over time in a given rank within the distribution of the population. Long term exposure to multiple CVRF and lifestyle behaviours confers a lifelong burden of CVD risk resulting in the development of early systemic atherosclerosis. Measurement of carotid intima-media thickness (CIMT) and large artery stiffness (LAS) are commonly used to determine the extensiveness and severity of asymptomatic disease and potential future risk. **Purpose:** To examine the relation between both physical activity (PA) and sedentary behaviour (SB) and i) selected CVRF and ii) subclinical disease in adolescent females. **Methods:** Data are presented as mean ± standard deviation, except where otherwise indicated. Participants (n=35; age = 14.4 ± 1.1 yrs.; BMI = 22.6 ± 2.9 kg/m²; percentage body fat 31.2 ± 3.0; mean arterial pressure (MAP) = 85.0 ± 8.3 mmHg) were randomly selected from 4 high-schools in Ireland. Height, weight, percentage body fat, blood pressure, CIMT, and LAS data was obtained for each participant. SB and PA were recorded for 4-6 days using an ActivPAL™ physical activity monitor. The amount of time spent sedentary, standing, and in both light and moderate to vigorous PA (MVPA) was calculated. Sedentary data was also examined to identify sedentary bouts of specific duration. **Results:** The mean left and right-sided CIMT score was 0.47 ± 0.0 cm and the mean LAS index was 5.20 ± 0.58. Participants spent 19.42 ± 0.94 h/d in sedentary activities (9.93 ± 1.03 waking sedentary h/d), 3.08 ± 0.74 h/d standing, 0.73 ± 0.17 h/d in light activity and 0.78 ± 0.26 h/d in MVPA. There was a significant inverse relation between light physical activity levels (independant of standing time) and mean arterial pressure

(MAP), (r = -0.5; p<0.05), BMI (r = -0.5; p<0.01) and percentage body fat (r = -0.4; p<0.05). There was no relation between other PA variables and CIMT or LAS. There was no significant relation between SB and CVRF, CIMT or LAS. **Conclusions:** Objectively measured light PA (independent of standing time) is correlated with MAP, BMI and percentage body fat, but not CIMT or LAS in this population of adolescent females. Although a large amount of time was spent sedentary (9.93 hr), SB were not related to CVRF, CIMT or LAS in this population of adolescent females.

Abstract submitted and presented at the American College of Sports Medicine, Denver 2011. Poster included on additional CD.

Abstract Title: Cadence (steps/minute) Patterns in High and Low Active Adoelscent Females.

[1,2]Deirdre M. Harrington, [2]Kieran P. Dowd, [1]Catrine Tudor-Locke, [2]Alan E. Donnelly

[1]*Pennington Biomedical Research Unit, Baton Rouge, Louisiana, USA;* [2]*Centre of Physical Activity and Health Research, University of Limerick, Limerick, Ireland.*

Steps/day has been interpreted as a measure of total daily physical activity, but it does not give information on physical activity intensity. However, minute-by-minute records of stepping data represent cadence (steps/minute), which in turn can be used to infer intensity. Adolescent females have been highlighted as a group who do not engage in adequate physical activity. Little is known about the cadence patterns of those who achieve high steps/day (and are identified as being more active), and those who take lower steps/day. **Purpose** To investigate differences in cadence patterns between adolescent females achieving high and low mean steps/day. **Methods** The activPAL was used to collect 7 days of free-living behavior from 52 adolescent girls who were part of a randomized sample. This analysis is based on 8 participants with the highest steps/day values (HIGH group) and the 8 with the lowest steps/day values (LOW group). No significant differences (p<.05) were found between groups' age, height, weight or BMI (mean age 15y 7mo, 1.7m, 67.8kg, 23.5 kg/m²). Data was categorized into incrementally increasing (by 10 steps/minute) cadence bands between 1-10 steps/minute up to 170-180 steps/minute. Independent sample t-tests with Bonferroni adjustment were used to compare the number of steps in each cadence band between groups. **Results** The LOW group took 6696 ±344 steps/day compared with the HIGH group who took 12959 ±1957 steps/day (p<.001). The two groups differed in the number of steps taken at cadences of 100-110 (p<.01) and 110-120 steps/minute (p<.001), with the HIGH group taking more steps in both of these cadence bands. There were no significant differences in the number of steps participants took at any cadence below 100 steps/minute (p=.059 to .939) or above 120 steps/minute (p=.122 to .427). No steps were recorded at between 1 and 20 steps/minute. **Conclusion** Although there are no adolescent-specific studies to assist with interpretation of these results, adult studies have consistently demonstrated that 100 steps/minute demarks the threshold for moderate intensity walking. This cadence represents an achievable target for low active adolescent females to aim for to increase physical activity intensity to match their peers. The fact that no steps were recorded between 1-20 steps/minute may be an instrument artifact.

Abstract submitted and presented at the International Conference on Ambulatory Monitoring and Physical Activity Monitoring, Glasgow 2011. Slides from oral presentation included on additional CD.

Abstract Title: Physical Activity and Sedentary Behaviours immediately before and after school.

[1] Kieran P. Dowd, [2]Deirdre M. Harrington, [1]Alan E. Donnelly

[1]*Centre of Physical Activity and Health Research, University of Limerick, Limerick, Ireland;* [2]*Pennington Biomedical Research Unit, Baton Rouge, Louisiana, USA.*

Introduction: It is widely acknowledged that the consequences of physical inactivity are a major public health concern, particularly in children and adolescents. Unfortunately, the contribution of commuting to and from school and extracurricular physical activity before and after school is often overlooked when examining levels of daily PA. The purpose of this abstract is to examine the contribution of objectively measured PA to total daily PA in a group of adolescent females during the hour before school (8-9am) and the hour after school (3-4pm). This abstract also describes the objectively measured sedentary pattern of this group of adolescent during this time period. **Methods:** Participants were randomly selected from 5 schools across the mid-western region of Ireland (N=44). Four to six days of PA was recorded using accelerometry (ActivPAL™, PAL technologies Ltd, Glasgow, Scotland). Data obtained on school days was examined from 8-9am and from 3-4pm. Data was examined for sedentary, light and moderate to vigorous PA (MVPA). Data was also examined for duration of sedentary bouts using a computer program. **Results:** Participants accumulated 25% of their daily recommended MVPA between 8-9 am and between 3-4 pm (all means ± SD's; 14.9 ± 8.6 mins). No significant differences existed between levels of MVPA achieved between 8-9am (7.72 ± 7.97) and 3-4pm (7.19 ± 6.99; p >.05). The analysis also showed that participants spent 38.2 ± 13.3 mins in light activity, while 66.9 ± 14.8 mins were spent in sedentary activities. Significantly more sedentary time was accumulated in the hour after school (36.47 ± 12.82 mins) than the hour before school (30.06 ± 14.5 mins; p<.001, Wilcoxon Sign). Significantly more sedentary bouts less than 10 minutes in duration were also identified in the hour before school (2.4 ± 2.0) compared to the hour after school (1.94 ± 2.0; p=.034, Wilcoxon Sign). **Discussion and Conclusion:** It is indicated that participants achieved 25% of their daily MVPA immediately before and after school. However, it is also highlighted that considerable periods of time were also spent sedentary, with more time being spent in sedentary activities after school than before school. The time period immediately before and after school provides students with the

opportunity to be involved in active transport or in extracurricular PA. In particular, after school activities have the potential to significantly contribute to daily MVPA.

Appendix G: Example of Statistical Analysis Chapter 3

Presented in this appendix is an example of the mixed model analysis employed in chapter 3. Also included is the method used to examine the concordance correlation coefficient and the standard error of the estimate employed in Chapter 3.

Mixed Model Analysis

Model Dimension [b]

		Number of Levels	Covariance Structure	Number of Parameters	Subject Variables
Fixed Effects	Intercept	1		1	
	ActivPALCounts15	1		1	
Random Effects	ActivPALCounts15[a]	1	Variance Components	1	ID
Residual				1	
Total		3		4	

a. As of version 11.5, the syntax rules for the RANDOM subcommand have changed. Your command syntax may yield results that differ from those produced by prior versions. If you are using version 11 syntax, please consult the current syntax reference guide for more information.

b. Dependent Variable: Cosmed EE.

Information Criteria [a]

-2 Restricted Log Likelihood	300.023
Akaike's Information Criterion (AIC)	304.023
Hurvich and Tsai's Criterion (AICC)	304.098
Bozdogan's Criterion (CAIC)	312.211
Schwarz's Bayesian Criterion (BIC)	310.211

The information criteria are displayed in smaller-is-better forms.

a. Dependent Variable: Cosmed EE.

Fixed Effects

Type III Tests of Fixed Effects [a]

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	149.093	351.917	.000
ActivPALCounts15	1	14.470	201.926	.000

a. Dependent Variable: Cosmed EE.

Appendix G: Example of Statistical Analysis Chapter 3

Estimates of Fixed Effects [a]

Parameter	Estimate	Std. Error	df	t	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Intercept	.971011	.051761	149.093	18.759	.000	.868731	1.073291
ActivPAL Counts15	.000677	4.765139E-5	14.470	14.210	.000	.000575	.000779

a. Dependent Variable: Cosmed EE.

Covariance Parameters

Estimates of Covariance Parameters [a]

Parameter	Estimate	Std. Error
Residual	.218037	.025261
ActivPALCounts15 [subject = ID] Variance	3.300588E-8	1.266205E-8

a. Dependent Variable: Cosmed EE.

Estimated Marginal Means

Grand Mean [b]

Mean	Std. Error	df	95% Confidence Interval	
			Lower Bound	Upper Bound
4.019[a]	.214	14.416	3.561	4.477

a. Covariates appearing in the model are evaluated at the following values: ActivPAL Counts per 15 sec = 4501.4742.

b. Dependent Variable: Cosmed EE.

Calculation of Concordance Correlation Coefficient (CCC)

Observed = Cosmed EE (Cosmed Energy Expenditure)

Fitted = FXPRED Values (Fixed Predicted Values)

1. Σ (Observed – Fitted)^2
2. Σ (Observed – Observed Mean)^2
3. Σ (Fitted – Fitted Mean)^2
4. N(Observed Mean – Fitted Mean)^2

$$CCC = 1 - \frac{\Sigma\,(Observed - Fitted)^2}{(\Sigma\,(Observed - Observed\,Mean)^2 + \Sigma\,(Fitted - Fitted\,Mean)^2 + N(Observed\,Mean - Fitted\,Mean)^2)}$$

Calculation of the Standard Error of the Estimate SE E

$$SEE = \sqrt{\frac{\Sigma\,(Observed - Fitted)^2}{N}}$$

Table 3.2 Nonparametric Correlations Information

Correlations

			Cosmed EE	Predicted_V
Spearman's rho	Cosmed EE	Correlation Coefficient	1.000	.932**
		Sig. (2-tailed)	.	.000
		N	165	165
	Predicted_V	Correlation Coefficient	.932**	1.000
		Sig. (2-tailed)	.000	.
		N	165	165

**. Correlation is significant at the 0.01 level (2-tailed).

Correlations

			Cosmed EE	Predicted_V
Spearman's rho	Cosmed EE	Correlation Coefficient	1.000	.250
		Sig. (2-tailed)	.	.054
		N	60	60
	Predicted_V	Correlation Coefficient	.250	1.000
		Sig. (2-tailed)	.054	.
		N	60	60

Correlations

			Cosmed EE	Predicted_V
Spearman's rho	Cosmed EE	Correlation Coefficient	1.000	.873**
		Sig. (2-tailed)	.	.000
		N	105	105
	Predicted_V	Correlation Coefficient	.873**	1.000
		Sig. (2-tailed)	.000	.
		N	105	105

**. Correlation is significant at the 0.01 level (2-tailed).

Appendix G: Example of Statistical Analysis Chapter 5 and Chapter 6

Example of the linear regression statistical analysis included in Chapter 5 and Chapter 6. All analysis is included with the attached CD.

Light (excl. Standing Time) /Σ Skinfolds

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	PercLight_Log, Age[b]	.	Enter
2	PercMVPA_Log[b]	.	Enter

a. Dependent Variable: SumSkinfold_Log

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.234[a]	.055	.045	.17123
2	.243[b]	.059	.044	.17129

a. Predictors: (Constant), PercLight_Log, Age

b. Predictors: (Constant), PercLight_Log, Age, PercMVPA_Log

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.324	2	.162	5.521	.005[b]
	Residual	5.571	190	.029		
	Total	5.895	192			
2	Regression	.349	3	.116	3.966	.009[c]
	Residual	5.546	189	.029		
	Total	5.895	192			

a. Dependent Variable: SumSkinfold_Log

b. Predictors: (Constant), PercLight_Log, Age

c. Predictors: (Constant), PercLight_Log, Age, PercMVPA_Log

Appendix G: Example of Statistical Analysis Chapter 5 and Chapter 6

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.962	.229		8.561	.000
	Age	.001	.014	.007	.105	.917
	PercLight_Log	-.356	.108	-.234	-3.297	.001
2	(Constant)	1.964	.229		8.565	.000
	Age	.003	.014	.014	.203	.839
	PercLight_Log	-.331	.111	-.217	-2.980	.003
	PercMVPA_Log	-.067	.072	-.068	-.930	.354

a. Dependent Variable: SumSkinfold_Log

Excluded Variables[a]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	PercMVPA_Log	-.068[b]	-.930	.354	-.067	.937

a. Dependent Variable: SumSkinfold_Log

b. Predictors in the Model: (Constant), PercLight_Log, Age

Appendix G: Example of Statistical Analysis Chapter 5 and Chapter 6

Example of the binary logistic regression analysis and univariate analysis of variance included in Chapter 5. All additional analysis is included with the attached CD.

Odds ratios for High Sum of Skinfolds across Light (excl. Standing Time) Quartiles:

Variables not in the Equation

			Score	df	Sig.
Step 0	Variables	Age	.250	1	.617
		LightQuart	7.851	3	.049
		LightQuart(1)	3.487	1	.062
		LightQuart(2)	1.714	1	.190
		LightQuart(3)	1.431	1	.232
	Overall Statistics		7.981	4	.092

Block 1: Method = Enter

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
								Lower	Upper
Step 1ª	Age	.068	.189	.130	1	.718	1.070	.740	1.549
	LightQuart			7.440	3	.059			
	LightQuart(1)	1.151	.507	5.145	1	.023	3.160	1.169	8.543
	LightQuart(2)	1.026	.515	3.972	1	.046	2.791	1.017	7.656
	LightQuart(3)	.294	.551	.285	1	.594	1.342	.456	3.948
	Constant	-2.855	2.976	.921	1	.337	.058		

a. Variable(s) entered on step 1: Age, LightQuart.

Block 2: Method = Enter

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
								Lower	Upper
Step 1ª	Age	.094	.191	.242	1	.623	1.099	.755	1.599
	LightQuart			6.634	3	.085			
	LightQuart(1)	1.056	.517	4.170	1	.041	2.875	1.043	7.920
	LightQuart(2)	.968	.519	3.474	1	.062	2.633	.951	7.287
	LightQuart(3)	.203	.566	.129	1	.720	1.225	.404	3.713
	MVPAQuart			.903	3	.825			
	MVPAQuart(1)	.443	.507	.764	1	.382	1.557	.577	4.204
	MVPAQuart(2)	.413	.515	.643	1	.423	1.511	.551	4.149
	MVPAQuart(3)	.346	.522	.440	1	.507	1.414	.508	3.935
	Constant	-3.511	3.075	1.304	1	.254	.030		

a. Variable(s) entered on step 1: MVPAQuart.

Univariate Analysis of Variance: Light Quartiles and Sum of Skinfolds

Between-Subjects Factors

		Value Label	N
LightQuart	1.00	1st Quartile	49
	2.00	2nd Quartile	47
	3.00	3rd Quartile	49
	4.00	4th Quartile	49

Descriptive Statistics

Dependent Variable: SumSkinfoldrisk

LightQuart	Mean	Std. Deviation	N
1st Quartile	1.3469	.48093	49
2nd Quartile	1.3191	.47119	47
3rd Quartile	1.1837	.39123	49
4th Quartile	1.1429	.35355	49
Total	1.2474	.43263	194

Tests of Between-Subjects Effects

Dependent Variable: SumSkinfoldrisk

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.584[a]	4	.396	2.166	.074
Intercept	52.135	1	52.135	285.277	.000
MVPAQuart	.122	1	.122	.665	.416
LightQuart	1.281	3	.427	2.336	.075
Error	34.540	189	.183		
Total	338.000	194			
Corrected Total	36.124	193			

a. R Squared = .044 (Adjusted R Squared = .024)

Estimated Marginal Means Light Quart:

Estimates

Dependent Variable: SumSkinfoldrisk

LightQuart	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1st Quartile	1.339[a]	.062	1.218	1.461
2nd Quartile	1.319[a]	.062	1.196	1.442
3rd Quartile	1.184[a]	.061	1.064	1.305
4th Quartile	1.150[a]	.062	1.028	1.272

a. Covariates appearing in the model are evaluated at the following values: MVPAQuart = 2.5103.

Pairwise Comparisons

Dependent Variable: SumSkinfoldrisk

(I) LightQuart	(J) LightQuart	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1st Quartile	2nd Quartile	.020	.088	.818	-.153	.193
	3rd Quartile	.155	.087	.076	-.016	.327
	4th Quartile	.189[*]	.088	.033	.016	.363
2nd Quartile	1st Quartile	-.020	.088	.818	-.193	.153
	3rd Quartile	.135	.087	.124	-.037	.307
	4th Quartile	.169	.088	.055	-.004	.342
3rd Quartile	1st Quartile	-.155	.087	.076	-.327	.016
	2nd Quartile	-.135	.087	.124	-.307	.037
	4th Quartile	.034	.087	.694	-.137	.205
4th Quartile	1st Quartile	-.189[*]	.088	.033	-.363	-.016
	2nd Quartile	-.169	.088	.055	-.342	.004
	3rd Quartile	-.034	.087	.694	-.205	.137

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Univariate Tests

Dependent Variable: SumSkinfoldrisk

	Sum of Squares	df	Mean Square	F	Sig.
Contrast	1.281	3	.427	2.336	.075
Error	34.540	189	.183		

The F tests the effect of LightQuart. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

Profile Plots
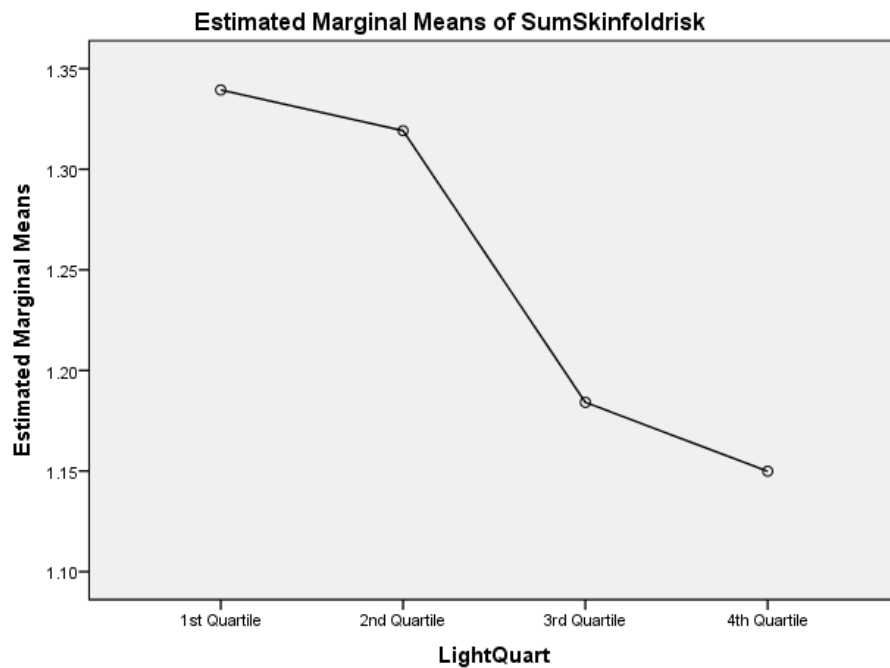
Estimated Marginal Means of SumSkinfoldrisk

Covariates appearing in the model are evaluated at the following values: MVPAQuart = 2.5103

Appendix H: Additional Linear Regression Results: Chapter 6

Associations between standing time and cardiovascular risk factors in adolescent females.

	Model 1			Model 2			Model 3		
	β	p	Adj. R^2	β	p	Adj. R^2	β	p	Adj. R^2
BMI	-.20	.13	.03	-.21	.12	.01	-	-	-
% BF	-.19	.14	.05	-.19	.15	.03	-	-	-
Σ SF	-.19	.14	.04	-.19	.16	.02	-	-	-
HDL-C	.09	.53	.00	.10	.48	-.01	.05	.72	.01
LDL-C	-.16	.24	-.02	-.16	.27	-.04	-.10	.49	.04
T Chol.	-.10	.46	.01	-.10	.52	-.01	-.07	-.52	-.02
TG	-.13	.33	-.02	-.14	.32	-.03	-.08	.56	.05
Insulin	-.24	.07	.01	-.26	.06	-.00	-.19	.15	.12
Glucose	-.16	.23	.10	-.13	.33	.09	-.11	.43	.09
HMW Apo	.05	.71	-.05	.04	.79	-.06	.04	.78	-.08
LAS	-.02	.91	-.06	.05	.76	-.01	.07	.70	-.02
MAP	.01	.97	-.05	-.02	.89	-.06	.00	.99	-.06
CIMT	-.17	.20	.01	-.17	.23	-.01	-.18	.22	-.03
CMRS	-.18	.28	-.04	-.17	.32	-.07	-	-	-
CMRS-Obs	-.14	.38	-.05	-.16	.36	-.08	-.09	.56	.14

BMI = Body Mass Index; % BF= Percentage Body Fat; Σ SF = Sum of Skinfold Thickness; HDL-C = High Density Lipoprotein cholesterol; LDL-C = Low Density Lipoprotein cholesterol; T Chol. = Total Cholesterol; TG = Triglycerides; HMW Apo = High Molecular Weight Adiponectin; LAS = Large Artery Stiffness; MAP = Mean Arterial Pressure; CIMT = Carotid Intima-Media Thickness; CMRS = cardio-metabolic risk score; CMRS-Obs = cardio-metabolic risk score excluding the measure of adiposity. Model 1 adjusted for age and stage of pubertal development; Model 2 adjusted for age, stage of pubertal development and objectively measured MVPA; Model 3 adjusted for age, stage of pubertal development, objectively measured MVPA and adiposity (sum of four skinfolds).

Appendix H: Additional Linear Regression Results: Chapter 6

Associations between light intensity physical activity (including standing time) and cardiovascular risk factors in adolescent females.

	Model 1			Model 2			Model 3		
	β	p	Adj. R^2	β	p	Adj. R^2	β	p	Adj. R^2
BMI	-.24	.07	.04	-.26	.06	.03	-	-	-
% Body Fat	-.22	.10	.06	-.23	.10	.04	-	-	-
Σ Skinfolds	-.22	.10	.05	-.23	.10	.03	-	-	-
HDL-C	.10	.45	.01	.11	.42	-.01	.06	.69	.02
LDL-C	-.18	.19	-.02	-.17	.23	-.03	-.10	.47	.05
Total Chol.	-.11	.41	.01	-.10	.46	-.01	-.08	.57	-.02
Triglycerides	-.15	.26	-.01	-.16	.26	-.03	-.09	.53	.06
Insulin	-.26	.10	-.00	-.23	.11	-.02	-.14	.31	.13
Glucose	-.11	.39	.09	-.09	.53	.09	-.05	.70	.09
Adiponectin	.08	.56	-.04	.08	.60	-.06	.09	.57	-.08
LAS	-.01	.97	-.05	.05	.77	-.02	.07	.70	-.04
MAP	-.03	.83	-.05	-.05	.77	-.07	-.02	.91	-.07
CIMT	-.19	.16	.01	-.19	.18	-.01	-.21	.16	-.02
CMRS	-.19	.25	-.04	-.17	.32	-.06	-	-	-
CMRS-Obs	-.16	.34	-.05	-.15	.40	-.07	-.06	.68	.19

BMI = Body Mass Index; % BF= Percentage Body Fat; Σ SF = Sum of Skinfold Thickness; HDL-C = High Density Lipoprotein cholesterol; LDL-C = Low Density Lipoprotein cholesterol; T Chol. = Total Cholesterol; TG = Triglycerides; HMW Apo = High Molecular Weight Adiponectin; LAS = Large Artery Stiffness; MAP = Mean Arterial Pressure; CIMT = Carotid Intima-Media Thickness; CMRS = cardio-metabolic risk score; CMRS-Obs = cardio-metabolic risk score excluding the measure of adiposity. Model 1 adjusted for age and stage of pubertal development; Model 2 adjusted for age, stage of pubertal development and objectively measured MVPA; Model 3 adjusted for age, stage of pubertal development, objectively measured MVPA and adiposity (sum of four skinfolds).

Appendix H: Additional Linear Regression Results: Chapter 6

Associations between prolonged sedentary periods (sedentary periods lasting more than 30 minutes in duration) and cardiovascular risk factors in adolescent females.

	Model 1			Model 2			Model 3		
	β	p	Adj. R^2	β	p	Adj. R^2	β	p	Adj. R^2
BMI	.16	.23	.02	.17	.23	.00	-	-	-
% Body Fat	.09	.49	.03	.09	.54	.01	-	-	-
Σ Skinfolds	.13	.33	.02	.12	.39	.00	-	-	-
HDL-C	.11	.41	.01	.11	.43	-.01	.15	.30	.04
LDL-C	-.08	.57	-.04	-.09	.53	-.05	-.13	.36	.03
Total Chol.	-.05	.74	.01	-.06	.70	-.01	-.07	.65	-.02
Triglycerides	-.02	.86	-.03	-.03	.86	-.05	-.07	.63	.05
Insulin	.07	.60	-.05	.08	.60	-.06	.03	.83	.09
Glucose	.05	.70	.07	.01	.93	.07	-.01	.96	.08
Adiponectin	-.19	.18	-.01	-.18	.23	-.03	-.18	.23	-.05
LAS	.19	.28	-.03	.12	.52	-.01	.11	.54	-.02
MAP	.09	.57	-.04	.14	.41	-.04	.13	.45	-.04
CIMT	.22	.11	.02	.21	.14	.01	.22	.14	-.01
CMRS	.11	.49	-.06	.09	.60	-.09	-	-	-
CMRS-Obs	.09	.60	-.06	.09	.61	-.09	.06	.70	.15

BMI = Body Mass Index; % BF= Percentage Body Fat; Σ SF = Sum of Skinfold Thickness; HDL-C = High Density Lipoprotein cholesterol; LDL-C = Low Density Lipoprotein cholesterol; T Chol. = Total Cholesterol; TG = Triglycerides; HMW Apo = High Molecular Weight Adiponectin; LAS = Large Artery Stiffness; MAP = Mean Arterial Pressure; CIMT = Carotid Intima-Media Thickness; CMRS = cardio-metabolic risk score; CMRS-Obs = cardio-metabolic risk score excluding the measure of adiposity. Model 1 adjusted for age and stage of pubertal development; Model 2 adjusted for age, stage of pubertal development and objectively measured MVPA; Model 3 adjusted for age, stage of pubertal development, objectively measured MVPA and adiposity (sum of four skinfolds).