Walking for Health in Adolescent Girls

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Abstract

Research has highlighted that adolescent girls are insufficiently active which has serious implications for their current and future health. Walking is recognised as an effective way of implementing regular, health enhancing physical activity (PA) into the daily routine of the general population and in an adolescent population walking is a convenient alternative to active play and sports participation. However it is currently difficult to promote walking and walking initiatives with adolescent girls due to lack of well-established evidence regarding both the quantity and quality of walking that might be advocated to promote PA and health. Therefore the aim of this thesis was to provide step based guidelines with regard to both the quantity and quality of walking required for health and thus inform walking interventions in adolescent girls. In order to achieve this aim four studies were undertaken. Study one explored the most appropriate way to assess walking activity, specifically whether walking on a treadmill accurately replicates walking overground in adolescent girls. Treadmill walking was found to overestimate the metabolic cost of walking in this population. This indicated that studies with the aim of exploring or promoting moderate intensity walking should focus on overground walking. Study 2 explored the quality of walking ($steps \cdot min^{-1}$) required to achieve moderate intensity physical activity (MPA) overground. The influence of different anthropometric measures on step rate ($steps \cdot min^{-1}$) equating to MVPA were also compared. Results suggest that a generic step rate of 120 $steps \cdot min^{-1}$ and 7200 steps in 60 minutes may be advocated to achieve MPA in adolescent girls. However inter-individual variation in step rate associated intensity was observed and it was suggested that a step rate range based on the girl's body mass may be beneficial for use with adolescent girls.

Study 3 considered the most appropriate step measurement instrument to assess free-living walking. Five commercially available instruments (activPAL™ and pedometers; Omron HJ-720-ITC, Omron HJ-304-E, New Lifestyles NL-1000, Yamax CW-701) were compared to direct observation handtally step counts, during continuous (study 3a) and incidental (study 3b) walking overground. The New lifestyles NL-1000 was most consistently accurate in quantifying steps and 'activity time' during continuous walking, but not during incidental walking. However due to the ease of use and additional youth friendly design features, the New Lifestyles NL-1000 was utilised in study 4. Study 4 explored the quantity of walking (steps·day^{-1}) required for health in adolescent girls. The results indicated that in terms of walking activity, 'healthy' adolescent girls do not walk significantly more in term of steps·day^{-1} or time spent in activity than girls classified as at 'health risk'. Therefore specific thresholds for quantity and quality of walking required for health could not be defined for this population. Overall findings of this thesis highlight, that walking should be assessed overground with an appropriate measurement instrument. A step rate of 120 steps·min^{-1} and 7200 steps in 60 minutes may be advocated to achieve MPA in adolescent girls. However further research is required to explore the relationship between walking and health in this population before we can promote an appropriate threshold of walking that is conducive to good health in adolescent girls.

Acknowledgements

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Hannah, my gorgeous daughter this one is for you.

'You are braver than you believe, stronger than you seem and smarter than you think'

A.A. Milne

This piece of work is proof of that.

Declaration

I hereby state that the following thesis has been completed by the student, Mhairi J Mac Donald and that the work is the students own.

I declare that the work presented here has not been submitted for any other degree or professional qualification except as specified.

Mhairi J MacDonald

Signed………………………………………………………………………………

Date……………………………………………………………………………....

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List of Abbreviations

PA	Physical Activity
MPA	Moderate intensity Physical Activity
MVPA	Moderate to Vigorous Physical Activity
$\dot{\mathbf{V}}\mathbf{O_2}$	Oxygen uptake
METs	Metabolic Equivalents or Metabolic Energy Turnover
TM	Treadmill
OG	Overground
BMI	Body Mass Index
WC	Waist Circumference
%BF	Percentage Body Fat
BP	Blood Pressure
HP1	Health Profile 1
HP2	Health Profile 1

Glossary of terms

Adolescent: A young person between the age of 10 and 19 years

Adolescence: the transitional stage of physical and psychological human development between childhood and adulthood

Ambulatory activity: movement activity

Body Composition: refers to the proportion of fat and fat-free mass in the body.

Children: young human beings below the age of full physical development

Criterion: a principle or standard by which something may be judged or decided.

Energy expenditure: refers to the amount of energy a person uses

Epidemiology: is the measurement of disease outcomes in relation to a population at risk.

Growth: The process of increasing in physical size.

Health: The state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity.

Incidental activity: Activities of daily living

Intensity: the physiological effort or rate of energy expenditure associated with participation in a specific activity

Maturation: The timing and tempo of progress towards the mature biological state.

Metabolic equivalents (METs): The ratio of an individuals working metabolic rate relative to their resting metabolic rate, commonly use to express the intensity of physical activity.

Moderate intensity physical activity: A moderate level of effort is required to undertake a task. An individual who is working a moderate intensity will notice a slight increase in their heart and respiration rate and feel slightly warm. Typically requires 3 times the amount of energy above resting (3 METs)

Moderate to vigorous intensity physical activity: A moderate to hard level of effort is required to undertake a task. An individual who is working a moderate to vigorous intensity will notice a substantial increase in their heart and respiration rate. Typically requires 3-6 times the amount of energy above resting (3-6METs).

Obesity: is a medical condition in which excess body fat has accumulated to the extent that it may have an adverse effect on health.

Pedometer: A step measurement device

Physical activity: a complex set of behaviours that encompass any bodily movement produced by skeletal muscles that result in energy expenditure

Public health: The science and art of promoting and protecting health and well-being, preventing ill-health and prolonging life through the organised efforts of society.

Physical inactivity: A sedentary state or low levels of physical activity

Sedentary activity: Activity that require little energy expenditure where individuals to sit or stand for an extended period of time (e.g. watching TV or working at a computer).

Self-efficacy: An individual's belief in their ability to succeed in specific situations.

Sporadic activity: irregular, scattered or isolated activity

Youth population: the period between childhood and adult age, a more fluid category than a fixed age-group

List of Conference presentations

Below is a list a of conference presentations which have arisen from studies in this thesis

What is Moderate Intensity Walking? Presented to the *Scottish Physical Activity Research Collaboration Student Conference,* Strathclyde University, Glasgow, 2010

Real world, real people; Can we assess walking on a treadmill to establish step count recommendations in an adolescent population Presented to the *Annual Conference of the British Association of Sport and Exercise Sciences*, Essex 2011 and *Scottish Physical Activity Research Collaboration Student Conference,* Strathclyde University, Glasgow, 2011

What is the Minimum Step Rate Required to Achieve Moderate Intensity Walking in Adolescent Girls? Presented to the *International Convention on Science, Education and Medicine in Sport*. Scottish Exhibition Conference Centre, Glasgow, 2012 and *Scottish Physical Activity Research Collaboration Student Conference,* University of Edinburgh, 2012

List of Appendices

Chapter 1 : General introduction

1.1 Context of research

The benefits of physical activity (PA) for physical and psychological well-being are well documented for both adults and young people (National Institute for Health and Clinical Excellence (NICE), 2009). However a number of young people are not sufficiently active to attain these benefits, and critically low levels of physical activity become increasingly more evident in girls than in boys from the age of 10-11years of age. In terms of health inequalities, adolescent girls are at a serious disadvantage which has considerable implications for their current and future health status. These gender inequalities in physical activity participation among the adolescent population are apparent across the globe (The World Health Organisation (WHO) Collaborative cross-national study: Health Behaviour in School-aged Children (HBSC), 2010) and in Scotland have persisted for well over a decade (Inchley et al., 2005; Currie et al., 2011). Consequently adolescent girls have been identified as a priority in the Scottish Government's physical activity strategy (Physical activity review group, NHS Health Scotland., 2009).

The decline in activity levels in young girls is coincidental with both physical changes associated with maturation, and environmental and social changes involved with the transition from primary to secondary school. It is still not fully understood why these changes lead to low physical activity levels, but girls frequently cite that lack of skill and feeling embarrassed as barriers to being physical active (Inchley et al., 2005) along with poor access to appropriate facilities, poor availability of enjoyable activities, a focus on competitive sport in school, a need to change into specialist clothing, and perceived lack of confidence in being physical active (Biddle et al, 2005a). As a consequence, a ‘best buy’ for physical activity intervention in this population is thought to involve opportunities to be active that foster and nurture competence and confidence in being physically active (Biddle et al, 2005b), whilst also targeting these perceived barriers.

Walking has been called the ‘nearest activity to perfect exercise’ (Morris and Hardman, 1997; P.328) and for adolescent girls, the concept that walking might provide the health benefits associated with physical activity is extremely attractive. Walking has a number of advantages which may help to minimise the barriers to participation among adolescent girls: it requires no specialist skills, equipment, facilities or clothing, has no financial cost and has low risk of injury. Specifically, data from the Scottish Health Survey (Bromely et al., 2005) show that walking was the most common activity reported by girls, and that walking activity remained stable during the early adolescent years when active play and sport participation decreased. However there is evidence to suggest that opportunities for walking have decreased in recent years, especially in relation to transport. In Scotland the proportion of children walking to school had fallen from 69% in 1985/86 to 48% in 2010 (Scottish Executive, 2006, Health Behaviour in School-aged Children Scotland, Currie et al., 2011). Therefore it is evident that interventions that provide adolescent girls additional opportunities to walk might contribute to overall activity levels and be well received by the girls themselves. However there remains limited evidence with which to inform researchers and practitioners regarding the design and evaluation of walking interventions in an adolescent population.

1.2 Purpose and significance of the research

Adolescent girls are insufficiently active which has serious implications for their current and future health. Walking is considered a common and accessible form of PA that can be incorporated into everyday living, is a convenient alternative to active play and sports participation and is relatively easy to measure in an adolescent population. In order to promote walking, researchers have sought to identify both the quantity of walking (number of daily steps) and quality of walking (intensity of stepping) required for health. Current physical activity guidelines state adolescents should engage in at least 60 minutes and up to several hours of moderate to vigorous physical activity (MVPA) every day (Department of Health 2011), however step based recommendations that reflect this guideline are still emerging. With regard to the stepping rate required to promote moderate intensity walking in young people, and specifically adolescent girls, there is limited data.

It is currently not known how much walking should be recommended for adolescent girls to significantly increase PA levels and maintain health and therefore what to recommend for intervention in schools and communities or how to evaluate walking (interventions) in line with current PA guidelines. Considering the potential impact that walking interventions offer in terms of increasing activity in low active adolescent girls, these issues need to be addressed. Therefore the main focus of this thesis was to provide step based guidelines to inform walking interventions in adolescent girls.

1.3 Evaluation framework

The nature of this project does not allow it to conform to the usual definition of theoretical or evaluation frameworks, as would a project aimed at behavioural intervention (PA is behaviour). However, Bassett et al., (2008) outlined a valuable three stage process/paradigm to provide a framework for the thesis (see figure 1.1). In this model, the latter stages build directly on relevant research in the earlier stages, but the model is iterative, such that later stages can inform a need to return to the earlier stages. In the current context, the definitional stage refers to defining the characteristics of healthy walking in adolescents and the confirmatory stage refers to how this definition is accurately assessed and used to identify step count targets. The theory testing stage would refer to exploring the outcomes of healthy walking through interventions, and is not an aim of this thesis. The aim of this thesis is to inform the final step in the research process.

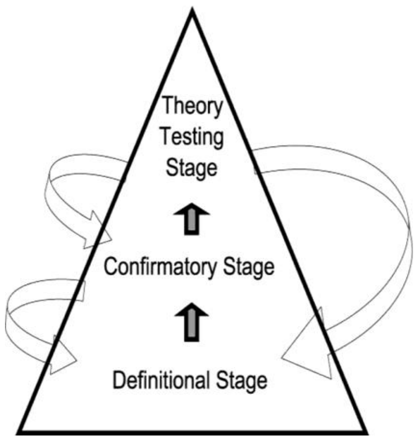


Figure 1.1. Three stage model for validation of walking research from Bassett et al., (2008)

1.4 Summary of individual chapters

In order to achieve the aim of this thesis it has been presented in 7 chapters. This chapter has provided a brief context and outlines the main aim of the thesis. Chapter 2 summarises the most relevant literature under the headings: Physical activity and Public health, Physical activity and Adolescent Girls, Physical activity assessment, Walking for Health and Walking for health in Adolescent Girls. Chapters 3 and 5(a & b) consider the most appropriate way to assess walking activity (both continuous and incidental walking activity). Chapter 4 explores the quality of walking (steps per min) required to achieve moderate intensity physical activity. Chapter 6 explores the quantity of walking (steps per day) that should be advocated for health in an adolescent girl population and Chapter 7 provides a summary of the research findings, conclusions and practical recommendations for future research direction.

Chapter 2 : Review of the Literature

2.1 Physical Activity and Public Health

Physical activity (PA) is defined as a complex set of behaviours that encompass any bodily movement produced by skeletal muscles that result in energy expenditure (Caspersen, Powell and Christenson, 1985). PA therefore incorporates a range of activities, including active play, incidental or sporadic movement, exercise, active travel and sports participation (Department of Health, 2011). The health benefits associated with being physically active are now well established in adults and include reduced risk of all-cause mortality and many chronic lifestyle diseases such as, cardiovascular disease, hypertension, diabetes, osteoporosis, cancer and depression, as well as improved cardiorespiratory and muscular fitness, body composition, bone health, psychological well-being and cognitive function (World Health Organisation (WHO) 2010a). Further there is also considerable evidence to support the role of PA in promoting good health in young people, for which the health benefits include healthy growth and development of the musculoskeletal and cardiorespiritory systems, maintenance of energy balance (and avoidance of obesity and related diseases), avoidance of coronary heart disease risk factors, the opportunity for social interaction, achievement and improved psychological well-being (Department of Health, 2011). Despite this documented evidence a considerable percentage of the global population remain insufficiently active for health (Lee et al., 2012a), for which the direct (health) and wider (economic, environmental and social) consequences have recently been described as ‘pandemic’ (Das and Horton, 2012; Kohl et al., 2012).

Physical inactivity is the fourth leading risk factor for all-cause mortality (Kohl et al., 2012) and the main preventable cause of chronic lifestyle diseases worldwide (Lee and Buchner, 2008). In the United Kingdom (UK) alone it is estimated that physical inactivity costs the National Health Service (NHS) approximately £1.06 billion every year (Department of Health, 2011). However this is likely a conservative estimate, as this figure is estimated on only five common lifestyle diseases (coronary heart disease, stroke, diabetes, colorectal and breast cancer) and excludes the cost of diseases, such as osteoporosis and associated falls and fractures (Department of Health, 2011). It also excluded sickness and absence from the work place, which has impact on the wider economy (Department for Health, 2011). Therefore increasing population PA levels is a key public health issue and is currently at the forefront of many public health strategies (Salmon et al., 2010; Kohl, et al., 2012) as a fundamental, cost effective health behaviour. In Scotland the Government has demonstrated a commitment to tackling the inactivity problem through the National Physical Activity Strategy and specifically aims to increase the proportion of adults and young people (children and adolescents) undertaking the minimum recommended level of PA to 50% and 80% respectively by 2022 (Physical Activity Task Force, 2003).

2.1.1 Physical Activity in Young People a 'Window of opportunity'

As many chronic lifestyle disease states only become evident during adulthood, direct evidence linking physical inactivity in the youth population with lifestyle related diseases such as cardiovascular disease, hypertension, diabetes and osteoporosis is limited (National Institute for Health and Clinical Excellence (NICE), 2009). However children and adolescents often display risk factors associated with many chronic disease states, for example excessive body fat, increased insulin levels and low bone mineral density (Malina, Bouchard and Bar-Or, 2004; Deckelbaum and Williams, 2001). Therefore the degree to which excessive risk factors are displayed in children and adolescence are often considered as indicators of their health status. A risk factor is a condition that, when present over an extended period, significantly increases the probability of a common degenerative disease (Malina, Bouchard and Bar-Or, 2004). PA in young people reduces such risk factors, which in turn positively impacts on their current health, for example active children and adolescents are generally leaner, display healthier cardiovascular profiles and develop higher peak bone masses than their less active counter parts (Twisk, 2001; Hallal et al., 2006). Further there is now evidence to suggest that such risk factors or health indicators (e.g. excessive body fat) track from childhood to adulthood and therefore may have an indirect impact on adult health (NICE, 2009) (see Figure 2.1). E.g. childhood obesity has been linked to higher and earlier death rates in adulthood (Krebs et al., 2007).

Additionally there is evidence to suggest that young people who are active in youth will remain active through to adulthood (Fuentes et al., 2003; Kjonniksen et al., 2008), specifically lifestyle choices and PA patterns established during adolescence may be key for adulthood PA patterns (Hallal et al., 2006). Therefore establishing lifetime PA patterns may also be a positive consequence of youth PA and a key opportunity to gain the health benefits associated with PA through the life stages. Thus childhood and adolescence (PA in young people) may be a ‘window of opportunity' or a time when chronic lifestyle diseases can to an extent be avoided (Twisk, 2001; Department of Health 2011).

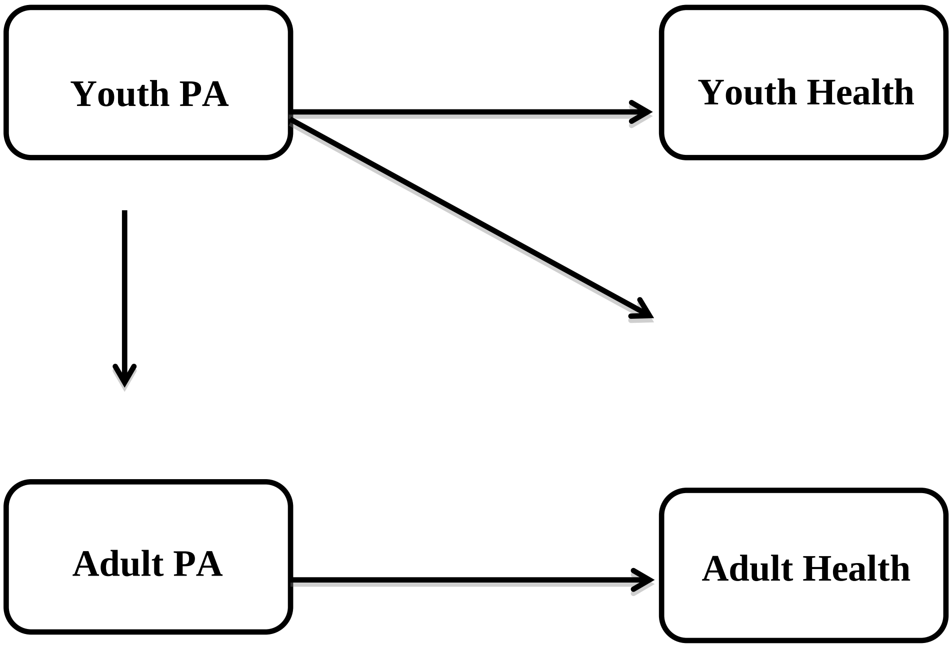


Figure 2.1. Associations between youth physical activity, adulthood physical activity and health outcome in both youth and adulthood, adapted from the Physical activity and children review 1: descriptive epidemiology. Promoting physical activity for children and young people, NICE guidelines 2009

2.1.2 Recommended levels of Physical Activity for Young People

A recent review of the PA guidelines in the UK has led to the development of UK wide guidelines (Department of Health, 2011) that supersede previous guidelines published by the English, Welsh, Northern Irish and Scottish governments (Department of Health 2004, Welsh Assembly Government 2005, The Health Service Executive (HSE), 2009, Physical Activity Task Force, 2003). Although fundamentally the message has not changed (that children and young people aged 5 - 16 should accumulate at least one hour of PA on all, or most, days of the week), the guidance also now focuses on encouraging vigorous exercise and discouraging sedentary activities.

The guidance states that:-

1. All children and young people should engage in moderate to vigorous intensity PA for at least 60 minutes and up to several hours every day.
2. Vigorous intensity activities, including those that strengthen muscle and bone, should be incorporated at least three days a week.
3. All children and young people should minimise the amount of time spent being sedentary (sitting) for extended periods.

Further this recommended dose of PA should be taken over and above normal baseline activity. Furthermore it is also acknowledged that even small amounts of PA are better than no PA (being inactive) and may significantly benefit the health of high risk individuals (e.g. children and adolescence that display excessive risk factors) (Department of Health 2011).

2.1.3 Current PA levels

In Scotland there have been a number of studies and surveys that have examined youth PA levels, which inform and update the national PA strategy. These include the Scottish health survey (1998, 2003, 2008, and 2011), the Health Behaviour in School-aged Children (HBSC) study: the WHO collaborative cross-national survey in Scotland (1985, 1989, 1993, 1995, 1997, 2001, 2005, 2009/10), the Physical Activity in Scottish Schools (PASS) study (2008) and the growing up in Scotland study (2003, 2008).

The most recent Scottish Health Survey (The Scottish Government, 2011) suggests that 76% of boys and 70% of girls are meeting recommended PA levels (table 2.1). However when these results are looked at more closely it is clear that PA levels differ slightly among children of different ages. PA levels remain fairly consistent in boys, but drop to only 48% in 13-15 year old girls. The 2010 Health Behaviour in School-aged Children (HBSC) survey suggested that only 19% of boys and 11% of girls aged 11-15 were meeting current PA guidelines in Scotland (Currie et al., 2011). Both of these surveys utilised self-report measures and despite the discrepancy, it is clear a large proportion of young people in Scotland are not sufficiently active to advocate good health, and that the problem is more pronounced in adolescence and in girls. This trend is replicated worldwide and is apparent from the Health Behaviour in School-aged Children (HBSC) cross-national survey which includes data from 43 countries across Europe, America and Canada. Several longitudinal studies have also confirmed that PA levels decline dramatically during adolescence (Nelson et al., 2006; Brodersen et al., 2007) with a more marked decrease in girls rather than boys (Brodersen et al., 2007; Inchley et al., 2008).

Table 2.1. Percentage of boys and girls achieving the recommended PA levels of 60 minutes every day of the week (The Scottish Government, 2011).

Age		2-4	5-7	8-10	11-12	13-15	Total
Boys	% 60mins/day	68	82	82	81	69	76
Girls	% 60mins/day	72	78	80	70	48	70

2.2 Physical Activity and Adolescent Girls

Research has highlighted that the dramatic decline in PA behavior in girls during adolescence coincides with both physical changes associated with maturation, and environmental and social changes involved with the transition from primary to secondary school (Biddle et al., 2004; Boreham and Riddoch, 2001). While research into PA correlates (factors associated with physical activity) and determinants (factors with a causal relationship) has burgeoned in recent years (Bauman et al., 2012), it is still not fully understood why these changes lead to low PA levels, though girls frequently cite that lack of skill and feeling embarrassed as barriers to being physically active (Inchley et al., 2005) along with poor access to appropriate facilities, poor availability of enjoyable activities, a focus on competitive sport in school, a need to change into specialist clothing, and perceived lack of confidence in being physically active (Biddle et al., 2005a). Further in a recent review of the correlates of PA, Bauman et al., (2012) identified self-efficacy, previous physical activity, family social support, neighbourhood design, appropriate facilities and locations, and the transportation environment as consistent correlates of PA in adolescents. However the aetiology of PA behavior is complex and varies by domain

(Bauman et al., 2012). It is therefore likely that there are numerous factors associated with this evident decline (Sallis, et al., 1992).

The majority of studies examining factors associated with PA behaviour are cross-sectional, which is a known limitation of correlates literature (Bauman et al., 2002). However these studies contribute to the evidence base for planning effective interventions, which target the factors known to cause inactivity (Bauman et al., 2012). Consequently a 'best buy' for intervention in adolescent girls is thought to involve opportunities to be active that foster and nurture competence and confidence in being physically active (Biddle et al., 2005b), whilst also targeting the perceived barriers.

Walking has been called the 'nearest activity to perfect exercise' (Morris & Hardman, 1997; p.328) and for adolescent girls the concept that walking may provide the health benefits associated with PA is extremely attractive. Walking has a number of advantages which may help minimise the barriers to PA participation among adolescent girls, for example walking is a familiar activity that requires no specialist skill, equipment, facilities or clothing, has no financial cost, can be a social activity and incorporated into everyday life, with low risk of injury. However, understanding the precise extent of the physical inactivity problem and how best to plan and design effective health interventions is complicated by the variety of methods adopted to measure PA.

2.3 Physical activity assessment

Effective PA assessment is crucial to understanding the nature and mechanisms underlying the health benefits of a physically active lifestyle, tracking and monitoring PA trends, evaluating interventions and informing public health policy (Wareham and Rennie 1998; Adamo et al., 2009). PA assessment is therefore a unique and critical area which, despite significant progress and recent advances in technology, continues to pose a number of inherent research challenges (Welk, 2002; McClain et al., 2007a; Ekelund et al., 2011). Further, additional challenges arise when carrying out research in relation to PA in children and adolescents as compared with adults. This is due to the cognitive, physiological and biomechanical changes that occur during natural growth and development, together with the sporadic and variable PA patterns found in the youth population (Armstrong and Welsman 2006; Corder et al., 2008).

PA can be determined and measured in many ways. However frequency, duration and intensity are consistently accepted characteristics of PA and have predominantly been used as appropriate dimensions in the assessment of PA. According to Caspersen et al., (1985) and Vanhees et al., (2005) PA assessment is built on these underlying indicators. Frequency is the number of events of PA during a specific time period; duration is the length of time of participation in a single bout of PA and intensity is the physiological effort or rate of energy expenditure associated with participation in a specific activity. Intensity is often expressed in multiples of resting metabolic rate (RMR) also known as metabolic equivalents or metabolic energy turnover (METs).

One MET is considered to be 3.5ml $O_2 \cdot kg^{-1} \cdot min^{-1}$ for the average adult (Spadano et al., 2003). Three METs is considered to be the minimum requirement to achieve moderate intensity and represents 3 times resting energy expenditure (i.e. 10.5ml $O_2 \cdot kg^{-1} \cdot min^{-1}$ for the average adult) (Norton et al 2010). However when assigning energy cost or intensity of relevant activities in children and adolescents a correction factor is required to be added to adult MET values to compensate for the higher resting metabolic rate per unit of body mass in this population (Bitar et al, 1999; Harrell et al, 2005). Pate et al., (1998) suggested 5-8 METs were representative of moderate intensity activity in children and adolescents, however this still assumes a RMR of 3.5ml $O_2 \cdot kg^{-1} \cdot min^{-1}$. To this extent Harrell et al, (2005) suggested that although young people have higher RMRs than adults (in the region of 4-5 ml $O_2 \cdot kg^{-1} \cdot min^{-1}$), the ratio of activity energy expenditure and resting energy expenditure appears to be similar in adults and youth. Thus moderate intensity in youth might still be defined by 3 METs, but only when a specific RMR is either measured or estimated.

Other definitions of moderate intensity PA in youth have derived from heart rate and oxygen uptake ($\dot{V}O_2$). Whilst considered a more direct assessment of exercise intensity, there remains considerable variation in the thresholds thought to represent MPA in young people. 139-159bpm, 55-70% maximum heart rate, 50% increase of resting heart rate, 40% heart rate reserve (HHR) and 40-60% $\dot{V}O_2max$ are frequently reported thresholds. However, how these physiological responses, correspond to MPA thresholds in youth are not well understood (Steap et al., 2001) and there remains no standardisation or confirmation as to the most appropriate criteria to use.

Furthermore, PA takes place in many different settings and this is usually referred to as the domain of PA, being the context or reason for PA e.g. occupational, household chores, leisure, travel and sport. Bauman et al., (2006) and Dollman et al., (2009) include setting and mode as dimensions of PA, mode being the specific activity undertaken e.g. walking or cycling. However setting and mode are more commonly considered as domains of PA.

While it remains virtually impossible to gain exact measures able to account for all characteristics of PA, it is imperative to have a clear specification of the characteristics (i.e. dimensions and domains) in order to choose an appropriate and feasible method of assessment (Stathi, Gillison and Riddoch, 2009). Additionally PA assessment methods must be socially acceptable, should not burden the individual and should only minimally influence normal PA patterns to reduce the likelihood of reactivity (Armstrong and Welsman, 2006). Measurement techniques examining youth PA must also demonstrate validity, reliability and practicality (Laporte, Montoye and Caspersen, 1985).

2.3.1 Subjective measures of youth PA

Self-report measures of PA are commonly used to assess youth PA and include retrospective questionnaires, interview administered questionnaires, diaries and proxy reports (Sallis and Saelens, 2000; Sinard and Pate, 2001). Such methods are simple, have low administration cost and the ability to be used with large sample sizes. However they also have a number of limitations (Ekelund et al., 2011). Self-report methods such as the physical activity questionnaire- adolescents (PAQ-A) (Kowalski et al., 1997) and the 3-day recall physical activity recall instrument (Motl et al., 2007; Stanley et al., 2007) prompt respondents to retrospectively recall different characteristics of PA e.g. dimensions and domains. These methods are therefore influenced by the respondent's ability to accurately recall relevant activities and are subject to recall bias (Sallis, 1991; Pate, 1993). As children and adolescents are less time conscious, they can have difficulties separating fantasy from reality, engage in more sporadic and variable intensities of PA and often feel compelled to respond in a socially desirable manner than adults, therefore accurate recall is often more problematic (Corder et al., 2008; Adamo et al., 2009; Ekelund et al., 2011). Thus, self report methods often overestimate PA levels among the youth population (Ekelund et al., 2011).

Further, error may also be introduced by the scoring of these self-report methods. Self-report methods are often scored in terms of duration, intensity or estimates of energy expenditure. However many differ on the type, intensity and/or the duration of activities and the recall period, making the validity of specific types and domains of PA difficult to assess (Ekelund et al., 2011).

Assigning energy cost or estimating energy expenditure (EE) of PA from self report methods can be particularly problematic in the youth population. EE derived from such methods is often expressed as metabolic equivalents (METs) and is calculated by multiplying the dimensions (frequency, duration and intensity) of reported PA (Ekelund et al., 2011). Although the MET system allows different activities to be compared in terms of the overall aerobic challenge to the body (Welk, 2002) and PA domains. For example walking (for pleasure) (equivalent to 3.5METs) and horse riding (equivalent to 4.0METs) are very different activities (Ainsworth et al., 2000).

The estimation of youth EE often employs adult derived energy costs (Ainsworth et al., 2000), which generally lead to underestimation of EE in youth (Roemmich et al., 2000; Harrell et al., 2005). Thus, results from validation studies suggest that self report methods, such as questionnaires are valid to classify a population in distinct categories (e.g. low, moderate and high active), but they are not appropriate to quantify energy expenditure at an individual level (Sheppard, 2003; Neilson et al., 2008; Corder et al., 2009).

Despite documented limitations regarding subjective methods of PA assessment, they remain the only available method for assessing the domains (setting and mode) of PA behaviour (Ekelund et al., 2011). Therefore Ekelund et al., (2011) has suggested they should be complemented by standard objective measures of PA.

2.3.2 Objective measures of youth physical activity

Objective measures of PA have considerably improved the capacity for accurate assessment of the dimensions (frequency, duration and intensity), volume and patterns of PA as well as sedentary behaviours (McClain and Tudor-Locke, 2009; Ekelund et al., 2011). There are a number of objective measures and an increasing number of instruments available to objectively assess youth PA (McClain & Tudor-Locke, 2009); these include doubly labelled water, indirect calorimetry, direct observation, heart rate and activity monitors. Doubly labelled water, indirect calorimetry and direct observation are often considered to be criterion or primary measures of PA, (as they directly measure EE, which is a consequence of PA, and individual movement) (Sinard and Pate, 2001). However secondary objective measures such as heart rate and activity monitors (accelerometers and pedometers) are more widely available and have become the instruments of choice when assessing PA in children and adolescents due to their lower cost, reduced subject burden, non-intrusive nature and practicality (Trost, 2001; Trost et al., 2006).

Heart rate (HR) monitoring is based on the linear relationship between HR and oxygen consumption and although it is not a direct measure of PA, it provides information on the stress placed upon the cardiopulmonary system during PA (Armstrong, 1998; Rowlands and Eston, 2007). This information can be recorded over time, facilitating the assessment of the dimensions (frequency, duration and intensity) and patterns of PA. However PA is not the only factor which can influence HR. Factors such as psychological state (e.g. anxiety), environmental conditions, hydration status, muscle physiology and fitness level can effect HR, and these factors are particularly influential at low intensity (Armstrong and Welsman, 2006). Thus the use of HR to quantify exercise intensity in the youth population is considered questionable (Eklund et al., 2001). Despite this, HR monitoring is a non-intrusive, low reactive, valid and reliable method commonly used to measure youth PA (Malina et al., 2004; Rowlands and Eston, 2007) and is relatively cost effective for use in small to moderate sized studies.

Activity monitors (e.g. accelerometers and pedometers) are small, unobtrusive body worn instruments, which have become increasingly popular as a means of measuring ambulatory activity. Accelerometers are generally considered to be more advanced monitors than pedometers as they have the ability to sense and register accelerations within a movement and not just the number of movements. Accelerometers are also the most commonly used method to assess free living PA in the youth population (Rowlands, 2007; Oliver et al., 2007) as they provide useful insight into complex physical activity patterns and time spent at various intensities (Tudor-Locke et al., 2011c). However they are generally more expensive than pedometers and require expertise for efficient use. Pedometers therefore provide a low cost, practical, easy to use means of quantifying volume of daily ambulatory activity (Bassett and Strath, 2002; Freedson and Millar, 2000; Welk et al, 2000b) and thus are a useful tool for large scale studies and well suited to assess youth PA (Rowlands et al., 1997). Despite this pedometers have been commonly criticised for their limited output of number of steps taken and their inability to quantify intensity of PA or time spent in moderate to vigorous activity (MVPA). New technologies have seen the development of accelerometry-based pedometers. These are sophisticated pedometers which feature a piezoelectric accelerometer mechanism (compared to the traditional spring lever arm mechanism) for improved precision of step counts (Crouter et al., 2005; Duncan et al., 2007a) and an internal digital timing mechanism allowing them to quantify time spent at various intensities (i.e. intensity of stepping, steps·min^{-1}) in addition to number of daily steps (Hart et al., 2011, Tudor-Locke et al., 2011c). This new generation of pedometer therefore provides practical and affordable opportunities to measure and communicate walking activity in terms of steps·day^{-1} and activity time e.g. time spent at or above pre-specified intensity thresholds (steps·min^{-1}) (Tudor-Locke et al., 2011c; Beets et al., 2011).

Assessment of walking

Pedometers have been predominantly used to assess walking as a specific mode of PA. They are commonly employed by researchers, practitioners and the general public alike to measure, communicate and motivate walking behaviour (Tudor-Locke, Bassett, Rutherford et al., 2008a; Tudor-Locke and Lutes, 2009), as they provide immediate feedback regarding steps taken, distance covered and time spent in activity (MVPA in some models) to the end user. While pedometers are a valuable tool in the assessment of walking behaviour, concerns have been raised regarding the lack of standard practice and comparability among the many competing technologies now available on the commercial market (Freedson et al., 2012).

Although the fundamental properties of these pedometers are similar, they are defined by manufacturer sensitivity thresholds for detection of step and activity time (Tudor-Locke et al., 2009). Sensitivity, for example, can be controlled by the traditional spring lever arm mechanism or internal microprocessors which are inherently different between commercial products (Tudor-Locke et al., 2011c) and thus what constitutes as a step may also differ. Further in the attempt to improve accuracy, pedometer manufactures have developed inbuilt features that prevent the counting of accidental steps, non-steps or erroneous movement, therefore some pedometers only record steps taken in bouts of four seconds or longer. While it is important to distinguish steps from non-steps, these inbuilt features may lead to an underestimation of walking activity (Tudor-Locke et al 2011c), especially in the youth population where PA is often sporadic in nature and accumulated in short bouts throughout the day (Bailey et al., 1995; Berman et al., 1998; Baquet et al., 2007).

However a number of brand to brand comparisons have shown that outputs (steps and activity time) are reasonably comparable between studies and populations where high quality research grade pedometers have been used (Tudor-Locke et al., 2011c). Research grade pedometers refer to those that are manufactured to a sensitivity threshold of 0.35Gs, detect ±1 step error on the 20 step test (5% error), detect ±1% error most of the time during treadmill walking at approximately 3mph (normal walking pace) (Tudor-Locke et al., 2006) and have a mean absolute percent error (MAPE) of less than 3% (Crouter et al., 2003; Hatano 1997).

Although it is likely new pedometer models with additional features will emerge in the future, demonstrating that the model intended for use is accurate, valid, reliable, feasible, appropriate and evaluated relative to an accepted criterion within the population of interest (Hart et al., 2011a; Chen et al., 2012; Butte et al., 2012) is key for correct and accurate feedback (steps and activity time) to be given to the end user.

2.4 Walking and Health

Walking is one of the oldest and simplest modes of physical activity (PA) (Zhu, 2008), and is often cited as the 'nearest activity to perfect exercise' (Morris & Hardman, 1997; p.328) due to its unique epidemiological features. Unlike other forms of PA, walking is familiar, practiced daily and is appropriate regardless of gender, age, ethnic group, education and income level (Lee & Buchner, 2008; Bassett et al., 2008). Additionally walking boasts a number of functional features or capacities, such as transportation, household or occupational duties, stair climbing and shopping (Tudor-Locke & Ham, 2008). Thus walking can incorporate small or large (incidental or continuous) parts of work, be done inside or outside and be conveniently incorporated into everyday life.

Walking has also been called the 'perfect form of preventative medicine' (Tudor-Locke et al., 2012) as it is associated with a number of direct (health) and wider (economic, environmental and social) benefits. These benefits include a reduced risk of a number of chronic lifestyle diseases such as obesity (Murphy et al., 2007; Haines et al., 2007; Tully et al., 2007, Gordon-Larsen et al., 2009), cardiovascular disease (Albright and Thompson, 2006; Smith et al., 2007); diabetes (Caspersen and Fulton, 2008); cancer (Magne et al., 2011) and premature mortality (Hamer and Chida, 2008). Benefits also include prevention of functional losses associated with age-related disability (Pahor et al., 2006), improved psychological state (mood) (Haines et al., 2007; Ekkekakis et al., 2000; Murphy et al., 2002), and quality of life (Fisher and Li, 2004).

With regard to the wider benefits, walking has the potential to reduce the cost of the physical inactivity pandemic, through reduced rates of chronic disease states and thus medical care expenditure, in addition to the considerable saving made through reduced rates of sickness and absenteeism from the workplace (Davis, 2010; Aoyagi and Shephard, 2011). Walking has a high benefit to cost ratio in terms of intervention and investment in infrastructure, which provide greater opportunities for communities and subpopulations to become more active (Davis, 2010). It is also economical to the individual as it costs less than taking the car or using public transport (Beuhler & Pucher, 2012). Further, as a form of active travel walking reduces car use and thus road congestion and air pollution. This in turn may result in a reduction in illnesses aggravated by air pollution e.g. asthma and some cancers (Lee & Buchner, 2008), in addition to positively impacting on the environment. Furthermore walking can give exposure to the natural environment, whether as an escape from work surrounding or as a leisure time activity; there is evidence that such exposure (e.g. parks and green space) reduces stress (Yamaguchi, Deguchi & Miyazaki, 2006) and improves mental health (Barton & Pretty, 2010). In the social context, walking is often seen as a social activity e.g. adolescent girls walking to school with their friends, a group of mums on the school commute, colleagues on the daily commute or the elderly on their weekly walk with a walking group. Such social interaction has been shown to have independent effects on health as indicated by evidence that low social interaction is associated with increased mortality (Rowe & Kahn, 1997).

Walking therefore has a sustainable importance to public health as a familiar, accessible and affordable form of PA (Lee & Bucher, 2008), that can be incorporated into everyday life and sustained in to old age (Ogilvie et al., 2007). It is therefore not surprising that walking has been adopted by a number of public health strategies worldwide as a primary example of health related PA (O'Donovan et al., 2010; Paterson and Warburton, 2010).

2.4.1 Walking opportunities

For most people walking remains an essential part of daily living. However, today walking behaviour is continually influenced and altered by modern life (Tudor-Locke 2012). Evidence suggests that opportunities for walking have been replaced with more attractive and convenient sedentary alternatives, especially in relation to transport, occupational, household and preferred leisure time activities (Beuhler & Pucher, 2012). The most dramatic decline in walking activity throughout Western Europe, America and Australia is through walking for transport, with the exception of Holland where walking trips have remained stable in recent years (Beuhler and Pucher, 2012). Although active transport is promoted in the UK (Ng and Popkin, 2012), increased car use, ownership of a second car and vehicle miles travelled has led to only 22% of trips in the UK now being made on foot compared with 44% in 1975 (Beuhler & Pucher, 2012) and on average individuals walking approximately 75 miles less per year (Transport Scotland, 2011).

Active transport among the youth population has also declined with the reduction in the number of active (walking) trips to school being a major contributor (Giles-Corti et al., 2009). In Scotland the proportion of youth walking to school has fallen from

69% in 1985/6 to 54% in 2004/05 and further to 48% in 2010 (Scottish Executive, 2006, Currie et al., 2011). Furthermore active transport has been shown to be age dependent, with adolescents (12-18yrs) being less likely to walk or be driven by car to school than children (4-11yrs), but more likely to travel on public transport (Transport Scotland, 2011). This result is reflected in the most recent health behaviour in school aged children survey (2010) which reported that only 45% of adolescents in Scotland walk to school regularly (Currie et al., 2011).

Additionally with the advances in modern technologies, incidental walking activity in the home, schools and work place has also declined (Ng and Popkin, 2012). In some areas computers and machinery have made manual work almost redundant and the increased use and accessibility of electronic media (e.g. televisions, mobile phones and internet) has similarly contributed. Among the youth population and specifically adolescent girls the use of such technologies greatly increases between the age of 11 and 15 years (Currie et al., 2011), a time where PA decreases (Bradshaw et al., 2012). Although such sedentary behaviours e.g. watching the television have been shown not to replace time in PA (Ray-Lopez, 2008), they are associated with adverse health outcomes such as obesity (Rennie et al., 2005). Thus it is evident that interventions are required to reverse the decline in walking activity and provide opportunity for individuals to be active within their daily lives.

2.4.2 Walking interventions

Walking interventions have been shown to encourage and increase walking activity, when they are tailored to individual needs and targeted at the least active or at those most motivated to change (Ogilvie et al., 2007). Therefore such interventions have the potential to contribute towards increasing PA levels among low active populations. Consequently interventions that provide adolescent girls with additional opportunities to walk might contribute to overall activity levels and be well received by the girls themselves.

In a systematic review of interventions to promote walking, Ogilvie et al. (2007) identified only one walking intervention involving adolescent girls. This study, by Schofield et al. (2005) found that pedometer-based interventions with individual goal settings led to short term increases in PA among low active adolescent girls. Since then a further four studies have involved adolescents in pedometer-based interventions to increase PA (Zizzi et al., 2006; Lubans & Morgan, 2008; Tsiros et al., 2008; Lubans et al., 2009a), however only two have documented increases in PA, which was again only seen among low active adolescents (Lubans & Morgan, 2008; Lubans et al., 2009a). While both these studies (Lubans & Morgan, 2008; Lubans et al., 2009b) involved adolescent boys as well as girls, it confirms that the intervention effect may be greater in low active or sedentary individuals (Tudor-Locke et al., 2011a).

Most recently Lee et al., (2012b) conducted a randomised control study that combined a twelve week pedometer-based intervention with self efficacy theory to promote PA primarily among, but not restricted to low active adolescent girls. The intervention group in this study were instructed to complete 12,000 steps of walking and/or 60 minutes of aerobic walking per day. Aerobic walking in this study was considered to be bouts of at least 10 minutes continuous walking at a step rate ≥ 60 steps·min^{-1}. The intervention group also received individually tailored contact meetings with the researcher, where walking was discussed and encouraged, as the use of pedometers and pedometer step counts alone have been shown not to increase

PA levels among youth (Lubans et al., 2009a). The result of the study showed significant increases in the number of aerobic steps among the intervention group compared with the control, but no difference in cardio respiratory endurance and perceived exercise self-efficacy scores at twelve week follow up. However it is unclear whether increases in aerobic steps were among both active and/or low active adolescents as the authors did not report the number or compare these groups.

Further, while the use of aerobic steps in this study is novel,(and now possible due to advances in technology) a step rate of 60 steps·min^{-1} is unlikely to represent moderate intensity and thus aerobic walking (Jago et al 2006; Graser et al 2009; Lubans et al 2009b, Graser et al 2011 and Tudor-Locke et al 2011a). However the author justifies the use of aerobic steps rather than total steps·day^{-1}, as they found the girls could achieve the advised number of steps (12, 000 steps·day^{-1}) by simply shaking the pedometer (Lee et al, 2012). This highlights the importance of appropriate assessment of technology prior to use. Furthermore 12,000 steps·day^{-1} is likely to be unachievable or sustainable for low active individuals (Tudor-Locke et al, 2011a). As it is acknowledged that among insufficiently active adolescence any increase in MPA or steps may be important in producing health related benefits, aiming to increase walking in small measurable increments is likely to be a more effective approach (Tudor-Locke et al 2011a).

Additionally the level of the intervention effect among these studies varies considerably, which may be due to differences in participant characteristics between studies (e.g. gender, age, younger vs. older adolescents, weight status, non-obese vs.

obese), assessment method/ instrument (e.g. pedometer model, sealed vs. unsealed) and study design (e.g. length of intervention, 1week-6months) (Lubans, Morgan & Tudor-Locke 2009). There remains very limited evidence however, with which to inform researchers and practitioners regarding the design and evaluation of walking interventions, especially when compared with what is known within the adult population (Bravata et al., 2007; Baker et al., 2008; Richardson et al., 2008; Kang et al., 2009, Fitzsimons et al., 2012). For example, adult studies that have employed pedometers have shown increases of approximately 2000 steps·day^{-1} (Bravata et al., 2007). Further those that have provided step count targets of 10,000 steps·day^{-1}, 3000 steps in 30 minutes or 1000steps in 10 minutes have shown the greatest increase in walking behaviour (stepping), and these changes have been maintained both in the short term (Bravata et al., 2007; Richardson et al., 2008) and over a period of 12 month (Fitzsimions et al., 2012). These step based targets are consistent with step based recommendations congruent with adult PA guidelines and therefore indicative of both the quantity (steps·day^{-1}) and quality (intensity of walking to replicate MPA or aerobic walking) of walking required to promote health in adults. Continued research is therefore required to inform step based guidelines with regards to using pedometers to promote walking activity in adolescents (Tudor-Locke et al., 2011a).

2.5 Walking for Health in Adolescent Girls

Among adolescent girls, walking has been identified as a convenient alternative to active play and sport participation, as it minimises the perceived barriers associated with PA, sport and exercise (e.g. walking is familiar, requires no specialist skill, equipment, facilities or clothing, has no financial cost, and can be a social activity). Therefore, in this generally low active population, the concept that walking may provide the health benefits associated with PA is extremely attractive and there is now increasing evidence that walking interventions can be effective in this population (Schofield et al., 2005; Lubans & Morgan, 2008; Lubans et al., 2009a). However it is currently difficult to promote walking and walking initiatives with adolescent girls due to lack of well-established evidence regarding both the quantity and quality of walking that might be advocated to promote PA and health.

2.5.1 Step recommendations

Various steps based recommendations have emerged in recent years and provide researchers, practitioners and general public with information regarding the amount of walking required to achieve current PA guidelines and thus health. Traditionally PA guidelines have focused on time spent in moderate-to-vigorous physical activity (MVPA), which should be achieved over and above normal habitual PA. Current PA guidelines also now acknowledge that "some physical activity is better than no activity". Therefore to avoid being another source of confusion and communicate the dose of walking required for health, step based recommendations must reflect these guidelines (Tudor-Lock et al., 2011b).

Expressing PA in terms of steps $\cdot day^{-1}$ has a number of advantages, for example steps are easily understood, steps $\cdot day^{-1}$ indices include all PA (incidental and continuous steps) and increasing daily steps is a sustainable approach for low active individuals (some steps, even incidental steps are better than being sedentary) (Duncan et al., 2011). However steps$\cdot day^{-1}$ recommendations have not traditionally taken in to account the fact that not all stepping is likely to be of moderate intensity activity and therefore health enhancing. More recently in adults, step rate or cadence (i.e. steps taken per minute) has been used to infer ambulatory intensity and used to promote healthy stepping (e.g. the required step rate to maintain a health-enhancing intensity of walking) (Tudor-Locke et al., 2005; Marshall et al., 2009; Beets et al., 2010; Rowe et al., 2011 and Abel et al., 2011). For adolescent girls, such step based recommendations either for total daily step counts or 'healthy steps' have not been identified.

2.5.2 Walking in Adolescent Girls, Normative data

Normative data (i.e. expected values for daily walking activity) suggests that among children (typically 5-11yrs) we can expect 10-13,000 steps$\cdot day^{-1}$ for girls' and 12-16, 000 steps$\cdot day^{-1}$ for boys (Tudor-Locke et al., 2009b). However steps$\cdot day^{-1}$ values generally peak before 12 years of age and steadily decline to 8-9,000 steps$\cdot day^{-1}$ during adolescence (Beets et al., 2010; Tudor-Locke et al., 2011a), especially among girls who generally have lower step values than their male counterparts (Craig, Cameron & Tudor Locke, 2013). Further, there are also apparent differences between expected values among different countries. For example American and Canadian youth have lower daily step values than those from European (Sweden, United Kingdom, Belgium, Czech Republic, France, Greece, and Switzerland) and

Western Pacific (Australia and New Zealand) countries (Beets et al., 2010). While it is important that these factors are acknowledged, expected values have largely been derived from isolated studies on small or non-specific populations (Beets et al., 2010). Thus continued research is required to further accumulate expected values across different ages and populations and especially among adolescents (Tudor-Locke et al., 2011a).

Such values are useful for comparison purposes and interpreting changes in walking behaviour. However, normative data does not differentiate between habitual and exercise steps and therefore does not represent optimal daily step targets (Tudor-Locke et al., 2004; Duncan et al., 2007c) or inform what children or adolescents “should” or “need” to be taking to fulfil PA recommendation and maintain health (Tudor-Locke et al., 2011a). Therefore step based translations, cut points and thresholds reflective of PA guidelines and health related outcomes have begun to emerge in the youth population (Tudor-Locke et al., 2011a).

2.5.3Step Based Translations of Current Youth Physical Activity Guidelines

It is recommended that adolescent girls should engage in at least 60minutes and up to several hours of moderate to vigorous physical activity (MVPA) every day, which should be accumulated over and above normal habitual activity (Department of Health, 2011). Although step based recommendations that reflect this guideline are still emerging, it remains difficult to compute estimates of steps·day^{-1} that include recommended amounts of PA, as there is currently no data to inform what quantity of stepping is indicative of normal habitual activity in the youth population (Tudor-

Locke et al., 2011a). However Tudor-Locke et al., (2011a) suggested that studies of free living behaviour may provide opportunities to identity the total number of steps·day^{-1} that include recommended amounts of PA.

Eight prior youth studies (of free living behaviour) have attempted to translate time and intensity based PA guidelines in to steps·day^{-1} (Cardon et al., 2004; Rowlands et al., 2005; Beighle et al., 2006a, Cardon et al., 2007; Tanaka et al., 2009; Adams et al., 2009; Olds et al., 2010 and Colley, Janssen & Trembly, 2012). 11,000-12,000 steps·day^{-1} for girls and 13,000–15,000 steps·day^{-1} for boys has been associated with 60 minutes MVPA (Tudor-Locke et al 2011a). However the majority of these studies have be conducted with children under 12years of age (Cardon et al., 2004; Rowlands et al., 2005; Beighle et al., 2006, Cardon et al., 2007; Tanaka et al., 2009) or included both children and adolescents (6-19 years) (Olds et al 2010; Colley, Janssen & Trembly, 2012), thus making it difficult to extrapolate steps·day^{-1} values inclusive of the recommended dose of daily MVPA specific to adolescence.
In the only study that has attempted to translate time and intensity based PA guidelines into steps·day^{-1} values specific to adolescence, Adams et al. (2009) used receiver operating characteristic (ROC) curves to determine steps·day^{-1} values inclusive of the 60minutes of accelerometer determined MVPA in 40 overweight adolescent girls (11-16years). They reported that 10,000 and 11,700 steps·day^{-1} (accelerometer determined) represented 60minutes of PA equivalent to 3 and 4 METS respectively, and produced the best sensitivity and specificity values for achieving 60mins MVPA accumulated within the course of daily living. However the small sample size and the restriction to overweight participants in this study

limits the generalisability of these findings among adolescent girls (Adams et al., 2009). Furthermore, although useful, these steps $\cdot day^{-1}$ values do not take into account the fact that not all activity or time in activity is likely to be taken at an intensity reflective of MVPA and thus do not communicate the intensity of walking required to fulfill PA guidelines.

Intensity of Walking

In order that walking can be undertaken at a level of intensity beneficial for health, researchers have attempted to translate current PA guidelines into step based cut points that reflect intensity of walking. As mentioned earlier in this chapter step rate or cadence (i.e. steps taken per minute) is often used to infer walking intensity and promote healthy stepping. In adults a step rate of 100 steps$\cdot min^{-1}$ is considered the minimum requirement to achieve moderate intensity activity, a reasonable heuristic used to promote 3000 steps in 30mins (Tudor-Locke et al., 2005; Marshall et al., 2009; Beets et al., 2010; Rowe et al., 2011 and Abel et al., 2011).

A limited number of controlled studies have provided data on step rate that reflects intensity of walking in the youth population (Jago et al., 2006; Graser et al., 2009; Lubans et al., 2009b; Graser et al., 2011 and Harrington et al., 2012) and based on these Tudor-Locke et al., (2011a) suggested that a step rate of 110-116 steps$\cdot min^{-1}$ or 6600-7000 steps in 60 minutes is representative of continuous walking at moderate intensity (at least 3METs) in 10-15 year olds. However a major limitation of the majority of these studies is that intensity or energy cost of walking was not directly assessed but estimated from walking speeds (Graser et al., 2009), the compendium of physical activities (Ainsworth et al., 2000), and heart rate (Lubans et al., 2009b and

Graser et al., 2011). Further, the step rates reported have been derived from pedometer determined step counts, rather than real time direct observation, which is considered to be the more appropriate criterion (Tudor-Locke et al., 2011a).

A more recent study by Harrington et al., (2012) has attempted to address such limitations, by directly assessing intensity of walking in a group of adolescent girls (15-18 years). They reported that 94 or 114steps·min^{-1} corresponded to moderate intensity (3 METs) walking depending on the analysis technique employed (mixed model and ROC analysis respectively). Consequently they suggested that 100steps·min^{-1} may be a practical value that could be used to promote moderate intensity walking in adolescent girls. While the step rates reported by Harrington et al., (2012) can be more closely matched to the adult values, the participants in this study were late adolescents (15-18yrs), indicating that age maybe a contributing factor in step rate associated intensity. However this study also has a number limitations, which may have also contributed to the lower step rate reported. Despite measuring each participants resting energy expenditure, Harrington et al., (2012) used the standard resting energy expenditure value of 3.5ml $O2 \cdot kg^{-1} \cdot min^{-1}$ to calculate 1MET, thus corresponding MET values were not individualised but based on this assumed value. Also steps were derived by accelerometer rather than directly.

Further, while the intended application of walking recommendation or step guidelines is overground in a real world setting, to date all reported step rates have been assessed on a treadmill, with the exception of the study by Jago et al., (2006), who assessed walking overground. Therefore another limitation of these studies is the assumption that treadmill walking is equivalent in energy cost to overground walking. While it is acknowledged that Harrington et al., (2012) cross validated treadmill walking with overground walking, the reported step rates were still established on the treadmill. Also a different metabolic system was used to during the cross validation trial, for which the accuracy of the two metabolic systems used by Harrington et al., (2012) appear to differ (McLaughlin et al., 2001; Jensen et al., 2002; Duffield et al., 2004). There is evidence to suggest that treadmill walking may overestimate the energy cost of walking overground in adults (Dal et al., 2010, Berryman et al., 2011), but it is not currently known if walking on a treadmill accurately replicates walking overground in adolescents.

In light of these limitations it remains difficult to determine the step rate required to achieve moderate to vigorous intensity of walking and thus promote health stepping in this population.

2.5.4 Steps per day and Health Outcomes

In addition to the translation of time in intensity and step based cut points that reflect moderate intensity walking, step based recommendations have also been informed by studies that relate step-defined physical activity to desired health outcomes, such as BMI and percentage body fat (Tudor-Lock et al., 2011a). Five prior youth studies have proposed daily step recommendations that relate to specific health criterion/indicators(Tudor-Locke et al., 2004; Duncan et al., 2007; Laurson et al., 2008; Dollman et al., 2010; McCormack et al., 2011).

10,000–13,000 steps·day^{-1} for girls and 13,000–16,000 steps·day^{-1} for boys have been associated with healthy body composition defined by BMI (Tudor-Locke et al., 2004; Laurson et al., 2008) and percentage body fat (%BF) (Duncan et al., 2007). However these proposed health referenced recommendations have been established in children age 5-12years and are therefore not appropriate for adolescents (Duncan et al., 2007; Laurson et al., 2008; Beets et al., 2008).

Only two prior youth studies have considered adolescents (Dollman et al., 2010 and McCormack et al., 2011). McCormack et al. (2011) proposed a single health referenced recommendation (using the contrasting group method, defined by BMI) of 16,000 steps·day^{-1} for both boys and girls aged 7-16yrs. While this may be useful for health promotion purposes, because of the inclusion of children as well as adolescents and both boys and girls, it is difficult to identify the number of daily steps required among the adolescents specifically (e.g. adolescents' specific recommendation). However, Dollman et al. (2010) examined health referenced recommendations in four separate age and gender groups (5-12yrs old girls and boys and 13-16yr old girls and boys) allowing for adolescent specific recommendations to be proposed. They used ROC analysis and reported that 11,000 steps·day^{-1} was associated with healthy body composition defined by BMI in adolescent boys (13-16year). However among adolescent girls daily step values did not discriminate between individuals classified as healthy or at health risk as defined by BMI (e.g. healthy weight vs overweight/obese). Dollman et al. (2010) suggested that this less clear association of pedometers steps and BMI among adolescent girls may be attributed to changes in body composition that occur during natural growth and maturation. In the youth population increases in BMI are often more closely associated with increases in stature than increases in adiposity and therefore incorrect weight status classifications are more likely during maturation (Maynard et al., 2001), highlighting the limitations of using such markers to classify health in youth.

Despite these limitations Eisenmann et al. (2007) reported that children not meeting such cut-points were more likely to be classified as overweight and thus at health risk. They also suggested that step recommendations that relate to optimal health should be a key consideration for setting any steps-based translation of physical activity guidelines and be a key research objective, although limitations of specific health parameters need also be acknowledged. Further the association between physical activity and single health risk indicators such as BMI are often weak and therefore health outcomes are often unclear in the youth population (Andersen et al., 2006). A more appropriate measure of health status would be to calculate the level of health risk, by clustering disease risk factors, specifically cardiovascular risk factors (Andersen et al., 2006). Thus a limitation of these prior youth studies is the classification of health status using a single health indicator. Despite this there are currently no daily step values based on any health indicators e.g. Body Mass Index (BMI), Waist circumference (WC), Percentage body fat (%BF) and Blood pressure (BP) in adolescent girls (Tudor-Locke et al 2011a) and therefore the amount of walking that should be advocated for health in this population is not known.

2.6 Summary and Research Aims

It is apparent from the literature reviewed that in terms of health inequalities, adolescent girls are at a serious disadvantage due to low PA levels. This has considerable implications for their current and future health status. Walking is a form of PA that has the potential to increase PA levels and be well received among adolescent girls. However it is currently not known how much walking activity should be recommended to significantly increase PA levels and maintain health, and therefore what to recommend for interventions in schools and communities or how to evaluate walking interventions with regard to current PA guidelines. These issues need to be addressed considering the potential that walking interventions offer in terms of increasing PA among low activate adolescent girls.

The aim of this thesis was therefore to:

i) identify guidelines for steps that equate to 1 hour of moderate intensity activity in adolescent girls
ii) identify methods for objective evaluation of walking activity and walking interventions in adolescent girls
iii) identify step count targets that contribute to health in adolescent girls

These aims will be addressed in the following four studies

i. Treadmill and overground walking: can we assess walking on a treadmill to establish step count recommendations?
ii. What is the minimum step rate required to achieve moderate intensity walking overground in adolescent girls
iii. Methods of objective evaluation of walking activity
iv. How much walking should be advocated for good health in adolescent girls

Chapter 3 Treadmill vs. overground walking: can we assess walking on a treadmill to establish step count recommendations in an adolescent population?

3.1 Introduction

It is currently not known how much walking should be advocated for good health in an adolescent population or how to assess it with regard to current physical activity guidelines. In adults 10,000 steps·day^{-1} is considered sufficient to maintain health and this is considered equivalent to normal habitual activity (7,000 steps) plus 30 min moderate intensity activity (3,000-4,000 steps) (Tudor-Locke et al., 2008). Whilst identifying the number of steps recommended is important, it is also pertinent to establish the step rate so that walking can be undertaken at a level of intensity beneficial for health. Step rates corresponding to moderate intensity walking in adults has been investigated in at least five prior studies (Tudor-Locke et al., 2005; Marshall et al., 2009; Beets et al., 2010; Rowe et al., 2011 and Abel et al., 2011). These studies were conducted in well controlled laboratory conditions on a treadmill (Tudor-Locke et al., 2005; Marshall et al., 2009; Abel et al., 2011), overground (Beets et al., 2010) and using both treadmill and overground (Rowe et al., 2011). From these studies it has been suggested that a step rate of ≥100 steps·min^{-1} (regardless of assessment mode) is associated with moderate intensity walking in adults and therefore recommended for health.

Within the youth population five studies have provided data on step rate that reflect intensity of walking (Jago et al., 2006; Graser et al., 2009; Lubans et al., 2009b and Graser et al., 2011, Harrington et al., 2012). These studies have suggested step rates ranging from 102-140 steps·min^{-1} are representative of moderate intensity activity in the youth population. However, it is difficult to accurately extrapolate step rates corresponding to moderate and moderate to vigorous walking in this population, as only one study (Harrington et al., 2012) has directly assessed intensity (energy expenditure). Further to this, while four studies have investigated walking on a treadmill (Graser et al., 2009; Lubans et al., 2009b and Graser et al., 2011) only one has investigated walking overground (Jago et al., 2006). A major limitation with this is the assumption that treadmill walking is equivalent in energy cost to overground walking. While there are clear advantages to using a treadmill to assess walking, for example walking is not limited by space, speed and environmental conditions, the intended application of walking recommendations is overground in a real world setting.

Further, in adults there is evidence to suggest that treadmill walking may overestimate the energy cost of walking overground (Dal et al., 2010, Berryman et al., 2011). Consequently, the recommendation of 100 steps·min^{-1} may be an underestimation of the stepping rate associated with moderate intensity walking overground in adults. It is not known if walking on a treadmill accurately replicates walking overground in adolescents. Thus, in order to undertake studies to identify step recommendations in an adolescent population it is important to first demonstrate that treadmill and overground walking are similar in terms of energy cost for the same step rate. The aim of this study was therefore to compare the energy cost of walking on a treadmill with overground walking in adolescent girls.

3.2 Methods

3.2.1 Design

The study was conducted in the exercise laboratory, Heriot Watt University, Edinburgh. All data were collected on the same day. Data were collected in the following order: a) anthropometric and resting metabolic rate measurements; b) three 6 minute treadmill walking trials; c) three overground walking trials lasting a minimum of 4 minutes.

3.2.2 Participants

The study was given ethical approval by the University research ethics committee and local council and approved by Edinburgh city council. Permission to conduct the study was also received from the head teacher and the principal teachers of both Science and Physical Education departments, as pupils were removed from school on the day of testing.

Twenty six adolescent girls aged between 12-15years (mean age 14.01±0.56yrs) volunteered to take part in the study. The girls were recruited via flyers and an information session, advertised through the Science and Physical Education departments. Both parents/guardians and the girls provided informed consent before taking part in the study

3.2.3 Procedures

Anthropometry

Stature and body mass were measured using a Seca portable stadiometer and Seca flat scales (Seca 761, Seca Birmingham, UK) respectively. Measurements were made according to the procedures recommended by the International Society for

Advancement of Kinanthropometry. Measurements were repeated and the mean was taken as the true measurement.

Metabolic measures

Gas exchange variables and heart rate were measured and displayed online using the Oxycon mobile portable metabolic cart (Viasys Healthcare, Hoehberg, Germany). A wearlink heart rate monitor band (Polar, Kempele, Finland) was fitted by the girls under their clothing, around the ribcage and under the chest. The participants breathed through an appropriately sized tight-fitting mask (Hans Rudolph ING, USA) with the total dead space volume, including turbine, of 120ml. The gas analyser, volume sensor and turbine were calibrated according to manufacturers' specifications before each test. Oxygen uptake ($\dot{V}O_2$) was measured continuously on a breath-by-breath basis and averaged over 5 seconds for data analysis.

Step count measures

Step counts were measured by real-time direct observation, using a hand tally counter. This method is considered to be an accurate way of directly measuring steps and is often used as a criterion measure against which other step measurement methods are compared (Marshall et al., 2009; Rowe et al., 2011, Agioulasitis et al., 2012).

3.2.4 Experimental protocol

On receipt of a signed consent form, an initial meeting was set up with the group of participants, where the study was verbally explained and the participants were able to familiarise themselves with the equipment e.g. facemask and metabolic cart. All participants were given the opportunity to ask any questions they had at this time.

Anthropometry

Upon arrival to the lab, prior to the resting metabolic measures, each participant's stature, and body mass were taken as described above.

Resting metabolic rate

Resting metabolic rate was measured after at least an hour of fasting. The Oxycon metabolic system and heart rate monitor were fitted. Participants were seated and instructed to remain as quiet and motionless as possible, while watching a DVD. Gas exchange was recorded over a 20minute period. A 5 minute average of $\dot{V}O_2$ was computed between the 10th and 14th minute of the 20-min seated period. $\dot{V}O_2$ was then converted to energy expenditure reported as Kcal and kJ, using the Weir equation (Weir 1949). The calculated resting energy expenditure was then standardised to 1 metabolic equivalent (MET) for each participant.

Treadmill walking trials

Participants completed three 6 minute controlled treadmill trials at 2, 3 and 4 mph respectively. The treadmill incline was set at 0%, which is deemed appropriate at walking speeds <6.5mph as there is no wind resistance (Jones and Doust., 1996). Following a ≈ 4minute warm up where participants practiced stepping onto and off the treadmill at all speeds. The participants were fitted with a heart rate monitor and the Oxycon metabolic system (weighing 1.2 kg), held by a harness, which slipped over the girls' shoulders and clipped into place securely without restricting movement.

The participants were then asked to stand on the treadmill with a foot on either side of the belt, while it was set to the appropriate speed. Following a 5 second countdown, the participant stepped on to the treadmill and began walking. The event marker on the metabolic cart was pressed immediately prior to and following each trial, for later reference in the $\dot{V}O_2$ data. Treadmill speed was calibrated using a digital tachometer, twice during the first minute of each walking trial.

Step rate was measured using two methods; total observed step count over the 6 minute trial, measured by handtally and a 60 second stride rate taken during the fifth minute of each trial, which allowed an overground stride rate (stepping speed) to be prescribed.

A 5 second count down was given to each participant indicating when she should step off the treadmill. Within each trial, heart rate was recorded during the last 15 seconds of each minute, for determination of steady state (defined as a change of less than 5 beats per min) (American College of Sports Medicine 2010). An average of 5 minutes of static rest was taken between trials.

Overground walking trials

Following the treadmill walking trials, participants completed three overground walking trials on a 34m indoor oval track, which was marked out, for the duration of the overground walking trials.

The treadmill step rate obtained from the 60-s handtally count was prescribed for the overground walking trials to replicate the treadmill speed. This was accomplished by setting a metronome to the treadmill step rate and asking each participant to match their step rate to the metronome. Total number of steps taken were measured, using real time direct observation handtally count by means of a researcher walking behind each participant counting steps taken.

For logistical reasons, the overground walking trials were not limited to 6 minutes, as complete number of laps had to be taken in order to provide a known distance from which the average walking speed could be calculated. Participants started and finished each trial at the same point and were informed by the researcher half way round the last lap to stop at the finish line. In order to obtain steady state data the participant walked for between 4 and 6 minutes. As with the treadmill trials the event marker on the metabolic cart was pressed immediately prior to and following each trial, for later reference in the $\dot{V}O_2$ data, and heart rate data was recorded during the last 15 seconds of each minute of the trials, to determine steady state.

3.2.5 Data Analysis

Where step rate overground did not match the prescribed step rate, data were excluded from further analysis (n=5). Step rate was calculated by dividing the total steps taken during each walking trial by total time walked. Walking speed overground was calculated by dividing the distance walked by the time walked. One MET was calculated individually as the mean $\dot{V}O_2$ for 5mins between the 10^{th} and 14^{th} min of the 20-min seated period. For each walking trial, $\dot{V}O_2$ was determined for the final 2 min, and subsequently converted into METs. Oxygen cost per step was calculated for each walking trial by dividing $\dot{V}O_2$ by step rate. Descriptive statistics were expressed as mean ± standard deviation for the dependent variables. Differences in treadmill and overground response variables ($\dot{V}O_2$ and METs) were tested using a factorial repeated measures analysis of variance (ANOVA) and Bonferroni corrected post hoc pairwise comparisons. All analysis was conducted using PASW Statistics version 18.0.0 (IBM Corp., Somers, NY, USA). Statistical significance was set at $p < 0.05$

3.3 Results

3.3.1 Descriptive results

Twenty one participants successfully completed all walking trials at the prescribed walking speed. 5 participants were excluded from further analysis as their step rate overground did not match the prescribed step rate. There were no significant differences in physical characteristics and other outcome variables measured, between those participants that were not included and those included in the final analysis. Participants' physical characteristics and resting measures are presented in table 3.1. Participants covered a broad range in height, weight and BMI. Three participants were classified as at risk of underweight (BMI for age < -1SD > -2SD), 1 was at risk of overweight (BMI for age > +1SD < +2SD) and 3 were overweight (BMI for age > +2SD) according to world health organisation (WHO) (WHO, 2007; Cole et al., 2000).

Table 3.1. Physical characteristics

Variable	Mean±SD	Range
Age (yrs)	14.0±0.5	12.9-15.0
Height (cm)	160.73±5.80	150.30-178.20
Weight (kg)	52.52±10.27	37.00-75.00
BMI	20.27±3.57	15.92-29.07
Resting $\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	5.40±0.85	3.39-7.25

$\dot{V}O_2$ = Oxygen uptake

3.3.2 Treadmill and overground response parameters

Table 3.2 presents response parameters during each walking trial. The results of the ANOVA show a significant main effect of condition (treadmill and overground walking) $F(1, 19) = 10.74$, $p < 0.01$; speed $F(2, 38) = 243.15$ $p < 0.01$ and interaction $F(2, 38) = 71.16$ $p < 0.01$ on $\dot{V}O_2$(ml·kg^{-1}·min^{-1}) and a significant main effect of condition $F(1, 19) = 10.94$, $p < 0.01$; speed $F(2, 38) = 125.75$ $p < 0.01$ and interaction $F(2, 38) = 70.91$ $p < 0.01$ on METs. Significant differences between treadmill and overground walking were apparent at step rates equivalent to the fast walking speed only. Despite matching step rate, walking speed at slow and fast pace was significantly different between conditions. The overground walking pace was significantly faster than treadmill walking in the slow walking trials and significantly slower in the fast walking trials

Table 3.2. Dependent variables at each speed comparing treadmill with overground walking

Variable	**Treadmill walking**			**Overground walking**		
Walking trial	Slow	Moderate	Fast	Slow	Moderate	Fast
Walking speed(mph)	2.0±0.0#	3.0±0.0	4.0±0.0**	2.5±0.16	3.1±0.15	3.5±0.17
Step Rate	100±7	120±6	133±6	100±6	120±5	133±7
$\dot{V}O_2$(ml·kg^{-1}·min^{-1})	13.72±1.50	16.27±1.52	21.85±2.16**	13.90±2.04	16.01±2.17	17.95±2.77
METs	2.63±0.35	3.15±0.54	4.23±0.79**	2.66±0.42	3.08±0.50	3.46±0.68
$\dot{V}O_2$ (ml· step^{-1})	7.34±1.30	7.23±1.44**	8.46±1.45**	7.25±1.38	6.80±1.22	7.00±1.19

$\dot{V}O_2$= Oxygen uptake; MET= metabolic equivalent. TM = treadmill; OG = overground

significantly lower than overground walking (p < 0.01), **significantly higher than overground walking (p < 0.01)

3.3.3 Oxygen cost per step

Figure 3.1 presents the oxygen cost per step, $\dot{V}O_2$ (ml· step $^{-1}$), for the mean step rate during each walking trial. Results of the ANOVA show a significant main effect of condition (treadmill and overground walking) $F (1, 20) = 10.99$, $p <0.01$; speed $F (2, 40) = 22.98$ $p <0.01$ and interaction $F (2, 40) = 44.99$ $p <0.01$ on $\dot{V}O_2$ (ml· step $^{-1}$). The oxygen cost per step was significantly greater during treadmill walking when compared to overground walking at step rates equivalent to the moderate and fast walking speeds.

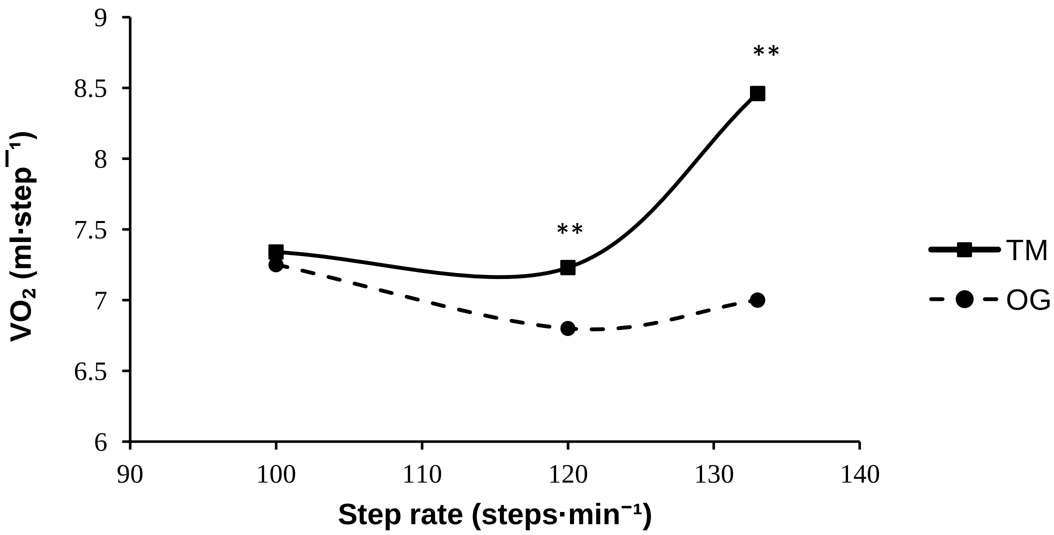


Figure 3.1. Comparison of the oxygen cost per step for the mean step rates during each walking trial for treadmill and overground walking.

TM=Treadmill walking, OG=Overground walking

**significantly higher than overground walking ($p < 0.01$)

3.4 Discussion

In order to determine whether walking can be assessed on a treadmill to establish step count recommendations, the current study has compared the energy cost for equivalent step rates during treadmill and overground walking in a group of adolescent girls. The results suggest that the energy cost of walking on a treadmill is greater than walking overground at step rates thought to be representative of moderate to vigorous intensity walking in the youth population (Jago et al., 2006; Graser et al., 2009) (also see chapter 4). Although the energy cost for equivalent step rates were compared, rather than walking speed per se, the results of the current study are consistent with the findings of Parvataneni et al., (2009), Dal et al., (2010) and Berryman et al., (2011) who observed a greater metabolic energy cost during treadmill walking when compared to overground walking at both pre selected (Berryman et al., 2011) and self selected (Parvataneni et al., 2009; Dal et al., 2010) walking speeds in adults (Dal et al 2010) and older adults (Parvataneni et al., 2009; Berryman et al., 2011).

3.4.1 Step rate, Speed, Energy Cost Relationship

The mechanisms underlying the higher metabolic energy cost observed during treadmill walking in comparison to overground walking are complex and not well understood (Berryman et al., 2011). Holt et al. (1991) suggested that when individuals walk overground in a natural setting (i.e. real world setting) they adopt a preferred walking speed and step rate (frequency) to minimise the metabolic energy cost and maintain energy efficiency. Based on this hypothesis it has been suggested that the relationship between oxygen cost and step rate gives a U-shaped curve when walking speed is kept constant (Holt et al., 1991; 1995). Further Rose, Ralston and Gamble (1981) suggested that during self selected walking overground an individual's arms, legs and trunk are coordinated in such a manner that keeps vertical displacement to a minimum, thus maximizing metabolic economy. Therefore when individuals are forced to walk at a slower or faster pace (e.g. on a treadmill), energy efficiency is reduced.

While walking speed was prescribed rather than self selected in the current study, a mismatch in walking speed for the same step rate was observed during the slow and fast walking trials between the two modes (e.g. during the slow walking trial the girls walked faster overground than on the treadmill, but slower overground during the fast walking trial). This suggests that the girls adopted a more energy efficient walking pattern overground, by adjusting their gait (stride length) to a more natural, comfortable walking speed to match the prescribed step rate overground. It also suggests that the treadmill may have forced the girls into walking at an unnatural and less energy efficient rhythm.

Similarly Dal et al., (2010) who compared self selected walking speed between the two modes reported that young adults tended to walk faster overground which was more energy efficient and resulted in a more advantageous position regarding the U-shaped curve than the slower self selected pace observed on a treadmill (Berryman et al., 2011). It has also been suggested that adopting a slower walking speed may also increase the relative intensity (Malatesta et al., 2004; Mian et al., 2007; VanSwearingen et al., 2009). Dal et al. (2010) also suggested that slower self selected treadmill walking speeds may be attributed to by additional balance and coordination being required during treadmill walking, which may also result in the higher energy costs observed (e.g. increased muscle force requirement) (Berryman et al., 2011). However 10minutes of treadmill familiarsation has been suggested to reduce these additional energy requirements (Van de Pautte et al., 2006; Dal et al., 2010). Although treadmill familiarsation was less than the recommended period of 10 minutes in the current study, all the girls regularly used the treadmill during physical education lessons and therefore this was not considered a likely contributor to the observed difference.

3.4.2 Optimal walking speed and step rate.

Interestingly during the moderately paced walking trial in the current study, walking speed was the same for both the treadmill and overground (approximately 3mph). This is consistent with the findings of Berryman et al. (2011) who found that an optimal speed of approximately 3mph (2.98mph) was the same for both treadmill and overground in older adults. They suggested that this walking speed may be the best compromise regarding the ability to use the elastic energy and maintain stability. These findings also support the hypothesis that there is a preferred rhythmical human behaviour (Holt et al. 1991, 1995).

Further studies which have aimed to establish step based recommendations with regard to moderate intensity walking have also indicated little difference in step rate at moderate intensity walking speeds between the two modes (Rowe et al., 2011; Harrington et al., 2012). Rowe et al., (2011) and Harrington et al., (2012) compared and cross validated treadmill walking overground respectively and concluded that the replication of prior treadmill step rates to overground supports the use of treadmill step recommendations for practical situations. However the focus of these studies was step rate associated intensity rather than the energy cost per se and despite this agreement in walking speed/step rate between the two modes, in the current study the oxygen cost per step was still significantly greater on the treadmill at step rates equivalent to the moderate walking speed. This illustrates that although 3mph and a 120 steps·min^{-1} may be a comfortable and economical walking speed (optimal speed and step rate) for adolescent girls, the treadmill artificially elevated the energy cost per step. This indicates that the step rate/speed relationship is different on a treadmill and overground in adolescent girls, as has been previously demonstrated in adults (Warabi et al., 2005) and further illustrates the problem with using the treadmill to infer step based recommendations.

3.4.3 Implication for step based recommendations

While the intended application of any step based recommendation is overground in a real world setting, the treadmill is often utilised as a matter of convenience. From the current study it is clear that treadmill walking does not replicate walking overground under controlled conditions and therefore increased oxygen cost per step observed on the treadmill may lead to an underestimation of the step rate required to achieve moderate intensity activity. It is also acknowledged that under such controlled conditions ecological validity is reduced (Marshall et al., 2009). However there is little known about the energy cost and step rate equivalence with regard to other overground walking conditions such as walking on other surface e.g. grass, gravel paths and pavement with curbs under free living conditions. Further research is required into natural and moderate intensity walking speed and step rates over such surfaces. This may be particularly important with regard to implementing step based recommendations and walking interventions.

3.4.4 Strengths and Limitations

The current study had several strengths. It is the only study to compare the energy cost of treadmill and overground walking with regard to step rate and step rate associated intensity in youth. The energy cost of walking was directly assessed using indirect calorimetry (METS derived from oxygen uptake) during both the treadmill and overground walking trials. Therefore MET values derived are 'true' MET values, rather than estimated. Resting metabolic rate was representative of 1 MET and therefore 3MET is approximately moderate intensity. The mean resting $\dot{V}O_2$ of 5.4 $ml \cdot kg^{-1} \cdot min^{-1}$is also similar to resting $\dot{V}O_2$ reported elsewhere (Fawkner et al., 2010; Harrel et al., 2005). Step rates have also been derived from real time direct observation rather than pedometers counts. Limitations of this study are that walking speeds were constant and not self-selected or randomised. Further, overground step rate was prescribed from treadmill step rate at the set speeds of 2.0, 3.0 and 4.0mph. Despite these measures, some of the girls naturally adjusted to a self selected speed overground. To overcome this limitation it may have been more appropriate to allow the girls to walk at self selected speeds overground, and subsequently match this speed to the treadmill.

3.5 Conclusion

In conclusion the results of the current study suggest that at step rates representative of moderate to vigorous intensity activity, treadmill walking overestimates the metabolic cost of walking overground. Step count recommendations translated from treadmill walking may therefore underestimate the step rate required to promote health enhancing overground walking. Consequently studies that aim to explore the step rate that corresponds to moderate intensity activity should focus on overground walking, as this would generalise more accurately to real-life walking behaviour.

Chapter 4 : What is the minimum step rate required to achieve moderate intensity walking overground in adolescent girls?

4.1 Introduction

Adolescent girls are insufficiently active which has serious implications for their current and future health. Walking is recognised as an effective way of implementing regular, health enhancing physical activity into the daily routine of the general population (Morris and Hardman, 1997) and in an adolescent population walking is a convenient alternative to active play and sports participation. While existing, physical activity guidelines state adolescents should engage in at least 60 minutes and up to several hours of moderate to vigorous physical activity (MVPA) every day (Department of Health 2011), step based recommendations that reflect this guideline are still emerging. Step rate or cadence (i.e. steps taken per minute) is often used to infer ambulatory intensity. Therefore in order to promote walking, researchers have sought to identify the required step rate to maintain a health-enhancing intensity of walking (Tudor-Locke et al., 2005; Marshall et al., 2009; Beets et al., 2010; Rowe et al., 2011 and Abel et al., 2011).

In adults, existing public health guidelines have been translated into step based cut points that reflect intensity of walking. A step rate of 100 steps·min^{-1} is considered the minimum requirement to achieve moderate intensity activity, a reasonable heuristic used to promote 3000 steps in 30mins (Tudor-Locke et al., 2005; Marshall et al., 2009; Beets et al., 2010; Rowe et al., 2011 and Abel et al., 2011).

With regard to the stepping rate required to promote moderate intensity walking in young people, and specifically adolescent girls, there is limited data. Five youth studies have provided data on step rate that reflect intensity of walking (Jago et al., 2006; Graser et al., 2009; Lubans et al., 2009b and Graser et al., 2011, Harrington et al., 2012), and Tudor-Locke et al (2011a) has suggested that 6600-7000 steps in 60 minutes, or a step rate of 110-116steps·min^{-1} is representative of continuous walking at moderate intensity (at least 3METs) in 10-15 year olds. However with the exception of a recent study by Harrington et al. (2012), none of these youth studies have directly assessed intensity (energy expenditure), but estimated it from walking speeds (Graser et al., 2009), the compendium of physical activities (Jago et al., 2006), and heart rate (Lubans et al., 2009b and Graser et al., 2011). Further, the step rates reported have been derived from pedometer or accelerometer determined step counts, rather than real time direct observation, which is considered to be the more appropriate criterion (Tudor-Locke et al 2011a). It is therefore difficult to extrapolate the step rate required to achieve moderate to vigorous intensity of walking in this population.

A further set of factors, such as height, leg length and weight status appear to affect step rate associated intensity and have been addressed within the adult literature (Rowe et al., 2011; Beets et al., 2010 and Marshall et al., 2009). However it is unclear what impact these factors may have on step rate in an adolescent population where growth and maturation is prevalent.

The aims of this study were therefore i) to address the limitations of previous youth studies, by directly assessing intensity and step count in order to determine the intensity of stepping (steps·min^{-1}) that is equivalent to MVPA (3METs) in adolescent girls. ii) determine how many moderate intensity steps equate to 60mins MVPA and iii) to explore the influence (if any) that different anthropometric measures may have on the step rate equating to MVPA in this population.

4.2 Methods

4.2.1 Design

The study was conducted in two separate locations, a local Edinburgh secondary school and the University exercise laboratory, Heriot Watt University Edinburgh. The same protocol was followed at each location and, where possible, the same equipment was used. All data were collected during the school day. Data were collected in the following order: a) anthropometric and resting metabolic rate measurements; b) three overground walking trials lasting a minimum of 4 minutes

4.2.2 Participants

The study was given ethical approval by the University research ethics committee and Edinburgh city council. Permission to conduct the study was also received from the head teacher and the principal teachers of both Science and Physical Education departments.

The Science and Physical Education departments were targeted because of the studies potential to create an interdisciplinary project, assisting the schools in meeting their Curriculum for Excellence and Health Promoting Schools outcomes.

Fifty six adolescent girls aged between 12-15years (mean age 13.8±0.7yrs) volunteered to take part in the study. The girls were recruited via flyers and an information session, advertised through the Science and Physical Education departments. Both parents/guardians and the girls provided informed consent before taking part in the study.

4.2.3 Procedures

Anthropometry

Stature and body mass were measured using a Seca portable stadiometer and Seca flat scales (Seca 761, Seca Birmingham, UK) respectively. Sitting height was measured while participants sat on a solid box (dimensions: 70x40x40cm), and sitting height was assessed whilst the spine was stretched and head held in the Frankfort plane. Sitting height was subsequently used to calculate leg length from stature. Waist circumference was measured at minimal waist site to the nearest millimeter, using a steel tape (non elastic flexible tape) with participants in the standing position and at the end of expiration. Measurements were made according to the procedures recommended by the International Society for Advancement of Kinanthropometry. Measurements were repeated and the mean was taken as the true measurement. The researcher's technical error of measurement (TEM) was 0.6%

Body mass index (BMI) was calculated by dividing body weight in kilograms (kg) by height in meters^2 (kg/m^2).

Maturation status

Chronological age (yrs); Weight (kg); Sitting height (cm) and leg length (cm) were used to calculate maturation status reported as maturity offset (time before or after peak height velocity) and was predicted using the equation of Mirwald et al., (2002).

Maturity offset = -9.376 + 0.0001882 x (leg length x sitting height) + 0.0022 x (age x leg length) + 0.005841 x (age x sitting height) – 0.002658 x (age x weight) + 0.07693 x (weight/height x100)

Metabolic measures

Gas exchange variables and heart rate were measured and displayed online using the Oxycon mobile portable metabolic cart (Viasys Healthcare, Hoehberg, Germany). A wearlink heart rate monitor band (Polar, Kempele, Finland) was fitted by the girls under their clothing, around the ribcage and under the chest. The participants breathed through an appropriately sized tight-fitting mask (Hans Rudolph ING, USA) with the total dead space volume, including turbine, of 120ml. The gas analyser, volume sensor and turbine were calibrated according to manufacturers' specifications before each test. Oxygen uptake ($\dot{V}O_2$) was measured continuously on a breath-by-breath basis and averaged over 5 seconds for data analysis.

Step count measures

Step counts were measured by real-time direct observation, using a hand tally counter. This method is considered to be an accurate way of directly measuring steps and is often used as a criterion measure against which other step measurement methods are compared (Marshall et al., 2009; Rowe et al., 2011, Agioulasitis et al., 2012).

4.2.4 Experimental protocol

On receipt of a signed consent form, an initial meeting was set up with the group of participants, where the study was verbally explained and the participants were able to familiarise themselves with the equipment e.g. facemask and metabolic cart. All participants were given the opportunity to ask any questions they had at this time.

Anthropometry

Upon arrival to the lab, prior to the resting metabolic measures, each participant's stature, sitting height, waist circumference and body mass were taken as described above.

Resting metabolic rate

Resting metabolic rate was measured after at least an hour of fasting. The Oxycon metabolic system and heart rate monitor were fitted. Participants were seated and instructed to remain as quiet and motionless as possible, while watching a DVD. Gas exchange was recorded over a 20minute period. A 5 minute average of $\dot{V}O_2$, was computed between the 10th and 14th min of the 20-min seated period. $\dot{V}O_2$ was then converted to energy expenditure reported as Kcal and kJ, using the Weir equation (Weir 1949). The calculated resting energy expenditure was then standardised to 1 metabolic equivalent (MET) for each participant.

Overground walking trials

Participants completed three overground walking trials at an individually prescribed step rate. An indoor oval track was marked out at each location, for the duration of the overground walking trials. Although the distance (34m and 48m) and dimensions of this space differed between locations the track was of the same shape.

The step rate obtained from the 60-s handtally count during the treadmill trials (see study 1 chapter 3) were used as the prescribed step rate for the overground walking trials. This was accomplished by setting a metronome to the treadmill step rate and asking each participant to match their step rate to the metronome. Total number of steps taken were measured, using real time direct observation handtally count by means of a researcher walking behind each participant counting steps taken.

For logistical reasons, the overground walking trials were not limited to 6 minutes, as complete number of laps had to be taken in order to provide a known distance from which the average walking speed could be calculated. Participants started and finished each trial at the same point and were informed by the researcher half way round the last lap to stop at the finish line. In order to obtain steady state data participants walked for between 4 and 6 minutes. As with the treadmill trials the event marker on the metabolic cart was pressed immediately prior to and following each trial, for later reference in the $\dot{V}O_2$ data, and heart rate data was recorded during the last 15 seconds of each of minutes of the trials, to determine steady state.

Stride length tests.

Two overground stride length tests, a 10 meter stride test and a 10 step test were conducted after the overground walking trials. Participants were instructed to walk at their normal walking pace. The 10 meter stride test began at a start line with two feet together, participant walked toward a target 15meters from the start line, their step being counted by the researcher until the heal strike of the 10 meter point. For the 10 step test, the participant started at a start line with two feet together and walked towards a target until instructed to stop by the researcher on the heal strike of their 10th stride. The distance travelled was then measured with a measuring tape to the nearest 0.1 centimeters. Each measurement was repeated and an average taken to be the true measure.

4.2.5 Data analysis

Step rate was calculated by dividing the total steps taken during each walking trial by total time walked. Walking speed was calculated by dividing the distance walked by the time walked. One MET was calculated individually as the mean $\dot{V}O_2$ between the

10th and 15th min of the 20-min seated period. For each walking trial $\dot{V}O_2$ was determined from the final 2 min, and subsequently converted into METS.

Descriptive statistics were expressed as mean ± standard deviation for the dependent variables. Linear regression was used to quantify the relationship between step rate and METs and to examine the data for potential outliers.

Multiple regressions were used to predict overground METs from step rate and stride length indicators (height, leg length and two stride length tests), as in Rowe et al., (2011), and from other variables and anthropometric measures (chronological age; weight, BMI, waist circumference and maturity offset).

To account for the multiple data points observed for each participant (which is a violation of the assumption of independence in multiple regression) a mixed model regression was used to develop equations that were used to determine step rate cut points, as in Marshall et al., (2009) and Rowe et al., (2011). In a mixed model regression individual intercepts and slopes are estimated separately for each participant and the repeated factor is modelled as a random, rather than fixed factor (Blackwell et al, 2006; Treuth et al, 2004; Welk, 2005).

All analysis was conducted using PASW Statistics version 18.0.0 (IBM Corp., Somers, NY, USA). Statistical significance was set at $p < 0.05$

4.3 Results

4.3.1 Descriptive results

Tables 4.1 and 4.2 present descriptive data for participants' physical characteristics, resting measures and response parameters during each overground walking trial. Participants covered a broad range in height, weight and BMI. One participant was classified as underweight (BMI for age < -2SD), 9 were at risk of overweight (BMI for age > +1SD < +2SD) and 4 were overweight (BMI for age > +2SD) according to world health organisation (WHO) (WHO, 2007; Cole et al., 2000). Maturity off set (time before or after peak height velocity) was used as an indicator of maturation status. 54 (96.4%) of the participants had attained peak height velocity at the time of data collection. From the walking trials the average walking speed was 2.5, 3.0 and 3.4mph for the slow, moderate and fast trials respectively. With each increase in walking speed the associated energy costs in terms of $\dot{V}O_2$ and METs also increased as did step rate.

4.3.2 Linear regression between step rate and METs

Four data points were identified as outliers (defined by ±2 Standard Deviations), two of which were further identified as data points from the same individual from the slow and moderate walking trials. This individual had a stepping rate of 72 and 68 steps·min^{-1} for the slow and moderate walking trials respectively compared to the mean step rate of 104 and 121 steps·min^{-1}. The individual was subsequently removed from further analysis along with the other outlining data points. Removal of all the outliers improved the model fit from $r^2 = 0.13$ to $r^2 = 0.20$.

Equation 4.1 presents the linear regression equation between step rate and METs

$$Y= 0.0217x + 0.381 \text{ (Y= METS, x= step rate; } r^2=0.20). \qquad [4.1]$$

Solving this equation for 3 METs, resulted in a step cut point of 120 steps·min^{-1}. In 60 minutes this would equate to 7200 moderate intensity steps.

Table 4.1. Physical characteristics

Variable	**Mean±SD**	**Range**
Age (yrs)	13.85±0.77	12.24-15.00
Height (cm)	160.10±6.57	144.80-178.20
Weight (kg)	52.18±9.90	34.00-75.00
Body Mass Index (BMI)	20.30±3.47	15.49-31.60
Waist Circumference (cm)	66.40±7.40	53.90-88.90
Leg Length (cm)	77.42±4.44	68.00-90.20
Maturity offset (yrs)	1.45±0.69	-0.24-2.99
10 meter step test (step)	14.50±1.21	11.00-18.00
10 step test (m)	6.80±0.69	5.45-8.57
Resting $\dot{V}O_2$ (ml·kg^{-1}·min^{-1})	5.24±1.04	3.39-7.44

Leg length = Height- Sitting height; $\dot{V}O_2$= Oxygen uptake;
MET= metabolic equivalent

Table 4.2. Response parameters for each overground walking trial

Variable	Walking trial 1 (Slow)	Walking trial 2 (Moderate)	Walking trial 3 (Fast)
Walking speed (mph)	2.5±0.4	3.0±0.4	3.4±0.8
Step rate (steps·min^{-1})	104±10	121±7	132±9
$\dot{V}O_2$(ml·kg^{-1}·min^{-1})	13.47±2.16	15.27±2.33	17.07±3.19
METs	2.60±0.53	2.97±0.57	3.33±0.79

$\dot{V}O_2$= Oxygen uptake; MET= metabolic equivalent

4.3.3 Multiple regression analyses

Results of the multiple regression analyses are presented in table 4.3. Each of the variables explained significant (p<0.01) additional variance in METs when added to step rate. Weight related variables (weight, BMI and waist circumference) accounted for the largest amount of variance (33, 30 and 30% respectively). The height related variables (height, leg length and the two stride length tests) accounted for less variability in the model than the weight related variables but still accounted for significant variance (21, 23, 23 and 20% respectively). Age accounted for a larger variance than height variables (28%), and maturity off set accounted for the least variance in the model (19%).

Table 4.3. Summary of multiple regression analysis

Model predictors	R^2	SEE
Step Rate	0.20	0.003
Step Rate, Age (yrs)	0.30	0.061
Step Rate, Height (cm)	0.26	0.008
Step Rate, Weight (kg)	0.35	0.005
Step Rate, BMI	0.32	0.013
Step Rate, Waist circumference(cm)	0.32	0.007
Step Rate, Leg Length (cm)	0.23	0.012
Step Rate, 10m step test (steps)	0.22	0.073
Step Rate, 10 step test (m)	0.26	0.041
Step Rate, Maturity off set (yrs)	0.19	0.100

BMI= Body Mass Index

4.3.4 Mixed model regression

A mixed model regression was used to develop regression equations to determine step rate cut points, adjusting for the random effects of the non-independent observations. The influence of the different anthropometric indexes was also tested. In agreement with the multiple regression analysis step rate, weight related variables (weight, BMI and waist circumference) and maturity off set were significant ($p<0.01$) predictors of METs. However age and height related variables (height, leg length and the two stride length tests) did not add significantly to the prediction accuracy (p=0.13, p=0.11, p=0.74, p=0.62 and p=0.14) respectively.

4.3.5 Development of step rate cut points

For comparison with the linear regression and previous adult studies (Tudor-Locke et al., 2005; Marshall et al., 2009; Rowe et al., 2011) a generic equation (4.2) using step rate only is provided below. Solving this equation for 3 METs, yielded a slightly lower step cut point of 117 steps·min^{-1} compared to 120 steps·min^{-1} in the linear regression.

As weight related variables were the best predictors of METs and weight itself is easily measured and is the most applicable to everyday situations, step rate cut points were subsequently developed according to weight status (equation 4.3). Using equation 4.3 step rate cut points for 3 and 4 MET were developed for various weight categories from 35kg to 85kg. The mean cut point for all weights was 117 steps·min^{-1}. The range of step rates were 99-130 steps·min^{-1} (3METs) and 139-169 steps·min^{-1} (4METs) and are presented in table 4.4. The recommendation of 60mins MPA per day therefore corresponds to step count targets ranging from 5940-7800 steps.

METs = 0.024990 step rate + 0.063649 [4.2]

METs = 0.025232 step rate + 0.019116 mass (kg) - 0.941304 [4.3]

Table 4.4. Step rate cut points for adolescent girls of different weights corresponding to 3 and 4METs

Weight (kg)	Step rate (3METs)	60min steps (3METs)	Step rate (4METs)	60min steps (4METs)
Generic [a]	117	7020	157	9451
35.00	130	7800	169	10140
40.00	126	7560	166	9960
45.00	122	7320	162	9720
50.00	118	7080	158	9480
55.00	115	6900	154	9240
60.00	111	6660	150	9000
65.00	107	6420	147	8820
70.00	103	6180	143	8580
75.00	99	5940	139	8340

[a] Based on all weights

4.4 Discussion

The current study has addressed the methodological limitations of prior youth studies, by directly assessing relative exercise intensity (METS derived from oxygen uptake) and steps taken (real time direct observation) to determine the minimum step rate required to achieve moderate intensity activity (MPA) and generate step based translation of minimal amount of MVPA (minimum number of steps required to achieve 60minutes of MVPA) in adolescent girls.

4.4.1 Minimum step rate required to achieve moderate intensity activity

Results of the linear regression analysis suggest that a step rate of 120 steps·min^{-1} represents moderate intensity stepping (3METs) in adolescent girls. However, based on the mixed model regression, which takes into account the multiple data points observed for each participant, the results indicate a slightly lower step rate of 117 steps·min^{-1}. Despite the more rigorous methods adopted in the current study and differences in methodologies, gender and ages, these results are consistent with the findings of Jago et al., (2006) and Graser et al., (2009).

In the only other study to investigate walking overground in youth (11-15 year old boys) Jago et al., (2006), reported pedometer determined step rates of 117 and 127 steps·min^{-1} at walking speeds of 3 and 4 mph overground. They suggested that these speeds were representative of moderate and moderate to vigorous intensity activity. However, as these walking speeds were defined by the adult compendium of physical activities (where 3 mph is indicative of 3 METS and 4 mph, 5 METs) (Ainsworth et al 2000), it was unclear whether the estimated MET values and corresponding step rates were representative of moderate intensity activity in this youth population. In her review, Tudor-Locke et al., (2011a) raised a similar concern with this study.

Graser et al., (2009) investigated walking on a treadmill in a slightly younger group of 10-12 year old boys and girls. Exercise intensity during walking was not directly measured, but walking speeds of 3, 3.5 and 4mph were considered by the author to represent MVPA walking, concluding that step rates of 120-140 steps·min^{-1} were associated with MVPA (120 steps·min^{-1} being the minimum step rate reported for both boys and girls). Despite the differences in age of the participants and use of the treadmill, this data is in support of the current study in which a comparative walking speed of ~ 3mph was approximately equivalent to MPA, and therefore a step rate of 117-120 steps steps·min^{-1}.

More recently however, Graser et al., (2011) investigated walking on a treadmill in 12-14 year old boys and girls, in which moderate intensity walking was defined using 40-59% of maximum heart rate. For the same walking speed (3mph) the minimum step rate reported for adolescent girls was 15 steps·min^{-1} lower (102 steps·min^{-1}) than in the current study (117 steps·min^{-1}). While heart rate reflects relative intensity rather than direct measures of intensity such as in the present study the difference in step rate between these studies may be explained by the increased energy cost of treadmill walking (see study 1, chapter 3). It is likely that the elevated energy demand for treadmill walking would be reflected in an elevated heart rate, implying that whilst the girls were walking at 3mph, they were working at a lower relative intensity reflected in a slower stepping speed.

Lubans et al., (2009b) also used heart rate determined exercise intensity (65-75% of maximum heart rate) to examine the relationship between exercise intensity and pedometer determined step counts in a group of 14 year old boys and girls, while walking and running on a treadmill. They reported 137 steps·min^{-1} for girls was associated with a heart rate of~140 beats per minute (BPM) and that this indicated a walking pace equivalent to MPA. This step rate is considerably higher than currently or previously indicated to represent moderate intensity activity. However, 139 BPM is indicative of a 'brisk walk' (upper end of moderate intensity) as suggested by Armstrong et al., (1991) and therefore the higher step rates reported by Lubans et al., (2009b) are more likely to represent MVPA and be more equivalent to walking at 4mph in the current study.

In the most recent study to provide data on step rate associated intensity, and the only other study to directly assess walking intensity in the youth population, Harrington et al., (2012) reported that accelerometer determined step rates of 94 or 114 steps·min^{-1} corresponded to moderate intensity walking on a treadmill in a group of older adolescent girls (15-18yrs) depending on the analytical approach employed (mixed model and ROC analysis respectively). Consequently they suggested that 100steps·min^{-1} may be a practical value that could be used to promote moderate intensity walking in adolescent girls. However despite this step rate being similar to that reported by Graser et al., (2011) and the same used to promote moderate intensity walking in adults, the walking speed suggested to represent this step rate was considerably slower than in the current and previous youth and adult studies (2mph compared to 3mph). It is suggested that slow walking speeds may be less economical (Dal et al., 2010) and adopting slower speeds may increase the relative intensity of an activity (Malatesta et al., 2004; Mian et al., 2007; VanSwearingen et al., 2009). This may therefore explain the lower step rate for a given MET value as reported by Harrington. Harrington also used the standard resting energy expenditure value of 3.5ml O_2·kg^{-1}·min^{-1} to calculate 1MET. Thus corresponding MET values were not individualised. Further the use of this standard value often leads to underestimation in EE in the youth population (Roemmich et al., 2000; Harrell et al., 2005) which may have also lead to the higher MET values for lower step rates and walking speed being reported by Harrington et al., (2012).

4.4.2 Influence of anthropometric indices on step rate associated intensity

In the current study the influence of different anthropometric indices (individual characteristics) were explored using multiple regression (as in Rowe et al., 2011). Results indicated that all variables measured (weight related variables (weight, BMI and waist circumference); height related variables (height, leg length and the two stride length tests); chronological age and maturity offset explained significant additional variance in METs when added to step rate. However, in the mixed model analysis only weight and maturity offset were significant predictors of METs, suggesting that step rate associated intensity is likely to be influenced by these variables.

Jago et al., (2006) also observed in adolescent boys that those at risk of being overweight (BMI for age > +1SD < +2SD) recorded fewer steps (pedometer determined) than their normal weight counterparts. However Jago et al., (2006) goes on to attribute these differences to differences in stature rather than body mass (e.g. more overweight participants tended to be taller). Similarly within the adult literature Beets et al., (2010) and Rowe et al., (2011) suggested that leg length and height influence step rate associated intensity in adults, reporting that smaller individuals walk at a greater step rate than taller individuals for the same energy cost (Beets et al., 2010; Rowe et al., 2011). Subsequently Rowe et al., (2011) developed height- related step rate recommendation for adults. In these studies the influence of weight was not considered, and although weight related step rate recommendations have been considered within the adult literature (Marshall et al., 2009), they were not further developed due the small differences observed and inconsistency in step rate across different analytical models. The relationship between body size, resting energy expenditure, submaximal energy expenditure and economy of motion is complex (Rowland, 2005). However the current study assessed individualised METs to infer MPA, the effect of body mass is dealt with for the immediate requirements of the study design (i.e. that relative exercise intensity can be accurately quantified).

4.4.3 Step based translation of current physical activity guidelines

Results of the current study suggest that the minimum step rate require to achieve moderate intensity walking was 117 and 120 steps·min^{-1} depending on the analytical model employed. The step based translation of current PA guidelines (60 minutes of MVPA daily) would therefore be 7020 and 7200 steps respectively. While the use of a single recommendation that is able to communicate levels and intensity of ambulatory activity is attractive, due to its usability for researchers, practitioners and general public alike, Tudor-Locke et al., (2011a) suggested a minimum step range (for example 6600-7000 steps in 60 minutes) was representative of continuous walking at moderate intensity (at least 3METs) in 10-15 year olds rather than a single guideline. Graser et al., (2011) have also suggested than one size does not fit all and the individual variation in step rate associated intensity seen within the youth population highlights the need to address step rate recommendations individually rather than with a single guideline. They also suggest that for prescriptive purposes and to inform intervention the use of a standardized minimum step rate may influence adherence as some adolescents may become bored or unchallenged, while others may find it hard to achieve and have to work above their individual moderate intensity threshold. It is also apparent within the adult literature that factors such as weight status, height and leg length have been associated with inter -individual variation in step rate associated intensity (Marshall et al., 2009; Rowe et al., 2011; Beets et al., 2010) and thus it would be useful to have additional step rate recommendations relating individual characteristics that are easily measured by anthropometric indices.

From the step rate cut points developed according to weight status in the current study there was a large deviation from the generic step rate of 117steps·min^{-1} (range 99-130 steps·min^{-1}), with lighter individuals taking more steps per minute than heavier individuals. Therefore to achieve 60mins MPA, heavier individuals may be recommended to take more than 1000 steps/day more than necessary. This further highlights that a single recommendation may lead to an unachievable target for some individuals and that a step rate range, similar to that suggested by Tudor-Locke et al., (2011) may be beneficial for use with adolescent girls, to maximize adherence to intervention. In order to explore walking recommendations that are related to MVPA, we also reported step rates appropriate to achieve 4 METS according to weight status. It is clear however, that the step rate required to achieve 4 METS in some girls could not be sustained without running, and therefore walking recommendation in this population should focus on moderate intensity activity and not MVPA.

4.4.4 Strengths and Limitations

The current study had several strengths. It has directly assessed relative exercise intensity (METS derived from oxygen uptake) using indirect calorimetry during all walking trials. Therefore MET values derived are ‘true’ MET values, rather than estimated. Step rates have also been derived from real time direct observation rather than pedometers counts.

It is worth noting, however the large range in resting ($\dot{V}O_2$) values reported in the current study. While this may be partly due to resting metabolic rate (RMR) being measured with the participants in the seated position rather than the supine position and may be considered a limitation to the current study. The mean and standard deviations of the RMR values reported are within parameters previously reported by Harrell et al, (2005). Resting metabolic rate is assumed to capture influences such as body composition, age and maturation status (Spadano et al., 2003) and as concluded by Harrell et al., (2005) should always be used when calculating multiples of METs to define actual intensity. Therefore it is appropriate to be confident that RMR is equal to 1 MET and allows for accurate estimates of MPA.

Other limitations of this study are that it did not consider boys and therefore it remains unclear what the minimum step rate require to achieve moderate intensity walking is in adolescent boys. Furthermore, overground step rate was prescribed from treadmill step rate at set speeds of 2.0, 3.0 and 4.0mph. Treadmill step rate was replicated overground by setting a metronome to the treadmill step rate and asking each participant to match their step rate to the metronome. Despite these measures, some of the girls naturally adjusted to a self selected speed overground. To overcome this limitation it may have been more appropriate to allow the girls to walk at self selected speeds overground, and subsequently matched this speed to the treadmill.

4.5 Conclusion

In conclusion results of the current study suggest that for the purpose of a general public health message, a generic step rate of 120 steps·min^{-1} and 7200 in 60 mins may be advocated to achieve MPA in adolescent girls. However the current study also confirms that there is great inter-individual variation in step rate associated intensity and that the use of a single recommendation is likely to lead to unachievable target for some individuals. Therefore promotion of a step rate range may be beneficial for use with adolescent girls and where feasible individual step rate recommendations should be considered according to weight status. Further research is required into ways of implementing such recommendations (individualized step rates that correspond to various intensities) into a public health setting. With the recent advancement in technologies of body worn instruments, such as pedometers, some of which are now able to provide feedback on time spent in MVPA this may be possible.

Chapter 5a Methods of objective evaluation of walking activity

5a.1 Introduction

Accurate, valid and reliable methods for assessing both the quantity and quality of walking required for health in an adolescent population are critical in establishing step based recommendations congruent with physical activity guidelines (Tudor-Locke et al., 2009). Body worn activity monitors such as pedometers and accelerometers are commonly employed within the field of physical activity research to objectively measure ambulatory activity. While pedometers provide a practical, low cost, easy to use way of quantifying volume of daily ambulatory activity (Bassett and Strath, 2002; Freedson and Millar, 2000; Welk, Corbin and Dale, 2000), they are often criticised for their limited output of number of steps taken and their inability to quantify intensity of physical activity (PA) or time spent in moderate to vigorous activity (MVPA). In contrast accelerometers provide useful insight into complex physical activity patterns and time spent at various intensities (Tudor-Locke et al 2011). However they are generally expensive and require expertise for efficient use.

Recent technological advances of these body worn activity monitors have seen the development of accelerometry-based pedometers, sometimes referred to as low cost accelerometers (McClain and Tudor-Locke 2009). The advanced features of these sophisticated pedometers include a piezoelectric accelerometer mechanism for improved precision of step counts (Crouter et al., 2005; Duncan et al., 2007a) and an internal digital timing mechanism allowing them to quantify time spent at various intensities (i.e. intensity of stepping, steps·min^{-1}) in addition to number of daily steps

(Hart et al 2011., Tudor-Locke et al., 2011a). This new generation of pedometer therefore provides researchers, practitioner and the general public alike, with practical and affordable opportunities to measure and communicate walking (ambulatory) activity in terms of $steps \cdot day^{-1}$ and activity time e.g. time spent at or above a pre-specified intensity threshold ($steps \cdot min^{-1}$) (Tudor-Locke et al., 2011b; Beets et al., 2011).

However despite the potential of these pedometers to further facilitate the objective evaluation of walking activity, concerns have been raised regarding the lack of standard practice and comparability among the many competing technologies now available on the commercial market (Freedson et al., 2012). Although the fundamental properties of these pedometers are similar, they are defined by manufacturer sensitivity thresholds for detection of steps and activity time (Tudor-Locke et al., 2009). Therefore before these devices can be implemented for use with specific populations it must be demonstrated that they are valid, reliable, appropriate and feasible for use. It is therefore necessary to evaluate any new instrument's performance relative to an accepted criterion within the population of interest (Dolman et al., 2007, Hart et al., 2011; Chen et al., 2012).

The purpose of this study was therefore to i) compare step counts from five commercially available measurement tools to direct observation handtally step counts, during continuous overground walking. ii) to identify an appropriate measurement instrument able to quantify 'moderate intensity stepping' within an adolescent population.

The instrument selected will be utilised in the second part of this thesis (study 4, chapter 6) where the focus further builds on the translation of current PA guideline into daily step defined physical activity and desired health outcomes.

5a.2 Methods

5a.2.1 Participants

Data for the 56 girls who had participated in the overground walking trials were used to compare the accuracy of step measurement tools during overground walking trials (controlled conditions). The methods are therefore in full accordance with those outlined in study two (chapter 4). Additional measures relevant solely to this study are documented below.

5a.2.2 Instruments

Five step measurement instruments were employed in the study. The cost, main features and outcome measures of each instrument are presented in table 5a.1

The Omron HJ-720-ITC (Omron Healthcare, Inc, Bannockburn, IL) is a piezoelectric pedometer with dual accelerometer sensors for detection of steps. This feature allows steps to be detected when worn in both vertical and horizontal positions. In addition to daily step counts the Omron HJ-720-ITC offers measures of aerobic steps, calorie counts and distance walked (miles). The aerobic steps function refers to continuous steps accumulated at the manufacturers moderate intensity threshold ($\geq$ 60 step·min^{-1}) in bouts of 10 minutes or longer. Data recall includes a 7day recall on the pedometer display and a 41 day storable memory for all measures. Data can be transferred via a USB cable to a computer.

The Omron HJ-304-E (Omron Healthcare, Inc, Bannockburn, IL) is a micro electrical mechanical system (MEMS) pedometer with a three dimensional acceleration sensor or for detection of steps. As with the Omron HJ-720-ITC, the Omron HJ-304-E can detect steps when worn in both vertical and horizontal positions. Other features of the Omron HJ-304-E include an exercise mode, MET indicator, calorie and distance (km) counters. The exercise mode includes measures of exercise steps and exercise units. Exercise steps refer to steps accumulated at the manufacturers moderate intensity threshold (3METs equivalent to a walking pace of $\geq$ 2.5mph or $\geq$100 step·min^{-1}) in bouts of 20seconds or longer. Exercise units refer exercise quantity calculated using an internal equation (5.1) based on step rate.

Exercise units = METs (calculated from step rate) x activity duration (hrs.) [5.1]

Data recall includes a 7 day recall on the pedometer display and a 4 week recall of weekly totals.

The Yamax Digi-walker CW-701 (Yamax, Tokyo, Japan) is an electronic pedometer that uses a horizontal spring suspended lever arm, which moves up and down with vertical accelerations of the hip to detect steps. The lever arm detects vertical force at waist level greater than approximately 0.35g. It also offers a 7 day recall and 2weeks memory for steps and additional outputs, which include time in activity (hrs and min), distance walked (miles/km) and a calorie counter.

The New Lifestyles NL-1000 (New Lifestyles, Inc, Lee’s Summit, MO) is a uniaxial piezoelectric pedometer. The internal mechanism used by this instrument for the detection of steps is the same as the Lifecorder Ex, which detects vertical accelerations at waist level at 32Hz and assesses values in the range of 0.06g-1.94g (Mc Clain et al., 2007). In addition to step counts the NL-100 offers feedback on distance walked and time spent in moderate to vigorous physical activity (MVPA). MVPA stepping is classified every 4seconds into one of 9 intensity categories that correspond to various estimated MET levels. The intensity threshold for detection of MVPA can be adjusted via the pedometers display screen. The manufacturers default MVPA threshold is level 4, equivalent to 3.6METs and was used in the current study. Data recall includes a 7 day recall on the pedometer display for daily steps, cumulative time in MVPA displayed in hours, minutes and seconds and distance walked in miles.

The activPAL™ (PAL Technologies Limited, Glasgow UK) is a uniaxial MEMS accelerometer that provides direct output measures of steps, step rate (cadence) and postural changes e.g. time spent sitting/lying, standing and stepping. Body accelerations are measured at a sampling frequency of 10Hz and summed in 15second epochs. Step data can be summed in 1 second epoch allowing for more detailed analysis. A software package (activPAL™ professional research addition) is used to process the raw accelerations using proprietary algorithms. In addition the activPAL™ also offers an indirect estimate of METs, calculated using an internal equation (5.2) based on step rate. 120 $\text{step}\cdot\text{min}^{-1}$ is equivalent to 4METs, based on data from the adult compendium of physical activities (Ainsworth et al., 1993).

$$\text{MET}\cdot\text{h}^{-1} = (1.4\text{x activity duration (hrs.)}) + (4-1.4) \text{ x (step rate/120) x activity duration (hrs.)} \quad [5.2]$$

Data recall includes 7 days data for all outputs, downloaded via a USB docking station to a computer.

5a.2.3 Procedures

Step count measures

Five step measurement instruments (activPAL™ and pedometers; Omron HJ-720, Omron HJ-304, New Lifestyles NL-1000, Yamax CW-701) were used to assess number of steps, and where the instrument allowed, intensity of steps, during all walking trials. Each measurement instrument was compared to direct observation handtally counts where the researcher manually pressed the counter registering each step observed. This was used as the criterion measure of step count.

All pedometers were attached to the waistband according to manufactures specifications; NL-1000 above the midline of the right knee, Omron HJ-720-ITC above the right pocket on the hipbone, Omron HJ-304-E above the left pocket on the hipbone and the Yamax CW-701 above the midline of the left knee. The activPAL™ accelerometer was attached using the manufacturers recommended method (PALstickies™-hydrogel adhesive pad) to the mid right anterior thigh by the girls underneath their clothing prior to the start of the walking trials.

The NL-1000 and Yamax CW-701 pedometers were re-set to zero between each trial. Both the Omron HJ-720-ITC and HJ-304-E automatically reset at mid night and cannot be zeroed manually without resetting several components, therefore number of steps taken during each walking trial was subtracted from previous steps taken. The activPAL™ device remained attached throughout the trials and activPAL™ data were downloaded and referenced against time at the end of each testing session. Pedometers were checked prior to each walking trial using a standard 20 step test (Tudor-Locke and Myers, 2001).

5a.2.4 Exercise protocol

The step measurement instruments; activPAL™, Omron HJ-720-ITC, HJ-304-E, New Lifestyles NL-1000 and Yamax CW-701 were positioned by the researcher as described above prior to the walking trials. Number of steps taken from all measurement instruments and total time walking were noted for data analysis and compared to real-time direct observation handtally counts for the entirety of each of the three walking trial (3 speeds). Activity outputs (MVPA stepping) were also noted and compared to metabolic ($\dot{V}O_2$) data (indirect calorimetery).

Table 5a.1. Description of step measurement instruments (Adapted from Hart et al., 2011a)

Instrument characteristics	Omron HJ-720ITC	Omron HJ-304-E	Yamax CW-701	New lifestyles NL-1000	activPAL™ system
Cost (£)	45	22	18	50	1900
Dimensions (cm)	4.7(W), 7.3(H) 1.6(D)	7.5(W), 3.3(H), 1.8(D)	6.1(W), 4.6(H), 1.9(D)	6.3(W), 3.8(H), 2.2(D)	3.5(W), 5.3(H), 0.7(D)
Internal sensor	Dualaxial piezoelectric accelerometer	3 dimensional Micro electro mechanical system (MEMS)	Spring coli and pendulum	Uniaxial piezoelectric accelerometer	Uniaxial Micro electro mechanical system (MEMS)
Outputs	Steps Aerobic steps - (>60steps·min^{-1}) Distance (Miles/km) Calorie counter	Steps Exercise steps Exercise units Distance (Miles/km) Calorie counter METs indicator	Steps Time in activity - (hrs:min) Distance(Miles/km) Calorie counter	Steps Activity time - MVPA (hrs:min:s) Distance(Miles/km)	Steps Step rate (cadence) Posture indicator METs indicator
Epoch	4 seconds 1 hour	4 seconds 1hour	N/A	4 seconds 1 min	10Hz 15 seconds 1second (steps only)
Memory	7days 41days to PC (downloaded Via USB)	7 days 4 weekly total	7 days 2 weeks	7days	7 days (on instrument)
Display screen	Multifunction LCD	Multifunction LCD	Multifunction LCD Covered	Multifunction LCD Covered	N/A
Attachment site	Waist band Pocket Neck chain	Waist band Pocket Neck chain Bag	Waist band at midline of thigh	Waist band at midline of thigh	Midline of thigh between hip and knee

METs: Metabolic equivalent, MVPA: Moderate to Vigorous Physical Activity

Dimensions -W=Width, H=Height, D= Depth

5a.2.5 Data analysis

Step count analysis

Descriptive statistics were expressed as mean ± standard deviation for total step counts from each step measurement instrument and real time direct observation handtally for all overground walking speeds. Overground walking speed was calculated by dividing the distance walked by the time walked.

For validity evidence the mean absolute percent error (MAPE) was calculated for each step measurement instrument and compared to direct observation handtally at each walking speed (2.5, 3.0 and 3.5mph).

MAPE = (measurement instrument steps- handtally steps)/handtally steps x 100

A small MAPE represents better instrument accuracy and a MAPE less than 3% is considered acceptable (Crouter et al., 2003; Hatano 1997).

Bland and Altman analyses were used to test the agreement between each step measurement device and handtally counts at each of the walking speeds. This technique allows the graphical representation of the mean error and the 95% prediction intervals. Greater accuracy of an instrument results in tighter limits of agreement. Limits of agreement were established as mean difference ±1.96SD of the difference (Bland and Altman, 1986).

Paired sample t-tests were used to evaluate the difference in the number of steps detected between the five step measurement devices and direct observation handtally counts at each of the walking speeds.

Activity time analysis

Where the step measurement instrument gave indication of energy expenditure, steps or time at or above moderate intensity activity, it was recorded and subsequently reported as, or converted to activity time. The Omron HJ-304-E exercise units were converted to activity time using the following equation as advised by the manufacturers.

$$\text{Activity time (minutes)} = \text{Exercise units} / 3 \qquad [5.3]$$

activPAL™ $MET{\cdot}h^{-1}$ for each minute walked were calculated using the manufactures energy expenditure equation (equation 5.2). Where the $MET{\cdot}h^{-1}$ were ≥ 3METs for each minute of walking it was noted activity time.

The New Lifestyles NL-1000 activity time was calculated at the manufactures default MVPA threshold equivalent to 3.6 MET.

Actual activity time e.g. time spent at or above 3 METs was calculated for each individual from the metabolic ($\dot{V}O_2$) data (indirect calorimetry) and subsequently compared to the activity time specified by each step measurement instrument.

Descriptive statistics for activity time were expressed as mean ± standard deviation from each step measurement instrument and metabolic ($\dot{V}O_2$) data for all overground walking speeds (2.5, 3.0 and 3.5mph). MAPE for activity time was calculated for each step measurement instrument and compared to actual activity time.

Bland and Altman plots were used to test the agreement of activity time measured by each step measurement instrument and metabolic data from indirect calorimetry.

Paired sample t-tests were used to evaluate the difference between the instruments calculated activity time and measured activity time (indirect calorimetry).

PASW Statistics version 18.0.0 (IBM Corp., Somers, NY, USA) was used for statistical analysis. Statistical significance was set at $p < 0.05$.

5a.3 Results

5a.3.1 Descriptive results

Missing data were recorded when the Omron-HJ-720-ITC malfunctioned in 10 girls. The activPAL™ also failed to record data in 30 girls, when the device malfunctioned (n=24) and where the device fell off (n=6). All 56 girls had complete data for the Omron-HJ-304-E, Yamax CW-701 and NL-1000. Descriptive data for total steps and activity time detected by each instrument during all walking trials are presented in table 5a.2 and 5a.3 respectively. The Yamax and activPAL™ significantly underestimated handtally step counts and Omron HJ-304-E overestimated handtally step counts at the slow walking speed. There was no significant difference between the estimated steps taken from each step measurement instruments and handtally step counts at the moderate and fast walking speeds.

5a.3.2 Step count analysis

The mean absolute percent error (MAPE) of each instrument compared to direct observation handtally are presented in Figure 5a.1. MAPE ranged across each walking speed, the largest MAPE for all instruments was observed at the slow walking speed (2.5mph) with exception of the activPAL™, which was most accurate during the slow walking trial. The Omron HJ-304-E and Yamax CW-701 presented an MAPE greater than the acceptable level of ±3% at the slow walking speed. The smallest MAPE was observed in the activPAL™ at the slow walking speed (2.5mph), in the Omron HJ-720-ITC, Omron HJ-304-E and Yamax CW-701 at the moderate walking speed (3.0mph) and in the New Lifestyles NL-1000 at the fast walking speed (3.5mph). MAPE for all walking speeds ranged from 0.01 to 1.30%. The activPAL™ and the NL-1000 demonstrated the smallest MAPE for all walking speeds (0.01 and -0.12%) respectively.

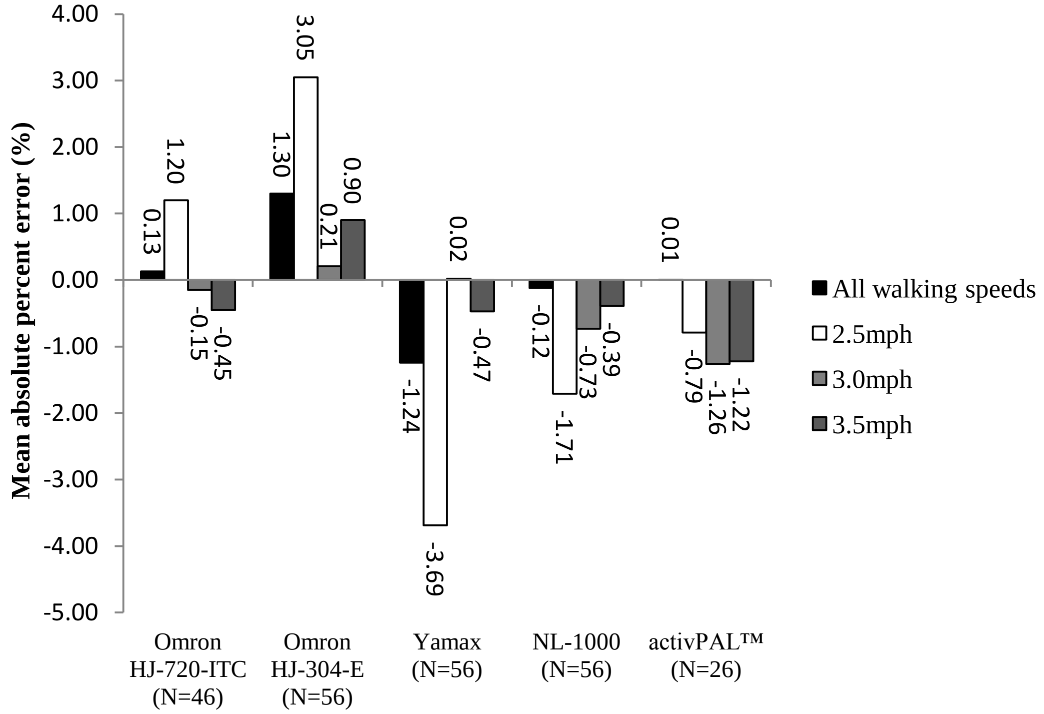


Figure 5a.5.1. Mean absolute percent error of each instrument compared to handtally

Table 5a.2. Descriptive statistics for mean±SD total step count and Bland and Altman limits of agreement for all instruments

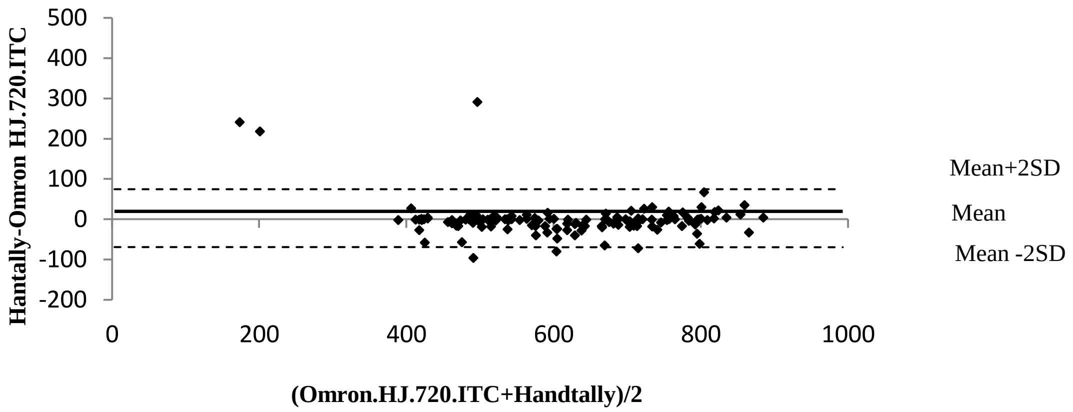
Walking trial		**Slow (2.5mph)**				**Moderate (3.0mph)**				**Fast (3.5mph)**				**All**			
Instrument	**N**	**Steps**	$\bar{d}$	$\bar{d}$**+2s**	$\bar{d}$**-2s**	**Steps**	$\bar{d}$	$\bar{d}$**+2s**	$\bar{d}$**-2s**	**Steps**	$\bar{d}$	$\bar{d}$**+2s**	$\bar{d}$**-2s**	**Steps**	$\bar{d}$	$\bar{d}$**+2s**	$\bar{d}$**-2s**
Handtally	56	527±116	-	-	-	607±122	-	-	-	662±137	-	-	-	598±136	-	-	-
Omron HJ-720-ITC	46	552±113	-6.6	114.4	-127.7	630±139	0.9	82.6	-80.6	682±136	3.0	40.2	-34.0	623±145	-0.8	85.9	-87.6
Omron HJ-304-E	56	544±135††	-16.1	59.5	-91.8	608±138	-1.3	98.1	-100.7	660±133	2.4	35.3	-30.5	603±143	-5.0	71.0	-81.1
Yamax CW-701	56	508±130*	19.4	151.8	-112.9	607±127	-0.1	27.8	-28.1	656±131	3.1	35.4	-29.1	590±142*	7.4	89.1	-74.2
NL-1000	56	518±128	9.0	133.2	-115.1	602±129	4.4	54.2	-45.3	657±110	2.5	43.3	-38.1	595±139	2.9	85.8	-75.1
activPAL™	26	444±76**	3.6	8.5	-0.1	528±111	6.5	42.4	-27.1	569±104	7.0	44.6	-30.5	511±110**	5.7	28.1	-17.4

N= Number of complete data sets, $\bar{d}$ = mean difference (Handtally –Instrument), $\bar{d}$**±2s** = mean difference±2Standard deviation of the differences, *significantly lower than handtally step counts ($p < 0.05$), ** ($p < 0.01$), †† significantly higher than handtally step counts ($p < 0.01$)

Bland and Altman analysis

Bland and Altman analyses for total steps at each walking speed are presented in table 5.2 and Bland and Altman plots for the five step measurement instruments compared to direct observation handtally counts for total steps at all walking speeds are presented in figures 5.2 A-E. The tightest limits of agreement were observed in the activPAL™ during the slow walking trial and in the Yamax CW-701 during the moderate and fast walking trials. The activPAL™ demonstrated the tightest limits of agreement for all walking speeds followed by the Omron HJ-304-E, New Lifestyles NL-1000, Yamax CW-701 and Omron HJ-720-ITC respectively.

A



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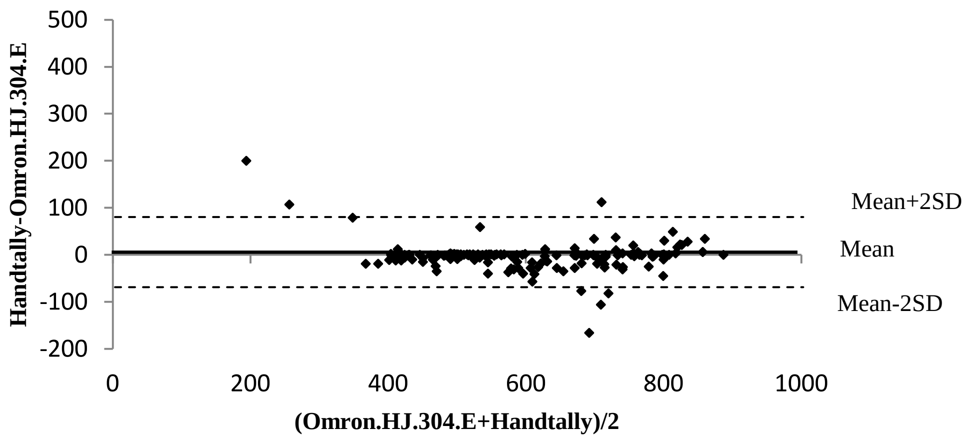
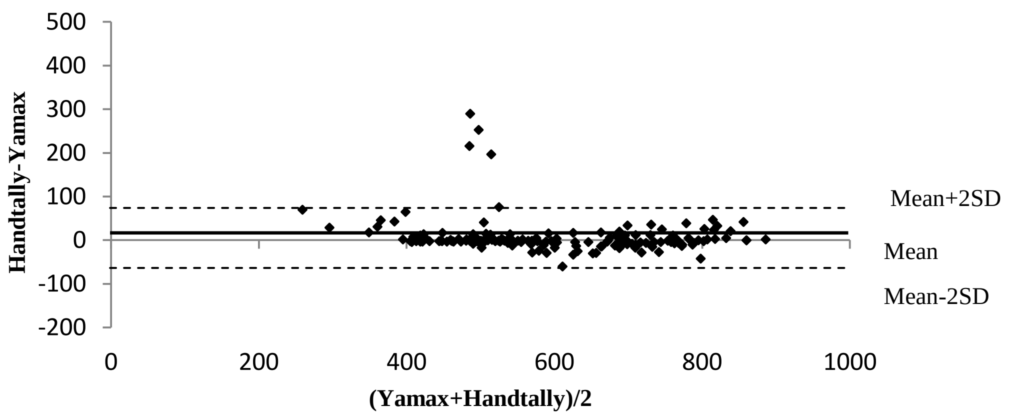
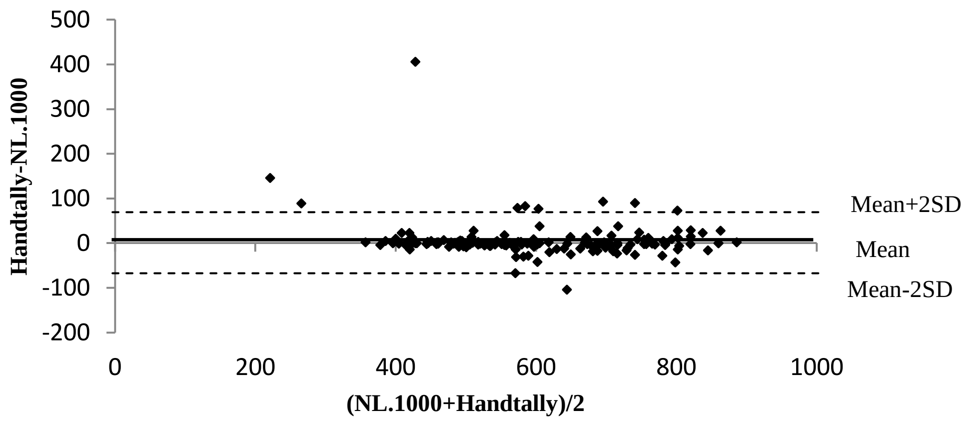


C



D



E

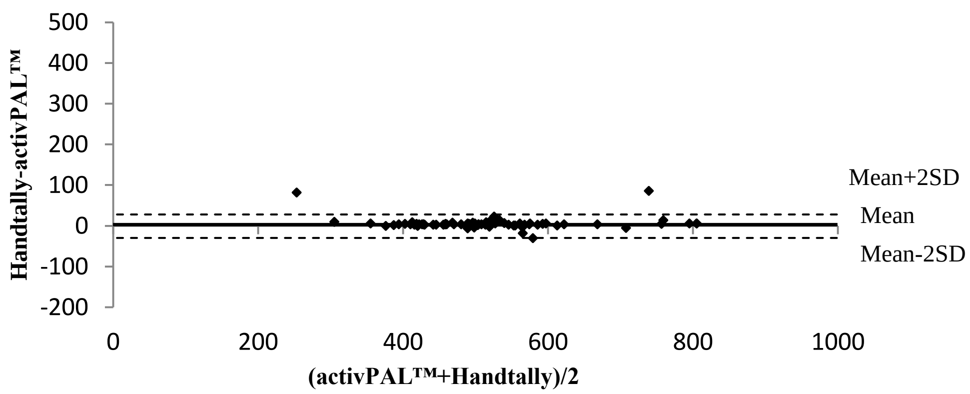


Figure 5a.5.2 A-E. Bland and Altman plots for the five step measurement instruments for all walking speeds. A- Omron HJ-720-ITC, B- Omron HJ-304-E, C- Yamax CW-701, D- New lifestyles NL-1000, E- activPAL™

5a.3.3 Activity time analysis

Activity time were recorded for the Omron HJ-304-E, New Lifestyles NL-1000, activPAL™ and actual time spent at or above 3 and 3.6METs ($\dot{V}O_2$ data). The Omron HJ-720-ITC only records activity time in bouts greater than 10 minutes. As walking trials were a maximum of 6 minutes long activity time was not recorded by the Omron HJ-720-ITC and it was therefore excluded from further analysis. The Yamax CW-701 recorded time in activity rather activity time. Paired sample t-tests revealed no statistically significant difference in the mean total walking time and the Yamax CW-701 time in activity for each walking trial (slow, moderate and fast). The mean total walking time for the slow, moderate, fast walking trials were 5:04, 5:01, and 4:58 minutes respectively and the Yamax CW-701 estimated time in activity for the slow, moderate, fast walking trials were 5:00, 5:03 and 4:58 minutes respectively.

Table 5a.3 presents activity time detected by the Omron HJ-304-E, New Lifestyles NL-1000, activPAL™ and actual time spent at or above 3 and 3.6METs ($\dot{V}O_2$ data). All step measurement instruments significantly ($p < 0.01$) overestimated activity time at all walking speeds when compared to measured activity time (at 3METs or above: Omron HJ-304, New Lifestyles NL-1000 and activPAL™, 3.6METs or above: New Lifestyles NL-1000 only) with the exception of the New Lifestyles NL-1000 at the slow walking speed compared to the $\dot{V}O_2$ 3MET threshold.

Figure 5a.2 presents the mean absolute percent error (MAPE) for activity time detected by the Omron HJ-304-E, New Lifestyles NL-1000, activPAL™, compared to actual time spent at or above 3 and 3.6METs (NL-1000 only) ($\dot{V}O_2$ data). All instruments presented an MAPE much greater than the acceptable level of ±3%. MAPE ranged across each walking speed, the largest MAPE was observed in the Omron HJ-304-E at the fast walking speed (3.5mph), New Lifestyles NL-1000.at the moderate walking speed (3.0mph) for both 3 and 3.6METs and at the slow walking (2.5mph) in the activPAL™. The smallest MAPE was observed at slow (2.5mph) walking speed, for the Omron HJ-304-E and New Lifestyles NL-1000 (3 METs) respectively and the fast (3.5mph) fast walking speed for the New Lifestyles NL-1000 (3 METs) and activPAL™ respectively. For all the walking speeds the smallest MAPE was demonstrated by the New Lifestyles NL-1000 using $\dot{V}O_2$ data at 3METs. The largest MAPE was demonstrated by the New Lifestyles NL-1000 sing $\dot{V}O_2$ data at 3.6METs.

Table 5a.3. Descriptive statistics for mean±SD $\dot{V}O_2$ and step measurement instrument determined moderate intensity activity time and Bland and Altman limits of agreement for all instruments

Walking trial		Slow (2.5mph)				Moderate (3.0mph)				Fast (3.5mph)							
Instrument	**N**	**AT (Min)**	$\bar{d}$	$\bar{d}$+2s	$\bar{d}$-2s	**AT (Min)**	$\bar{d}$	$\bar{d}$+2s	$\bar{d}$-2s	**AT (Min)**	$\bar{d}$	$\bar{d}$+2s	$\bar{d}$-2s	**AT (Min)**	$\bar{d}$	$\bar{d}$+2s	$\bar{d}$-2s
$\dot{V}O_2$ (3Mets)	56	1:07±1:38	-	-	-	2:12±1:55	-	-	-	2:57±1:50	-	-	-	2.06±1.56	-	-	-
$\dot{V}O_2$(3.6Mets)	56	0.21±0.55	-	-	-	0.50±1.16	-	-	-	1.45±1.49	-	-	-	0.58±1.29	-	-	-
Omron HJ-304-E	56	3:38±2:59**	-2.31	2.15	-7.19	7:15±2:16**	-5.03	-0.11	-9.95	9:34±2:55**	-6.37	-1.47	-11.27	6.49±3.40**	-4.43	1.83	-10.69
NL-1000	56	1:21±1:46†	-1.00	2.00	-4.00	4:09±1:31†**	-3.19	-0.43	-5.95	4:46±1:11†**	-3.01	0.09	-6.11	3.25±2.07†**	-2.27	1.81	-6.35
activPAL™	26	4:24±1:06**	-3.17	-0.25	-6.09	4:15±0:40**	-2.13	0.69	-4.95	4:11±0:37*	-1.14	1.42	-3.70	4.19±0.49**	-2.13	0.83	-5.09

N= Number of complete data sets, AT= activity time (minutes), $\bar{d}$ = mean difference (Handtally –Instrument), $\bar{d}$±2s = mean difference±2Standard deviation of the differences, **significantly higher than $\dot{V}O_2$ activity time (3 Mets) ($p < 0.01$), † significantly higher than $\dot{V}O_2$ activity time (3.6 Mets) ($p < 0.01$). NL-1000 activity time was calculated at the manufactures default threshold equivalent to 3.6 MET and was therefore compared to the $\dot{V}O_2$ data at 3 and 3.6 Mets

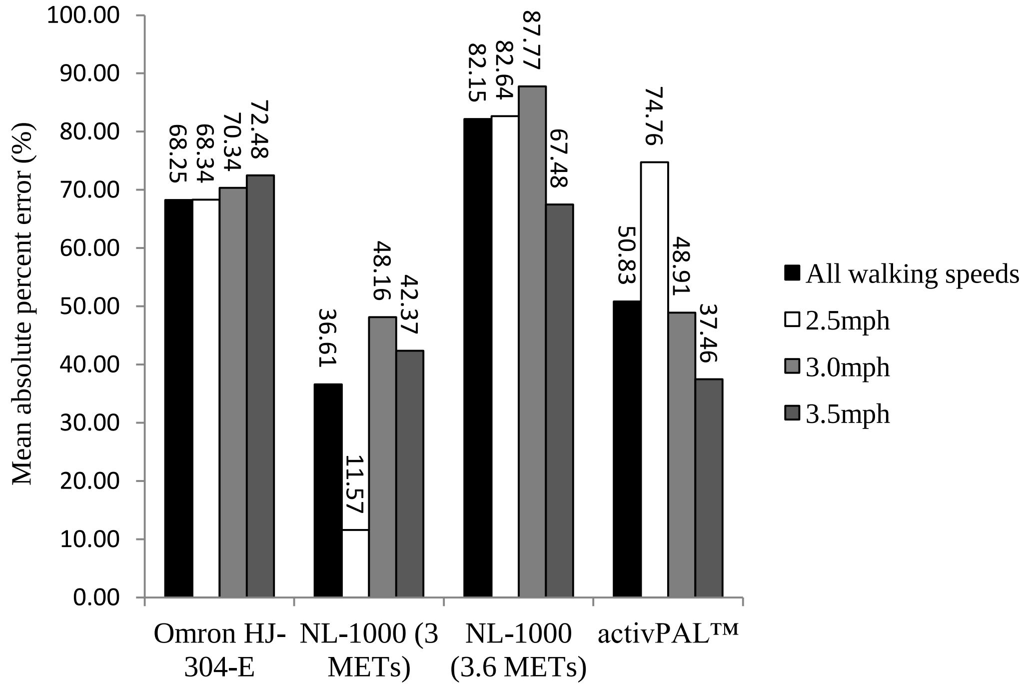


Figure 5a.5.3. Mean absolute percent error for activity time detected by the Omron HJ-304-E NL-1000 and activPAL ™ compared to measured activity time (indirect calorimetry)

Omron HJ-304-E and activPAL ™ were compared to the $\dot{V}O_2$ data at 3 and the NL-1000 activity time was calculated at the manufactures default threshold equivalent to 3.6 MET and was therefore compared to the $\dot{V}O_2$ data at 3 and 3.6 Mets

Bland and Altman activity time analysis

Bland and Altman analysis for total activity time at each walking speed are presented in table 5.3. The tightest limits of agreement were observed in the New Lifestyles NL-1000 at the slow walking speed and in the activPAL™ at the moderate and fast walking speeds. The activPAL™ demonstrated the tightest limits of agreement for all walking speeds followed by the New Lifestyles NL-1000 and Omron HJ-304-E respectively.

5a.4 Discussion

In preparation for more substantial data collection the current study has compared the performance of five commercially available step measurement instruments during continuous overground walking, to identify the most appropriate measurement instrument able to accurately quantify step counts and 'moderate intensity stepping' in adolescent girls.

5a.4.1 Step count accuracy

Results of the current study demonstrated that all step measurement instruments tested (activPAL™, Omron HJ-720-ITC, Omron HJ-304-E, New Lifestyles NL-1000, Yamax Digi-walker CW-701), accurately recorded steps taken (MAPE <3.0%), with exception of the Yamax CW-701 and the Omron HJ- 304-E during the slow walking trial. The underperformance (greater error) of step measurement instruments is commonly observed at slow walking speeds (< 2mph) in both adult and youth populations (Bassett et al., 1996; Le Masurier and Tudor-Locke 2003; Beets et al., 2005; Duncan et al., 2007a). In the youth population it has been suggested that this underperformance may be attributed to insufficient acceleration, due to long controlled steps frequently observed in youth at slow walking speeds (Duncan et al., 2007a; Nakae et al., 2008; Mitre et al., 2009). However McNamara et al., (2010) suggested that the practical significance of such underperformance (errors) at slow walking speeds may be irrelevant in the youth population, as young people tend not to adopt such a slow walking pace (< 2mph) in free living environments and that step measurement instruments demonstrate accuracy at more practical speeds, required for health benefits (i.e. speeds indicative of MVPA).

While there is not currently a body of data that demonstrates walking speeds normally adopted in this population the subsequent study in this thesis (study 3b chapter 5b), addresses this and presents a contention that in fact adolescent girls do walk at these slow speeds. Thus, instrument accuracy at slow walking is likely to be of practical significance.

All step measurement instruments demonstrated greater accuracy at faster walking speeds with exception of the activPAL™ which was most accurate during the slow walking trial. This is consistent with the findings of Harrington et al., (2011) who reported that the activPAL™ maintained greater accuracy at slower walking speeds (2mph) when compared to the Actigraph accelerometer in a group of young females aged 15-25years. Harrington et al., (2011) suggested that this may be attributed to the activPAL's™ positioning on the thigh rather than the waist, thus increasing its sensitivity to the low acceleration observed at slow walking speeds. Of the waist mounted instruments the lowest MAPE was observed in the Omron HJ-720-ITC, Omron HJ-304-E and Yamax CW-701 during the moderate walking trial (3.0mph) and in the New Lifestyles NL-1000 during the fast walking trial (3.5mph). This highlights the difference in sensitivity to steps across different walking speeds among the competing technologies (Nakae et al., 2008; Hart et al., 2011).

Piezoelectric pedometers have been shown to be more accurate than traditional spring based pedometers especially at slow walking speeds (Crouter et al., 2005; Hasson et al., 2009; Holbrook et al., 2009; McClain et al., 2009; Hart et al., 2011). The results of the current study also demonstrate the difference in sensitivity to steps by sensor type (e.g. spring based vs. micro electro mechanical system vs. piezoelectric). The performances of the piezoelectric pedometers (Omron HJ-720-ITC and New Lifestyles NL-1000) were most consistent in the current study and have previously been shown to be accurate and reliable under controlled and free living conditions in both adult and youth populations (Holbrook et al., 2009; Ginnakidou et al., 2012; Tudor-Locke et al., 2009a; McMinn et al., 2010; Hart et al., 2011).

Despite being spring based (spring leaved mechanism), Yamax pedometers and specifically the Yamax Digi-walker SW-200 are one of the most commonly utilised instruments in the youth population (Tudor-Locke et al, 2009a) and are often considered to be criterion pedometers due to their established validity in the youth population (2-18yrs olds) (De Vries et al., 2009). Although the Yamax CW-701 was used in the current study rather than the Yamax Digi-walker SW-200 the internal step counting mechanism is the same in all Yamax models; differences between the models is in the additional features offered (e.g. distance travelled, time in activity). While the Yamax CW-701 demonstrated the greatest accuracy during moderate intensity walking when compared to the other instruments and handtally counts, it significantly ($p < 0.05$) underestimated handtally step counts at slow walking speeds and all walking trials collectively. Although it is likely that the significant underestimation of steps in the collective walking trials may be attributed to the underperformance at slow walking speeds, during free living activity, individuals are likely to change pace and therefore instruments must demonstrate accuracy over a number of walking speeds.

Similarly, the Micro electro mechanical system (MEMS) of the Omron HJ-304-E and activPAL™ also detected significantly different step counts ($p < 0.01$) (overestimated and underestimated respectively) when compared to handtally step counts at slow walking speeds and all walking trials collectively (activPAL™ only). While the activPAL™ demonstrated good accuracy across all walking speeds (MAPE) and the tightest agreement (Bland and Altman analysis) when compared to handtally step counts, it is also worth noting that the activPAL™ failed to record data in 30 girls, which resulted in missing data. Missing data are considered a threat to validity and can violate statistical assumptions and reduce power and may therefore be a reason for this incongruous result. However the activPAL™ has previously been shown to be a valid instrument for the detection of steps in larger samples of adults and adolescents (Ryan et al., 2006; Harrington et al., 2011).

5a.4.2 Activity time

In the current study all instruments tested claimed to provide feedback on energy expenditure, steps or time at or above moderate intensity activity, with exception of the Yamax CW-701 which provided feedback on time in activity. While feedback on time in activity may be useful in some situations (e.g. calculating time spent in ambulatory activity during a 1hour physical education class), it has limited utility in the assessment of MVPA within a free living environment. Further, the Omron HJ-720-ITC aerobic steps (activity time) function refers to continuous steps accumulated at the manufactures moderate intensity threshold of ≥ 60 step·min^{-1} in bouts greater than 10 minutes. As the walking trials in the current study were a maximum of 6 minutes long no aerobic steps were recorded. It therefore remains unknown whether the Omron HJ-720-ITC would accurately detect aerobic steps in a free living environment with the youth population. However it is likely that a step threshold of 60 step·min^{-1} is much lower than the step rate required to achieve moderate intensity walking in the youth population (see study 2, chapter 4). Additionally as aerobic steps are only calculated if accumulated in at least 10 min bouts, MVPA may not be calculated (missed and therefore underestimated) in the youth population, due to the incidental and sporadic nature of youth PA (Bailey et al., 1995). Thus the Omron HJ-720-ITC may not be an appropriate instrument to assess MVPA steps in the youth population.

Despite the limitations of the Yamax CW-701 and Omron HJ-720-ITC, activity time was recorded for the Omron HJ-304-E, New Lifestyles NL-1000 and activPAL™ in the current study. The results demonstrate that instrument detected MVPA overestimates actual activity time measured by $\dot{V}O_2$ in adolescent girls. Despite the more rigorous methods adopted in the current study and differences in methodologies, gender and ages, these results are consistent with the findings of Hart et al., (2011) who also reported large MAPE values for instrument detected MVPA (NL-1000, Omron HJ-151 and Walk4Life MVP) compared to MVPA detected by the ActiGraph GT3X accelerometer.

Of the instruments tested in the current study, the NL-1000 is the only instrument to have been previously investigated with regard to MVPA within the youth population (McMinn et al., 2010; Duncan et al., 2011; Hart et al., 2011). The NL-1000 is also the only instrument tested, where the intensity threshold for detection of MVPA can be adjusted. The manufacturers default MVPA threshold, level 4, equivalent to

3.6METs and has been previously validated in adults (McClain et al., 2007a). While level 5, equivalent to 4.2 METs has previously been recommended for children aged 10-11years (McClain et al, 2007b), Lubans et al., 2008 indicated that walking activity was not sustainable at speeds indicative of 4METs without running. Therefore as walking activity was the focus of this study it was deemed acceptable to set the NL-1000 to level 4 (3.6METs). However it is also acknowledged that for studies investigating other more vigorous forms of PA, level 5 (4.2METs) may be a more appropriate MVPA threshold to use within the youth population.

In addition to the NL-1000 detected activity time being compared to the $\dot{V}O_2$ data at 3.6METs (manufactures default threshold, level 4) it was also compared to the $\dot{V}O_2$ data at 3 METs, as the most common definition of MVPA is activity that is at or above an intensity of 3 METs (American College of Sports Medicine, 2000). The results demonstrate that the NL-1000 detected MVPA more accurately when compared to the $\dot{V}O_2$ data at 3 METs suggesting that the manufactures default threshold, level 4 (equivalent 3.6METs) may be closer to 3 METs in adolescent girls. Similarly the manufactures default threshold for the detection of MVPA of the Omron HJ-304-E (3METs being equivalent to a walking pace of ≥ 2.5mph or ≥100 step·min^{-1}) is likely too low for the youth population and more appropriate for the adult population (Tudor-Locke et al., 2005; Marshall et al., 2009; Beets et al., 2010; Rowe et al., 2011 and Abel et al., 2011). This may explain the overestimation of detected MVPA by the Omron HJ-304-E. The activPAL™ threshold is based on 4 METs being equivalent to a step rate 120 step·min^{-1}. Although 120 step·min^{-1} is reprehensive of MPA (see study 2 chapter 4) in adolescent girls, the proprietary algorithm used by the activPAL employs data from the adult compendium, which is not appropriate for use with the youth population.

5a.4.3 Instrument choice *(appropriate and practical to use with children)*

Aside from the accurate detection of steps and activity time, when selecting the most appropriate instrument we must also consider its cost, monitor size, sealed or unsealed monitor (when working with children), battery life, technical support and software packages. A full description of each instrument's additional features can be found within the method section of this study and summarised in table 5a.1.

In terms of cost, the Yamax CW-701 and the Omron HJ-304-E were the cheapest of the instruments tested and therefore may be appropriate for large, low budget studies. The Omron HJ-720-ITC, New Lifestyles NL-1000 were slightly more expensive than the Yamax CW-701 and the Omron HJ-304-E, but still considered low cost compared to the activPAL™. However in terms of both cost and accuracy the NL-1000 was the most practical measurement instrument tested.

All step measurement instruments tested varied in size and dimension. Although all were generally small and discrete, the Yamax and New Lifestyles NL-1000 and activPAL™ were more compact than the Omron models. Further the attachment clips on the Omron models were also not as secure as those on the Yamax CW-701 and New Lifestyles NL-1000. Due to this the Omron instruments tended to protrude further from the waist band. Although this was not an issue in the current study as conditions were controlled, during free living studies issues may present especially among the adolescent girls themselves. For example there is an increased risk of the instrument falling off the waist band resulting in a lost or damage instrument and thus lost data. Also the less discrete the instrument is the less likely the adolescent girl will wear the instrument for the period of data collection also potentially resulting in lost data. The activPAL™ is the smallest and most discrete of all the instruments tested. However in the current study there were issues with the activPAL™ falling off the girls during testing. There are also potentially some sensitive issues regarding the attachment of the activPAL™ with adolescent girls as they have to expose their thigh. Although in the current study this was not a problem, this may be an obstacle in other situations.

A further advantage of the New Lifestyles NL-1000 and Yamax CW-701 over the other instruments tested is the plastic protective cover they are cased in. This protective cover allows the instruments to be easily sealed, thus giving the researcher the ability to conceal the step counts from the participants, which may reduce the problem of reactivity where the participants behaviour is influenced by visual feedback from the measurement instrument (Rowlands, Stone and Eston, 2007). While it is acknowledged that one of the most appealing features of pedometers is their ability to provide immediate feedback to the end user acting as a motivation tool, in the current study and further study in this thesis (study 4, chapter 6) the aim was to monitor walking behaviour rather than change or promote behaviour change. Therefore in this case sealed pedometers were advantageous. Further the plastic cover also offers protection from accidental reset, which is often considered a practical feature essential when working with the youth population (Warren et al., 2010). Both the Omron HJ-720-ITC and HJ-304-E are unsealed and unprotected pedometers and although they have features to avoid being accidently reset e.g. both models cannot be zeroed manually without resetting several components, but automatically reset at mid night, such features are not always practical and do not prevent damage to the display screen. In the current study each instrument ideally needed to be reset between each walking trial and each participant, however due to time constraints this was not possible with the Omron HJ-720-ITC and HJ-304-E and steps were noted between each trial and participant instead, which may have potentially introduced error. However these features may be more appropriate during free living activity. Finally, the step analysis of the activPAL™ was time consuming and thus the activPAL™ may not be feasible for large sample studies.

In terms of battery life, all the instruments tested, with exception of the activPAL™ claimed that battery life was approximately 1-3years depending on how much the instrument was used. The activPAL™ is self-charging via computer and requires to be charged every 8 days. Similarly all the instruments tested came with a one year warranty from the date of purchase, if the instrument failed to operate under normal use, as well as access to technical support if required.

Only two of the instruments tested (activPAL™ and Omron HJ-720-ITC) featured analysis software and PC interface. While such software was essential for analysis of the activPAL™ data, it was an additional feature of the Omron HJ-720-ITC. Both the PC interfaces supplied with these instruments allow data to be presented graphically. Such features may act as a motivational tool to increase walking behaviour in the youth population and/or learning tools within a class room situation.

5a.4.4 Strengths and limitations

This study had several strengths. It has provided information on criterion validity of five different step measurement instruments within an adolescent girl population. It is also the first study to assess step count accuracy in the Omron HJ-304-E and Yamax CW-701models within an adolescent population. Melanson et al., (1995) stated that validation of any step measurement instrument should be undertaken in a field setting, employing direct observation as a criterion measure. Although the current study was undertaken in a controlled environment, stepping was overground and the instrument detected step counts were compared to real time direct observation handtally step counts. Also activity time measured by each instrument was compared to real activity time measured by $\dot{V}O_2$. This is the first study to address this issue. Previous studies have often compared steps and MVPA to accelerometers cut point, however it is acknowledged that the majority of these studies mainly investigated free living activity where direct observation is not always feasible. However it is essential we understand how an instrument performs in both controlled and free living conditions in the population of interest before they are implemented for use, therefore a limitation to this study is that the instruments performances were compared under controlled conditions.

Another Limitation of this study is the positioning of the waist mounted instruments. Although positioning of the instruments remained constant throughout the study, previous research has indicated that the accuracy and reliability of two instruments positioned on the right and left sides of the body may differ (McClain et al., 2007c; Powell and Rowlands, 2004; Reneman and Helmus, 2010, Van Hees et al., 2009; Welk et al., 2004). However in the current study the instruments were attached according to manufacturer instructions. Further the Omron models have previously been shown to accurately detect steps in positions other than the waist (pocket and neck chain), due to their multi-axial sensors (Holbrook et al., 2009). Therefore it was decided to place the Omron pedometers adjacent to the New lifestyles NL-1000 and the Yamax CW-701which specified mid-line attachment.

5a.5 Conclusion

This study has highlighted some of the differences with regard to step accuracy and detection of 'moderate intensity stepping' (activity time) among some of the many competing technologies. It also highlighted that in order to choose the most appropriate measurement instrument, prior assessment with the population of choice and consideration of additional feature is essential. In conclusion the results of the current study acknowledge that ultimately the research aims, budget and population of interest will shape the decision on the most appropriate instrument. In the current study although all the instruments tested demonstrated acceptable levels of accuracy and reliability, the New lifestyles NL-1000 was most consistently accurate in quantifying steps and activity time 'moderate intensity stepping' in the group of adolescent girls tested. The ease of use and additional design features of the New Lifestyles NL-1000 also make it particularly appealing for use with the youth and specifically an adolescent population.

Chapter 5b : Methods of objective evaluation of incidental walking activity

5b.1 Introduction

Incidental ambulatory activity occurs sporadically through daily living activities such as shopping and stair climbing. Its impact on total daily physical activity (PA) is therefore often greater than that of structured or purposeful PA (Tremblay et al., 2007) and there is increasing evidence that incidental activity is as important as achieving recommended daily moderate to vigorous physical activity (MVPA) targets (Levine et al., 2006). While the health benefits of being incidentally active are not fully known or understood, its potential to reduce sedentary activity (for which there is evidence to suggest that it is an independent risk factor for ill health) is now increasingly recognised (Tremblay et al 2007, Department of Health 2011). Accurate quantification of incidental (habitual) ambulatory activity would therefore provide insight and lead to better understanding of its relationship with health.

Pedometers are commonly employed to measure and communicate walking (ambulatory) activity. However in the attempt to improve the accuracy of these step measurement instruments, manufactures have developed inbuilt features that prevent the counting of accidental steps, non-steps or erroneous movement, the latter prevalent whilst sitting and standing. For example some pedometers only record steps taken in bouts of four seconds or longer. While it is important for instruments to demonstrate improved accuracy in the detection of steps during continuous walking, it is also important to demonstrate the accurate detection of incidental steps. This may be of particular importance within a youth population where PA is often accumulated in short bouts throughout the day. Consequently these inbuilt features may lead to an underestimation of daily step counts (Tudor-Locke et al., 2011c).

Therefore the purpose of this study was to i) compare step counts from the step measurement instruments used in study 5a to direct observation handtally step counts, during incidental walking activity ii) Explore whether incidental walking may contribute to daily PA targets

5b.2 Methods

5b.2.1 Participants

The study was conducted in a local secondary school and was given ethical approval by the University research ethics committee and local council. Permission to conduct the study was also received from the head teacher and the principal teacher of the Physical Education (PE) department. All data were collected within the school environment during timetabled PE lessons.

Fifteen adolescent girls aged between 12-15years (mean age 13.41±0.25 yrs) volunteered to take part in the study. The girls were recruited via flyers and an information session, advertised through PE department. Both parents/guardians and the girls provided informed consent before taking part in the study.

5b.2.2 Instruments

A full description of step measurement instruments used can be found in chapter 5a, table 5a.1, page 85.

5b.2.3 Procedures

Anthropometry

Stature and body mass were measured using a Seca portable stadiometer and Seca flat scales (Seca 761, Seca Birmingham, UK) respectively. Measurements were made according to the procedures recommended by the International Society for Advancement of Kinanthropometry. Measurements were repeated and the mean was taken as the true measurement.

Body mass index (BMI) was calculated by dividing body weight in kilograms (kg) by height in meters^2 (kg/m^2).

Step count measures

Five step measurement tools (activPAL™ and pedometers; Omron HJ-720-ITC, Omron HJ-304-E, New Lifestyles NL-1000, Yamax CW-701) were used to assess number of steps and where the instrument allowed intensity of steps, during each incidental walking trial. Each measurement tool was compared to direct observation, handtally counts were the researcher manually pressed the counter registering each step observed. This was used as the criterion measure to step count.

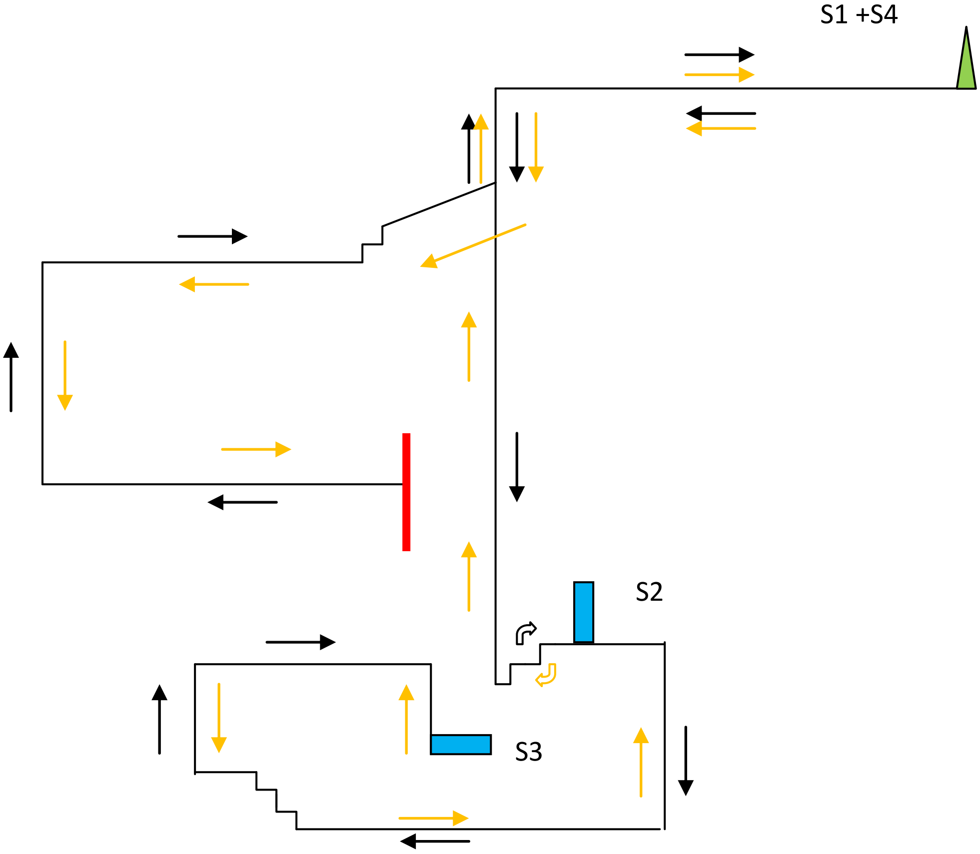
All pedometers were attached to the waistband according to manufactures specifications; NL-1000 above the midline of the right knee, Omron HJ-720 –ITC above the right pocket on the hipbone, Omron HJ-304-E above the left pocket on the hipbone and the Yamax CW-701 above the midline of the left knee. The activPAL™ accelerometer was attached using the manufacturers recommended method (PALstickies™-hydrogel adhesive pad) to the mid right anterior thigh by the girls underneath their clothing prior to the start of the walking trials.

The NL-1000 and Yamax CW-701 pedometers were re-set to zero between each trial. Both the Omron HJ-720-ITC and HJ-304-E automatically reset at mid night and cannot be zeroed manually without resetting several components, therefore number of steps taken during each walking trial was subtracted from previous steps taken. The activPAL™ device remained attached throughout the trials and activPAL™ data were downloaded and referenced against time at the end of each testing session. Pedometers were checked prior to each walking trial using a standard 20 step test (Tudor-Locke and Myers, 2001).

5b.2.4 Exercise protocol

Incidental walking circuit

A walking circuit designed to reflect incidental activity during the school day was set up in school (see figure 5b.1). The sensitivity of each step measurement instrument to incidental movement was explored throughout the circuit by comparing step counts on each measurement instrument with the handtally counts taken by the researcher as described above. Participant wore all step measurement instruments as described above and were instructed to walk at a normal (self selected) walking pace throughout the circuit. Participants began the circuit with two feet together on a start line. Participants then followed a standard set of instructions (see appendix 1) given by the researchers as they progressed through the circuit, which included walking, sitting, standing and stair climbing. Number of steps taken from all measurement instruments and total time walking were noted for data analysis



Start/Finish line

Corridor walking (arrow indicate the direction of walking)

Stair climbing

Direction of stair climbing

Sedentary time in a seated position (Station 1 and 4)

Sedentary time in a standing position (Station 2 and 3)

Figure 5b.5.1. Incidental walking circuit

Total distance walked: 308meters, total stairs climbed: 52, total sedentary time: 3min 40s, average walking time: 4min 53s, average circuit completion time: 8min 22s.

Table 5b.1 presents each section of incidental walking circuit

Table 5b.1. Sections of incidental walking circuit

Location	Distance walked (meters)	Stairs	Sedentary time (seconds)	Mean walking time (min:secs)	Postural changes
Start line to Station 1	61	5	60	0:58±0.06	2 (a + b)
Station 1 to Station 2	57	5	50	0:56±0.17	2 (c + d)
Station 2 to Station 3	36	16	70	0:40±0.05	2 (a + d)
Station 3 to Station 4	93	21	40	1:22±0.09	2 (a + b)
Station 4 to Finish	61	5	*	0:58±0.06	1 (c)

Postural changes: **a** - standing-walking, **b** - walking-standing – siting, **c** - sitting –standing –walking, **d** - walking-standing

5b.2.5 Data analysis

Descriptive statistics were expressed as mean ± standard deviation for total step counts from each step measurement instrument and real time direct observation handtally at self-selected walking speeds during incidental walking trials. Walking speed was calculated by dividing the distance walked by the time walked between each station. Step rate was calculated by dividing the total steps taken by total time walked between each station (minus sedentary time).

The mean absolute percent error (MAPE) was calculated for each step measurement instrument compared to direct observation handtally for the incidental walking trials (equation 5.1).

MAPE = (measurement device steps- handtally steps)/handtally steps x 100

[5.1]

Bland and Altman analyses were used to compare total step count data from each step measurement instrument to the direct observation handtally counts at self selected walking speeds during incidental walking trials. This technique allows the graphical representation of the mean error score and the 95% prediction intervals. Greater accuracy of an instrument results in tighter limits of agreement. Limits of agreement were established as mean difference ±1.96SD of the difference (Bland and Altman, 1986).

In order to explore whether incidental walking may contribute to daily PA targets, step rate between each station was calculated. MVPA was defined as a step rate ≥ 120 steps·min^{-1} (see study 4). Walking time at or above this threshold was subsequently recorded as activity time. Where the step measurement instrument gave indication of energy expenditure, steps or time at or above moderate intensity activity (3METs), it was recorded and subsequently reported as activity time (see study 5a for further detail). Instrument activity time was then compared to activity time measured by the step rate threshold ($\geq$ 120 steps·min^{-1}) using Bland and Altman analysis.

Paired sample t-tests were used to evaluate the number of steps detected by the step measurement instruments and direct observation handtally counts. Activity time was subsequently compared to walking time at or above the step rate threshold ($\geq$ 120 steps·min^{-1}).

In addition the activPAL™ provides feedback on body position. The number of postural changes observed (direct observation) throughout the incidental walking circuit were recorded and compared to the postural changes recorded by the activPAL™.

PASW Statistics version 18.0.0 (IBM Corp., Somers, NY, USA) was used for statistical analysis. Statistical significance was set at $p < 0.05$. Bland and Altman plots were created in Excel.

5b.3 Results

5b.3.1 Descriptive results

All 15 participants had complete data for all step measurement instruments with exception of the activPAL™ which failed to record data in 10 participants. Table 5b.2 presents descriptive data for participants' physical characteristics and response parameters for the incidental walking circuit. Participants covered a range in height, weight and BMI. One participant was classified as at risk of overweight (BMI for age > +1SD < +2SD) and 3 were at risk of underweight (BMI for age < -1SD > -2SD) according to world health organisation (WHO) (WHO, 2007; Cole et al., 2000). The walking circuit took about 8 minutes (22 seconds), an average of 10 seconds in moderate intensity stepping (>120 steps·min^{-1}) and an average of 856 steps. The average walking speed during the incidental walking circuit was 2.34 mph and step rate was 107 steps·min^{-1}.

Table 5b.2. Participants' physical characteristics and response parameters for incidental walking circuit

Variable	Mean±SD	Range
Age (yrs)	13.41±0.25	12.80-13.72
Height (cm)	156.5±5.73	148.90-167.30
Weight (kg)	45.83±6.08	38.00-56.00
BMI	18.76±2.43	15.80-24.88
Walking speed (mph)	2.34±0.22	2.09-2.74
Step rate (steps·min^{-1})	107±8	95-123

BMI-Body Mass Index

5b.3.2 Step count analysis

Step counts determined by each step measurement instrument and direct observation handtally are presented in table 5b.3. The Yamax CW-701 and the New Lifestyles NL-1000 significantly overestimated incidental steps when compared to direct observation handtally step counts. Although not significant the Omron HJ-304-E also overestimated incidental steps, whereas the Omron HJ-720-ITC and activPAL™

underestimated incidental steps. Figure 5.3 presents the absolute mean percent error of each step measurement instrument compared to handtally. The MAPE for all instruments were within levels considered to be acceptable (<3%) (Crouter et al, 2003; Hatano 1997). Both the Omron HJ-720-ITC and HJ-304-E and the activPAL™ demonstrated the smallest MAPE, (0.43, 0.47 and 0.46% respectively). The Yamax CW-701 and NL-1000 demonstrated the largest MAPE, (2.58 and 2.74% respectively).

Table 5b.3. Descriptive statistics for mean±SD total step count and Bland and Altman limits of agreement for all instruments

Instrument	N	Steps	$\bar{d}$	$\bar{d}$+2s	$\bar{d}$-2s
Handtally	15	494±46	-	-	-
Omron HJ-720-ITC	15	492±49	2.13	41.79	-37.53
Omron HJ-304-E	15	497±46	-2.33	29.33	-33.99
Yamax CW-701	15	507±45**	-12.80	14.88	-40.48
New Lifestyles NL-1000	15	508±41**	-13.60	17.54	-44.74
activPAL™	5	480±19	10.80	43.24	-21.64

N= Number of complete data sets, $\bar{d}$ = mean difference (Handtally –Instrument),
$\bar{d}$**±2s** = mean difference±2Standard deviation of the differences
**significantly higher than handtally step counts ($p < 0.01$)

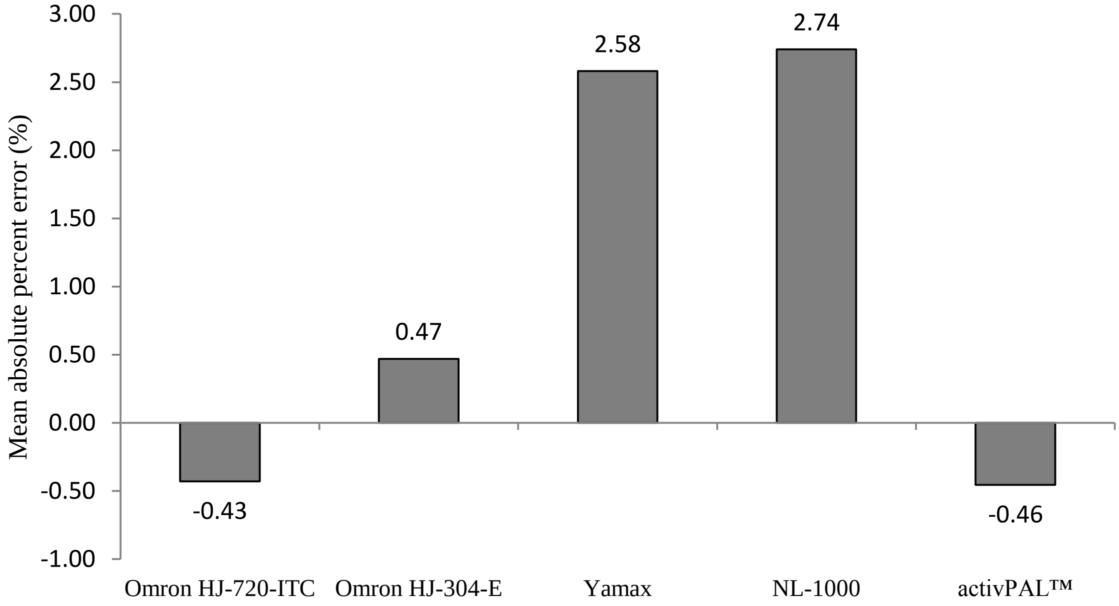


Figure 5b.5.2. Mean absolute percent error of each instrument compared to Handtally

Bland and Altman analysis

Bland and Altman analysis are presented in table 5b.3 and Bland and Altman plots for the five step measurement instruments compared to handtally for total incidental steps are presented in figures 5b.3 A-E. Despite significantly overestimating incidental steps and demonstrating the largest MAPE, the tightest limits of agreement were seen in the Yamax CW-701 and the NL-1000 (figure 5b.3 C and D respectively).

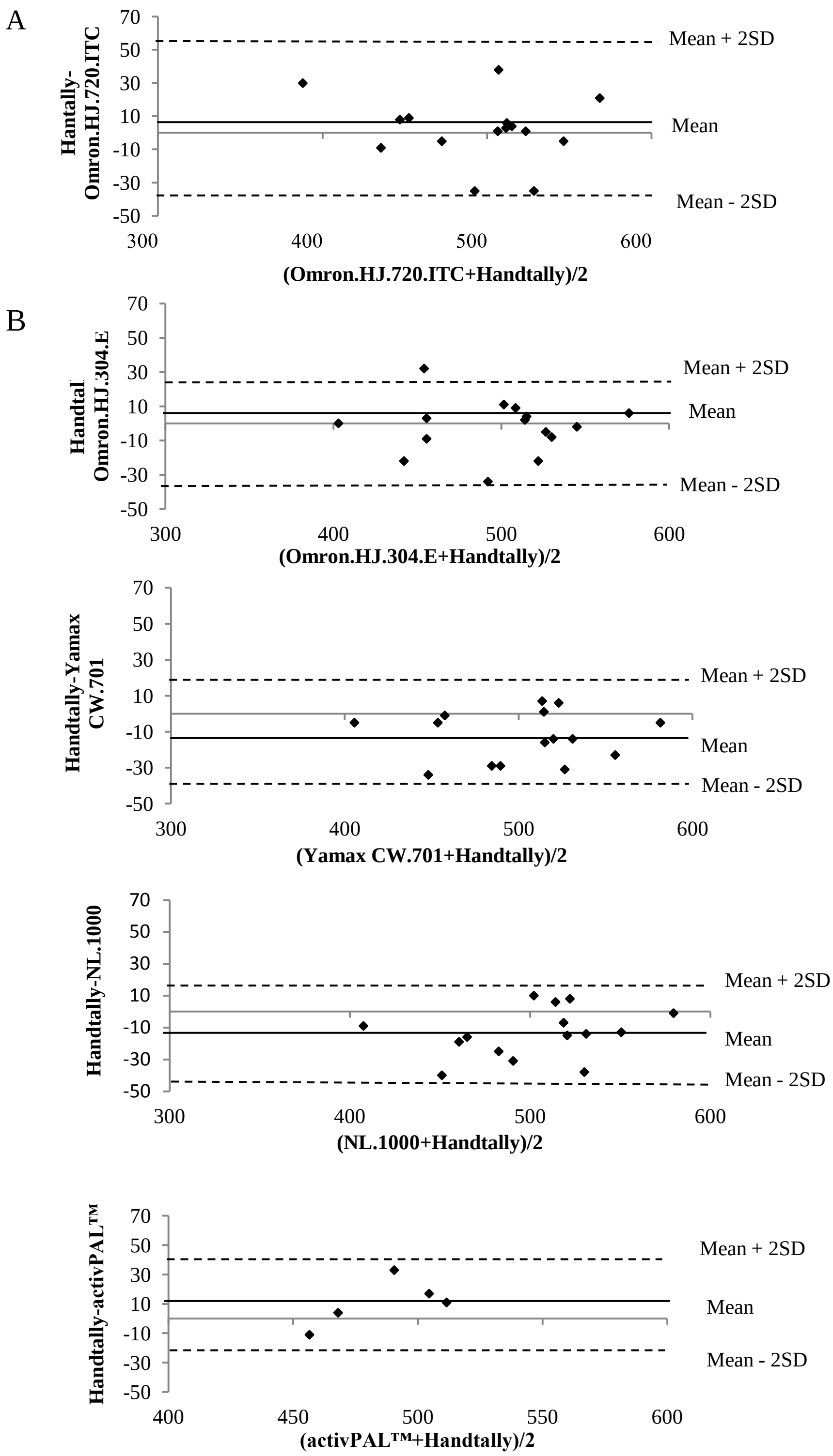


Figure 5b.5.3 A-E. Bland and Altman plots for the five step measurement instruments compared to handtally for total incidental steps. A- Omron HJ-720-ITC, B- Omron HJ-304-E, C- Yamax CW-701, D- New lifestyles NL-1000, E- activPAL™

5b.3.3 Activity time analysis

The average time spent in incidental activity were recorded for the Omron HJ-304-E, New Lifestyles NL-1000, activPAL™ and actual walking time at or above a step rate threshold of 120steps·min^{-1}. The Omron HJ-720-ITC only records activity time in bouts greater than 10 minutes therefore incidental activity time was not recorded by the instrument. The Yamax CW-701 recorded time in activity rather activity time. Both the Omron HJ-720-ITC and the Yamax CW-701 were therefore excluded from activity time analysis. When compared to total incidental walking time the Yamax CW-701 significantly ($p > 0.01$) underestimated time in activity Table 5.7 presents activity time detected by the Omron HJ-304-E, New Lifestyles NL-1000, activPAL™ and actual walking time at or above a step rate threshold of 120steps·min^{-1}. All step measurement instruments significantly ($p < 0.01$) overestimated activity time when compared to measured activity time (walking time ≥120steps·min^{-1}). Bland and Altman analysis (Table 5.7) revealed the NL-1000 to have the narrowest limits of agreement (-1.23, -3.37mins).

5b.3.4 Postural changes

All postural changes (detailed in table 5b.3) were correctly identified by the activPAL™.

Table 5b.4. Descriptive statistics for mean±SD activity time show in minutes and seconds and Bland and Altman limits of agreement for instruments able to quantify activity time

Instrument	N	Activity time (minutes)	Range	$\bar{d}$	$\bar{d}$+2s	$\bar{d}$-2s
Walking time ≥120steps·min⁻¹	15	0.10±0.40	0.00-1.30	-	-	-
Omron HJ-304-E	15	3.51±1.40**	0.00-6.00	-3.4	-0.7	-6.1
New Lifestyles NL-1000	15	2.32±0.50**	0.00-3.20	-2.2	-1.2	-3.2
activPAL™	5	4.30±0.14**	4.10-4.50	-4.3	-4.0	-4.5

N= Number of complete data sets, $\bar{d}$ = mean difference (Handtally –Instrument), $\bar{d}$**±2s** = mean difference±2Standard deviation of the differences, **significantly higher than measured walking time ≥120steps·min^{-1} ($p < 0.01$)

5b.4 Discussion

Due to the sporadic and school based nature of youth PA the current study has compared the performance of five commercially available step measurement instruments during incidental school based walking activity, to identify the most appropriate instrument able to accurately quantify incidental step counts in adolescent girls. The study also explored whether incidental stepping may contribute to daily MVPA counts.

5b.4.1 Incidental Step counts

Results of the current study demonstrated that all step measurement instruments tested (activPAL™ and pedometers; Omron HJ-720-ITC, Omron HJ-304-E, New Lifestyles NL-1000, Yamax Digi-walker CW-701), recorded incidental steps taken within the accepted range (MAPE <3.0%). Despite this, the Yamax CW-701 and the New Lifestyles NL-1000 significantly overestimated incidental steps when compared to direct observation handtally step counts. From a practical perspective, a person walking 1000 incidental steps may have registered 1025 and 1027 steps by the Yamax CW-701 and New Lifestyles NL-1000 respectively. Although not significant the Omron HJ-304-E also overestimated incidental steps, where as the Omron HJ-720-ITC and activPAL™ underestimated incidental steps. While this demonstrates that non-ambulatory activity (e.g. postural changes and fidgeting) still yields erroneous step counts on these advanced step measurement instruments, it also confirms different sensitivity to such movement among the competing technologies, highlighting the importance of prior testing of instruments intended for use.

Of the instruments tested the Yamax CW-701 is the only instrument not to have any inbuilt features that prevent or minimise the counting of non-ambulatory activity. This may be a reason for the overestimation of incidental stepping in the current study as any vertical force greater than 0.35g is counted as a step. The New Lifestyles NL-1000 features a computer chip that measures the amplitude and frequency of movement to determine whether the movement should count as a step; if the movement is not within the threshold range (0.06g-1.94g) the instrument deducts these steps. The wider assessment threshold range of New Lifestyles NL-1000 compared to the Yamax CW-701 may explain its increased sensitivity to incidental movement when compared to the other instruments tested, and therefore why it overestimated incidental steps. Despite this finding the NL-1000 is commonly used within the youth population and has previously been shown to accurately quantify habitual stepping when compared to accelerometer counts within the youth population (McMinn et al., 2010).

Both the Omron HJ-304-E and Omron HJ-720-ITC feature a 4 second step filter to prevent non-ambulatory activity being counted. The sensitivity of the Omron HJ-

720-ITC, but not the Omron HJ-304-E, to non-ambulatory movement has previously been demonstrated under free living conditions (Silicott et al., 2010). Silicott et al., 2010 reported that the Omron HJ-720-ITC underestimated free living activity when steps were accumulated during intermittent activities, which is consistent with the results of the current study. Further Silicott et al., (2010) attributed this to the 4 second step filter, however in the current study this did not lead to an underestimation in incidental stepping in the Omron HJ-304-E. It is acknowledged however that the internal sensor of the Omron HJ-304-E is different to that of the HJ-720-ITC (3 dimensional Micro electro mechanical system compared to the Dual-axial piezoelectric accelerometer in the HJ-720-ITC), which may explain its increased sensitivity to non-ambulatory activity compared to the Omron HJ-720-ITC.

Furthermore both Omron instruments also claim to accurately record steps when worn around the neck or in a pocket. While the Omron HJ-720-ITC, but not the Omron HJ-304-E has again been shown to accurately detect steps when attached at these sites under treadmill and overground walking conditions (Holbrook et al., 2009), this additional feature may also in part affect the filtering of steps, which may not be advantageous in the measurement of incidental activity.

Of all the instruments tested the activPAL™ demonstrated the lowest MAPE. The activPAL™ has many features which are advantageous in the study of incidental movement such as it provides information on postural changes. Such information provides more in-depth information into the nature of incidental walking activity. In the current study all postural changes were correctly identified. Although the current study was conducted under controlled conditions this feature may be particularly useful in free living studies. However it should also be acknowledged that the activPAL™ failed to record data in 10 out of the 15girls and therefore the results are subject to reduced power due to the smaller data sets analysed. Further the activPAL™ is less feasible for larger youth studies due to its cost compared to the other instruments tested.

Incidental activity time

With regard to the accurate detection of incidental activity time, only 3 of the 5 instruments tested recorded activity time. As previously discussed in chapter 5a the Yamax CW-701 only provides feedback on time in activity, which has limited utility in the study of incidental activity. Further due to the incidental nature of the current study activity time was not accumulated by the Omron HJ-720-ITC as the activity time (aerobic steps) function refers to continuous steps accumulated at the manufactures moderate intensity threshold of ≥ 60 step·min^{-1} in bouts greater than 10 minutes. Incidental activity time was however detected by the New Lifestyles NL-1000 Omron HJ-304-E and activPAL™ in the current study and was compared to actual time spent at or above a step rate of 120 step·min^{-1}.

Although there remains a lack of objectively validated moderate-intensity step rate or cadence thresholds specific to adolescents (Hart et al., 2011), 120 step·min^{-1} has also been suggested to provide a reasonable estimate of MVPA when compared to MVPA from accelerometers using established cut points (Beets et al., 2011). Also, a step rate of 120 step·min^{-1} was used in the current study as it was shown to represent moderate intensity walking in adolescent girls in study 2 (chapter 4) of this thesis.

Incidental activity time detected by the New Lifestyles NL-1000, Omron HJ-304-E and activPAL™ was significantly overestimated in the current study. This overestimation may be attributed to the manufacturer's threshold and filtering of activity time, which may not be set at an appropriate level for the measurement of incidental activity time. The New Lifestyles NL-1000 demonstrated the smallest error in activity time during the incidental walking circuit. However for every minute of time in MVPA undertaken the NL-1000 recorded an additional 57seconds compared to an additional 58 and 59seconds by the Omron HJ-304 and activPAL™ respectively. As previously mentioned in study 3a these low cost instrument generally overestimate activity time in the youth population.

5b.4.2 Incidental walking activity and daily physical activity targets

In the current study the average step rate during the incidental walking circuit was 107 step·min^{-1}, which was significantly lower than the step rate required to accumulate activity time (MPA walking). The average walking speed and activity time accumulated during the incidental walking circuit was 2.3mph and 10seconds of the 4mins 53seconds respectfully. These results demonstrate that during incidental walking within the school environment, adolescent girls tend to walk at a slower walking speed and step rate than that thought to represent moderate intensity walking (see study 2, chapter 4). Thus incidental walking may not contribute to daily physical activity targets. However a study by McGuire and Ross, (2011) which explored whether incidental activity was associated with cardio respiratory fitness found that sporadic moderate physical activity (MPA) was positively associated with cardio respiratory fitness. They also suggested that all forms of physical activity (e.g. structured, continuous and incidental) carry health benefits and should be promoted to improve cardio respiratory fitness which is an established risk factor of morbidity and mortality (Kodama et al., 2009). Further current PA guidelines also now acknowledged that even small amounts of PA (e.g. incidental walking) are better than no PA (being inactive). However more research is required into the benefits of being incidentally active. Further research in this area (incidental walking) may provide insight into its impact on sedentary behavior patterns, whether individuals naturally walk at a pace that benefits their health, how to provide more opportunities to be incidentally active within daily life and how to promote it.

5b.4.3 Strengths and limitations

This study had several strengths; it is the first study to determine the accuracy of five commercially available step measurement instruments during a school based incidental walking circuit. It has also provided insight into incidental activity time and its impact on PA targets in a group of adolescent girls. The comparison of incidental steps detected by each instrument tested to direct observation is a further strength of this study. However the comparison of activity time detected by each instrument to a step rate threshold, although the step rate was directly measured, may be considered a limitation of the current study, as the energy cost of walking was not directly measured. As outlined in study 5a the attachment of the waist mounted instrument may also be considered a limitation, however each instrument was attached according to manufacturer instructions.

5b.5Conclusion

The current study has highlighted differences in the detection of incidental steps and activity time among some of the competing technologies available to measure youth PA. Youth PA is often accumulated in short bouts throughout the day therefore the accurate assessment of incidental activity is particularly important. As all instruments tested demonstrated relatively acceptable detection of incidental steps other factors may also influence which instrument is most suitable for uses e.g. research aims, budget and population of interest. With this in mind, although the NL-1000 was found to overestimate incidental walking activity compared to the other instruments tests and with the exception of accumulated incidental activity time, it was shown in chapter 5a to be the most consistently accurate instrument in quantifying steps and activity time ‘moderate intensity stepping’ during continuous walking. Its ease of use compared to the other instruments tested and additional design features such as modifiable intensity levels for the detection of activity time, make it particularly appealing for use with the youth and specifically an adolescent population.

With regard to incidental walking activity contributions to daily PA targets, the results of the current study suggests that in general incidental activity is not undertaken at a walking speed or step rate thought to represent MPA walking and thus is not indicative of health benefits. However current PA recommendations now imply that some activity is better than no activity therefore further research is require to explore what impact incidental activity may have on health.

Chapter 6 How much walking should be advocated for good health in adolescent girls?

6.1 Introduction

Walking is considered a common and accessible form of physical activity that is incorporated into everyday living and is relatively easy to measure. Consequently, guidelines as to the number of steps·day^{-1} that should be advocated to maintain good health have been published. In adults 10,000 steps·day^{-1} is considered sufficient to maintain health, however in the youth population there is conflicting evidence with regard to the number of daily steps (steps·day^{-1}) required.

Normative data suggests that among children (typically 5-11yrs) we can expect 10-13,000 steps·day^{-1} for girls' and 12-16, 000 steps·day^{-1} for boys (Tudor-Locke et al., 2009b), and during adolescence (12-19yrs) these step values steadily decline to 8-9,000 steps· day^{-1}, especially among adolescent girls (Beets et al., 2010; Tudor-Locke et al., 2011a). However these expected values do not represent optimal daily step targets (Tudor-Locke et al, 2004; Duncan et al, 2007c) or inform how much walking should be advocated for good health.

Five youth studies have proposed daily step recommendations that relate to specific health criterion/indicators (e.g. healthy body composition defined by body mass index (BMI) to discriminate healthy weight and overweight) (Tudor-Locke et al., 2004; Duncan et al., 2007c; Laurson et al., 2008; Dollman et al., 2010; McCormack et al., 2011). 10,000–13,000 steps·day^{-1} for girls and 13,000–16,000 steps·day^{-1} for boys have been associated with healthy body composition defined by body mass index (BMI) (Tudor-Locke et al., 2004; Laurson et al., 2008) and percentage body fat (%BF) (Duncan et al., 2007c). However, these proposed health referenced recommendations have been established in children age 5-12years and are therefore not necessarily appropriate for adolescents (Duncan et al., 2007c; Laurson et al., 2008; Beets et al., 2008).

On the other hand, both Dollman et al., (2010) and McCormack et al., (2011) have included adolescents in their recommendations. McCormack et al., (2011) proposed a single health referenced recommendation (defined by BMI) of 16,000 steps·day^{-1} for both boys and girls aged 7-16yrs. Although this recommendation may be useful for health promotion purposes, it is not an adolescent specific recommendation. Conversely, Dollman et al., (2010) examined health referenced recommendations in four age and gender groups (5-12yr old girls and boys and 13-16yr old girls and boys) allowing for adolescent specific recommendations to be proposed. 11,000 steps·day^{-1} was associated with healthy body composition defined by BMI in 13-16yr old boys. However among adolescent girls daily step values did not discriminate between individuals classified as healthy or at health risk as defined by BMI (e.g. healthy weight vs overweight/obese). It therefore remains unclear as to the number of daily steps required for health in adolescent girls.

Further there are currently no step based data relating to any other health indicators other than BMI, (other than one study that has considered %BF (Duncan et al., 2007), in any youth population. The limitations of BMI as a health indicator are well documented, and therefore it may be prudent to consider other health indicators to demarcate between healthy and unhealthy young people in identifying step guidelines.

Further more there are currently no step based data relating to time in activity (active stepping) that relate to specific health criterion/indicators and thus health status. Given that additional health benefits are gained from more vigorous activity (Department of Health, 2011). The consideration of time spent in activity or active stepping may also be important.

The aim of this study was therefore to i) establish health referenced standards for step defined (walking) physical activity (daily steps and activity time) relating to appropriate health criterion/indicators (BMI, waist circumference (WC), %BF and blood pressure (BP)) in a group of adolescent girls, ii) explore whether daily step counts and/or activity time is more important for health, and iii) evaluate previously published step recommendations, concurrently identifying the prevalence of adolescent girls achieving them.

6.2 Methods

6.2.1 Design

The study was conducted in five local Edinburgh secondary schools. The same protocol was followed at each school. Each participant met with the researchers on two separate occasions for a maximum of 20 minutes. Data were collected in the following order: a) anthropometric measurements; b) activity data, collected by pedometer over seven consecutive days, both week and weekend days.

6.2.2 Participants

The study was given ethical approval by Heriot Watt University's research ethics committee and was approved by Edinburgh City Council. Permission to conduct the study was also received from the head teacher and the principal teachers of the Science (Biology) departments at each school.

The Science departments were targeted because of the study's potential to enhance the learning experience of pupils in specific modules studied with in the science curriculum as well as, assisting the schools in meeting their Curriculum for Excellence and Health Promoting Schools outcomes.

Two hundred and thirty adolescent girls aged between 12-15years (mean age 13.45±1.04yrs) volunteered to take part in the study. Details of the girls recruited, exclusion criteria and dropout rates are shown in figure 6.1 and explained in section 6.2.5 (activity data). The girls were recruited via letter and an information session, advertised through the Science department at their school. Both parents/guardians and the girls provided informed consent before taking part in the study.

6.2.3 Procedures

Anthropometry

Stature and body mass were measured using a Seca portable stadiometer and Seca flat scales (Seca 761, Seca Birmingham, UK) respectively. Sitting height was measured while participants sat on a solid box (dimensions: 70x40x40cm). Sitting height was assessed whilst the spine was stretched and head held in the Frankfort plane. Sitting height was subsequently used to calculate leg length from stature. Waist circumference was measured at minimal waist site to the nearest millimeter, using a steel tape (non elastic flexible tape) with participants in the standing position and at the end of expiration. Measurements were made according to the procedures recommended by the International Society for Advancement of Kinanthropometry (Stewart et al., 2011). Measurements were repeated and the mean was taken as the true measurement. The researcher's technical error of measurement (TEM) was 0.5%

Body mass index (BMI) was calculated by dividing body weight in kilograms (kg) by height in meters^2 (kg/m^2).

Body composition (percentage body fat)

Total body fatness was measured using the Tanita BC-418MA segmental body composition analyser (Tanita Corporation, Tokyo, Japan). Measurements were taken according to manufacturer's instructions; at least three hours after waking and after eating. Participants were also asked to go to the toilet immediately before the measurement. The Scales were corrected for light indoor clothing (-1.0kg). As participants were all under the age of 17 years the standard body type option was selected.

Participants stood with bare feet on the analysers weighing platform. With their feet correctly placed on the foot plates, participants held a pair of hand grip with their arms relaxed by their side. The impedance measurement took approximately 30 seconds and was measured only once.

Procedures follow that of McCarthy et al., (2006) in order to assess participant's adiposity using the body fat reference curves and define participants as under fat, normal, over fat and obese. Prediction equations converting resistance into body fat used by McCarthy (2006) were provided by the manufacturer (Tanita Corporation, Tokyo, Japan). The equations were based on bio-impedance, weight, height and age and were derived from calibration studies against DXA (whole body dual x-ray absorptiometry). The standard error of estimate for girls was 2.8% body fat (McCarthy et al., 2006). The Tanita BC-418MA model used has been previously validated against DXA and air displacement plethysmography (BODPOD) in a youth population (Pietrobelli et al., 2004).

Blood pressure

Blood pressure was measured using an electronic (oscillometric) monitor, Omron-705IT (HEM-759-E, Omron Healthcare, Inc, Bannockburn, IL). Participants were seated and the appropriate sized cuff for the arm circumference was placed on the right arm. Participants were instructed to rest their arm on the table and relax. Measurements were repeated and the mean was taken as the true measurement. The Omron-705IT (HEM-759-E) monitor used has previously been validated against mercury sphygmomanometers and assessed using the European Society of Hypertension International Protocol criteria and the Association for the Advancement of Medical Instrumentation (AAMI) validation criteria for use within a youth population (Stergiou, Yiannes and Rarra, 2006).

Age

Age was calculated from date of birth and date on first day of testing

Maturation status

Chronological age (yrs); Height (cm); Weight (kg); Sitting height (cm) and leg length (cm) were used to calculate maturation status reported as maturity offset (time before or after peak height velocity) and was predicted using the equation of Mirwald et al (2002).

Maturity offset = -9.376 + 0.0001882 x (leg length x sitting height) + 0.0022 x (age x leg length) + 0.005841 x (age x sitting height) – 0.002658 x (age x weight) + 0.07693 x (weight/height x100)

Activity data (step count measures)

The New Lifestyles NL-1000 (New Lifestyles Inc, Lee's Summit, Missouri, USA) pedometer was used to assess daily step counts and accumulated daily activity time (e.g. time spent at or above a pre-specified intensity threshold (steps·min^{-1})) over seven consecutive days, both week and weekend days. The activity time threshold on each pedometer was set at the manufacturer's activity level 4, equivalent to 3.6 METs. A detailed technical description of the NL-1000 can be found in chapter 5a page 81.

All pedometers were attached to an elastic belt on the participants' waistband according to manufactures specifications; above the midline of the right knee. Participants were issued with a diagram and instructed on the correct positioning of the pedometer in case the pedometer should move from its position on the belt. Participants were instructed to wear their pedometers at all times except when sleeping and during water based activities e.g. showering, swimming. All pedometers were sealed with tamper evident security tape (Tamper Technologies LTD) to assure that they would not be tampered with or accidentally reset. Any pedometers returned without security tape or if the security tape suggested that pedometer had been tampered with (i.e. opened), data were excluded from further analysis.

Diary sheet

Participants were issued with a diary sheet and instructed to note down the time when they either forgot to attach or removed their pedometer for >1h, along with a brief reason.

Mobile text reminders

An optional standard daily text reminder was sent each morning to participants asking them to remember to attach their belt and pedometer. A text reminder was also sent to participants giving them information on the date, time and location to return their pedometers to the researcher.

6.2.4 Experimental protocol

On receipt of a signed consent form, an initial meeting was set up with the group of participants in each school, where the study was again verbally explained. All participants were given the opportunity to ask any questions they had at this time. Following this participants were given information on the date, time and location to meet with the researcher to have anthropometric measurements taken. On completion of all anthropometric measurements the participants were issued with a belt and pedometer.

Anthropometry

All anthropometric measurements were taken within the school environment during school hours. Upon arrival to the allocated classroom, each participant's height, weight, seated height, waist circumference, percentage body fat and blood pressure were taken as described above. BMI and maturity off set were subsequently calculated.

Activity data

Sealed pedometers (New lifestyles, NL-1000) were attached and positioned on the waist band by the researcher as described above. Following the data collection period all pedometers were collected by the researcher and daily step counts and activity time for each of the previous 7 days were used for data analysis

Mobile text reminders

Participants who opted for the daily text reminders were sent a standard text by the researcher at 07.00am on week days and 08.00am on weekend days.

6.2.5 Data treatment

Anthropometric health indicators

Gender and age appropriate cut points were used to classify participants as healthy ($>2^{nd} < 90^{th}$ percentile) or unhealthy (at health risk) ($<2^{nd} \geq 90^{th}$ percentile) (e.g. normal weight (healthy) or underweight, overweight and obese (unhealthy)) according to each health indicator examined: BMI (Cole et al., 2000), Waist circumference (McCarthy et al., 2001) and percentage body fat (McCarthy et al., 2006). Due to the lack of available blood pressure reference data within the UK the US department of health (National institutes for health (NIH); National heart, lung and blood institute (NHLBI), 2007) cut points for children and adolescents, were used to classify participants as normotensive (non hypertensive/healthy) ($<90^{th}$

percentile) or pre-hypertensive (≥90th <95th percentile), hypertensive stage 1(≥95th <99th percentile) and 2 (≥99th percentile) (unhealthy) by gender, age and height for both systolic and diastolic blood pressure. In addition to each of the single health indicators, cluster risk scores were calculated, as the use of single health indicators such as BMI often have weak associations with cardio-metabolic health (health risk) in children and adolescents (Andersen et al., 2008). The clustering of health indicators has also been shown to be a better measure of cardio-metabolic health in youth (Andersen et al., 2003, Andersen et al., 2008). Cluster risk scores were calculated by summing the Z-scores for each health indicator (as data is normally distributed). Two separate cluster scores were calculated to create two health profiles. The health profiles consisted of the following; profile 1 cluster score of BMI, WC and BP and profile 2, cluster score of %BF, WC and BP. Individuals with a cluster score (health profile score) of ±1SD were considered at health risk.

Activity data

Pedometer step counts and activity time were taken as the average number of $steps \cdot day^{-1}$ and $mins \cdot day^{-1}$ respectively, when at least 4 days data (3 weekdays and 1 weekend) were available (Vincent & Pangrazi, 2002a; Strycker et al., 2007). Step counts and activity time were weighted according to the ratio of weekdays to weekends (to account for any bias between weekdays and weekend days) (Duncan et al., 2006). Steps were smoothed to 1000 steps increments (Tudor-Locke et al., 2004a), which is considered to be approximately 10mins of brisk walking (Tudor-Locke et al., 2004b), and the minimum requirement to obtain health benefits (Woolf-May et al 1999; Murphy and Hardman 1998).

Daily step counts < 1000 or >30,000 were regarded as outliers (Rowe et al., 2004) and were subsequently excluded from further analysis as was the corresponding activity time. Daily step counts and corresponding activity time were also excluded where there was evidence that the pedometer had been tampered with (determined by security evident tape) or where participants indicated either non-attachment or removal of their pedometer for >1h on a given day (determined by self-report diary sheet). Figure 6.1 shows the participant numbers recruited to the study, exclusion criteria and dropout rates. There were no significant differences in age height between the girls included in analysis and those who fulfilled the exclusion criteria. However the girls that were excluded from further analysis weighed significantly more than the girls included in the analysis. Of the 230 girls recruited, 10 had insufficient step data after removal of outliers. 44 either lost/removed/tampered with their pedometer or returned it late with insufficient step data (24 lost, 11 had removed pedometer for more than 1hr on several days, 2 had tampered with the pedometer and 7 were absent from school on the day of pedometer collection resulting in lost/insufficient data). A further 4 girls withdrew from the study and 4 were absent from school on the day(s) when anthropometric measurements were taken and were subsequently withdrawn from further participation. Complete data (both pedometer and anthropometric measurements (with the exception of the body fat and blood pressure measurements)) were available for 168 girls (73%).

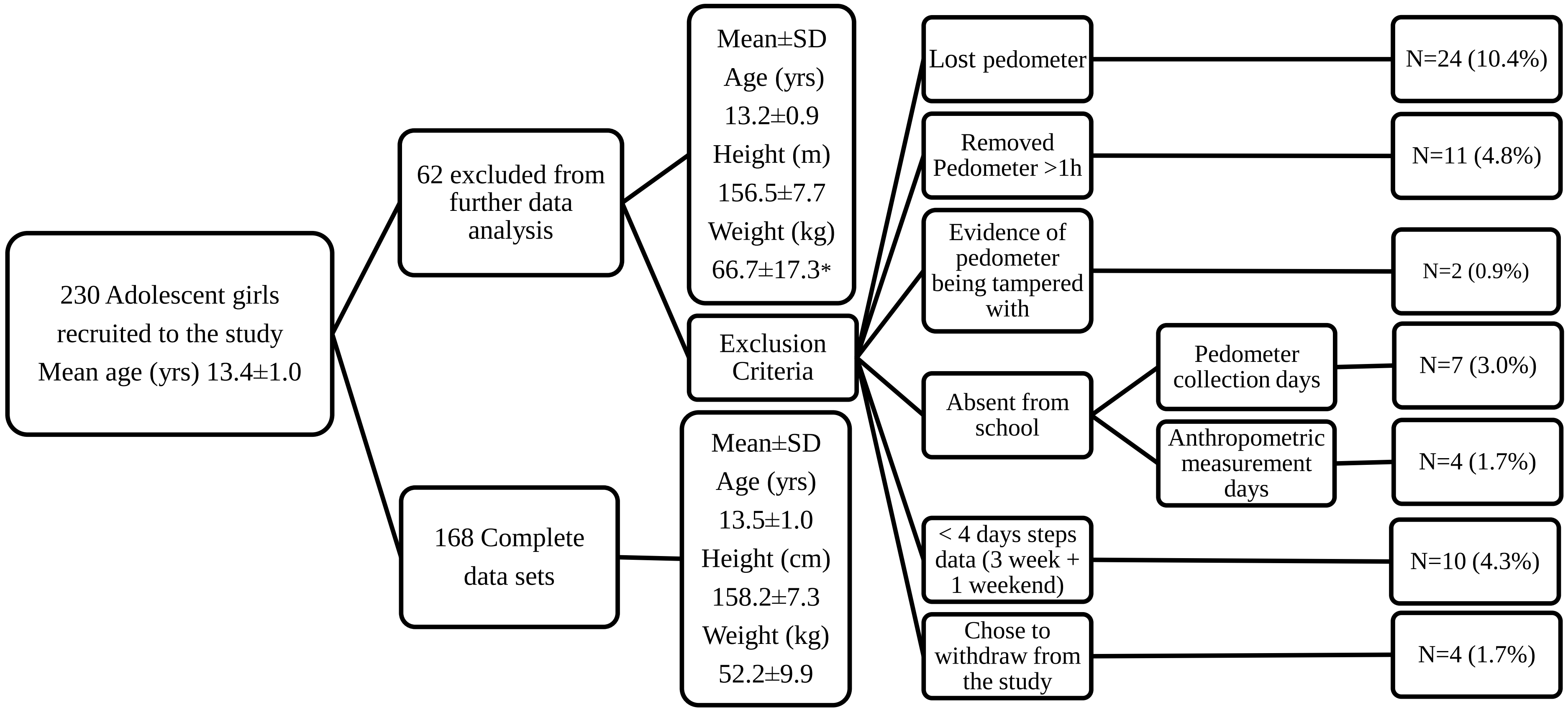


Figure 6.1. **Participant numbers recruited, exclusion criteria and dropout rates**
***** significantly heavier than the girls included in analysis ($p < 0.01$)

6.2.6 Data analysis

The differences in mean daily step counts (steps·day^{-1}) and daily activity time (mins·day^{-1}) between participants classified as healthy and unhealthy were examined separately for each of the single health indicators (BMI, WC, %BF and BP) and health profiles and compared using independent sample t-tests. In the first instance participants classified as 'unhealthy' by each single health indicator were further divided into underweight, overweight and obese for BMI, WC and %BF and pre-hypertensive or hypertensive stage 1 or 2 for BP and compared to normal weight and normotensive participants. Similarly for each health profile participants were separated into relevant tertiles of health (e.g. participants were classified as healthy, at some, moderate or great health risk). However due to the small numbers in the different health categories and no meaningful differences in steps and activity time, participants were there after classified as healthy and unhealthy for each single health indicator and profile.

Prior to further analyses the data were tested for the assumption of parametric tests. While all variables did not meet these assumptions, subsequent log transformation of the data (Tabachnick & Fidell, 2001) indicated no significant difference in the findings when using the log transformed or original data. Therefore, to ease interpretation, parametric tests were used for subsequent data analysis on the original data (Tabachnick & Fidell, 2001). Pearson correlations were used to explore bivariate associations between health status defined by each health indicator and health profile (cluster risk score), maturation status, daily step counts (steps·day^{-1}) and daily activity time (mins·day^{-1}).

To establish health referenced standards for pedometer determined physical activity (step and activity cut points) relating to each health indicator and health profile, two separate analysis techniques were considered; the criterion referenced approach using the contrasting group method (Safrit, 1986) and Receiver-operating characteristics (ROC) curves analysis. Analysis used to define criterion referenced standards using the contrasting group method followed that of other recent youth studies: Tudor-Locke et al., (2004b), Duncan et al., (2007c) and McCormack et al., (2011) and ROC analysis followed that of Laurson et al., (2008) and Dollman et al., (2010).

The contrasting group method (described in detail by Berk 1976 and Tudor-Locke et al, 2004b) is based on the existence of dichotomous groups with respect to a criterion (e.g. healthy or at health risk). This technique draws on several statistical indexes to establish the predictive ability of a given cut point and includes the probability of correct decisions, misclassification of errors (type I and type II errors), validity coefficient index and utility analysis (Berk, 1976; Safrit 1986). To determine the optimal steps (step·day^{-1}) and activity time (mins·day^{-1}) cut points, all statistical indices are considered simultaneously and should reflect a high probability of correct decisions, validity coefficient index and utility analysis and a low misclassification of errors.

ROC analysis is based on the relationship between the sensitivity (Se) and specificity (Sp) of various cut points. Se (true positive) is the probability that a child classified as 'unhealthy' will not meet the step/activity time cut point while Sp (true negative) is the probability that a 'healthy' child will meet the step/activity time cut point. ROC curves plot the Se and (1- Sp) across the range of cut point thresholds (steps·day^{-1}/min·day^{-1}). The areas under curve (AUC) calculates the accuracy of the cut point (Greiner et al., 2000), and ranges from 0.5 (predictive ability no better than chance) to 1.0 (perfect cut point). The optimum cut point should minimise misclassification error and maximizes Se and Sp.

To evaluate previously published step recommendations the Se and Sp values were estimated for norm referenced cut points (Vincent and Pangrazi, 2002), contrasting group method cut points (Tudor-Locke et al., 2004b; Duncan et al., 2006; McCormack et al., 2011) and ROC cut points (Laurson et al., 2008), for healthy and unhealthy girls according to BMI and %BF indicators and health profiles 1+2. The percentage of girls (separated by age group e.g. 12, 13, 14 and 15yr olds) achieving previous published recommended steps·day^{-1} were then compared to the cut points mentioned above.

PASW Statistics version 18.0.0 (IBM Corp., Somers, NY, USA) was used for statistical analysis. Statistical significance was set at $p < 0.05$.

6.3 Results

6.3.1 Descriptive results

Table 6.1 present descriptive data for participants' physical characteristics. Participants covered a broad range in height, weight, BMI, WC, %BF and BP. Maturity off set (time before or after peak height velocity) was used as an indicator of maturation status. 125 (74.4%) of the participants had attained peak height velocity at the time of data collection. Table 6.2 presents the mean daily step counts (steps·day^{-1}) and activity time (mins·day^{-1}) for each single health indicator (BMI, WC, %BF and BP). 37.50, 45.18, 31.03 and 38.84 % of participants were classified as 'unhealthy' according to BMI, WC, %BF and BP health indicators respectively. The percentage of participants in each of the further divided health categories (healthy weight, underweight, overweight and obese; normotensive, pre hypertensive and hypertensive are presented in table 6.3.

Table 6.1. Physical characteristics

Variable	Mean±SD	Range
Age (yrs)	13.5±1.0	12.6-15.8
Height (cm)	158.26±7.30	137.50-178.20
Weight (kg)	52.18±9.90	34.00-75.00
Maturity offset (yrs)	0.6±0.9	-1.5-2.3
Body Mass Index (BMI)	20.46±3.99	13.60-37.20
Waist Circumference (cm)	67.16±8.35	50.20-105.00
Body Fat (%)	27.31±6.31	12.40-50.50
Systolic Blood Pressure	117±14	87-166
Diastolic Blood Pressure	71±10	42-96

Table 6.2. Mean daily step counts (steps·day⁻¹) and activity time (mins·day⁻¹) for each health indicator and health category.

	BMI		Waist Circumference		Percentage Body Fat		Blood Pressure (Systolic)	
Health Status	**Healthy**	**Unhealthy**	**Healthy**	**Unhealthy**	**Healthy**	**Unhealthy**	**Healthy**	**Unhealthy**
N	105	63	91	75	81	35	85	54
Mean	19.3±1.6	22.3±5.7	62.1±3.2	73.3±8.51	24.1±3.1	34.3±5.9	108.9±7.6	132.1±14.8
Percentage	62.50	37.50	54.82	45.18	69.82	31.03	61.15	38.84
Steps·day^{-1}	10666±2947	9841±2984	10593±3211	10026±2671	10641±3071	9742±3165	10176±2956	10648±3291
Mins·day^{-1}	42.76±17.55	37.84±15.40	43.20±18.13	38.04±15.01	43.90±18.11	38.97±17.58	39.61±15.93	42.71±19.4

Unhealthy= individuals classified as at ‘health risk’ e.g. underweight, overweight, obese, pre-hypertensive and hypertensive

Table 6.3. Number and percentage of participants in each subdivided health category for each of the single health indicators

	BMI				Waist Circumference				Percentage Body fat			Blood Pressure		
Health Status	**Healthy**	**Under**	**Over**	**Obese**	**Healthy**	**Under**	**Over**	**Obese**	**Healthy**	**Over**	**Obese**	**Normal**	**Pre-HTN**	**HTN 1**
N	105	23	25	15	91	2	39	34	81	17	18	85	35	19
Percentage	62.50	13.69	14.88	8.93	54.82	1.20	23.49	20.48	69.82	14.65	15.51	61.15	25.17	13.66

Under = underweight; Over = overweight; Pre-HTN = pre-hypertensive, HTN 1 = Hypertensive stage 1

Table 6.4 presents the mean daily step counts (steps·day^{-1}) and activity time (mins·day^{-1}) for the two health profiles. Health profile 1 used a clustered risk score of BMI, WC and BP. 74.36% of participants were classified as healthy and 25.74% as unhealthy (20.73 and 2.44% were at some and moderate health risk respectively). Health profile 2 used a clustered risk sore of %BF, WC and BP. 70.69% were classified as healthy and 29.31% as at health risk (26.09 and 2.61% were at some and moderate health risk respectively). No participants were classified as at high health risk in either health profile.

Table 6.4. Mean daily step counts (steps·day^{-1}) and activity time (mins·day^{-1}) for each health profile

	Health Profile 1		**Health Profile 2**	
Health status	**Healthy**	**Unhealthy**	**Healthy**	**Unhealthy**
N	101	35	82	34
Percentage	74.26	25.74	70.69	29.31
Steps·day^{-1}	10532±2736	9863±3567	10500±2855	10058±3692
Mins·day^{-1}	42.14±16.51	37.64±17.28	43.59±17.39	39.54±19.36

Health profile 1 = Cluster score of Body Mass Index, Waist Circumference and Blood Pressure

Health profile 2 = Cluster score of % body fat, Waist Circumference and Blood Pressure

6.3.2 Activity Analysis

The mean daily step count (steps·day^{-1}) and activity time (mins·day^{-1}) for the girls was 10287±2931steps and 39.49±18.26mins respectively. Participants classified as ‘healthy’ (e.g. within the normal range according to the specific health indicator cut points used and health profiles scores), took more steps·day^{-1} and activity mins·day^{-1} than those classified as ‘unhealthy’, with the exception of the ‘unhealthy’ girls classified by the BP indicator (see tables 6.2). However results of the independent sample t-tests showed no significant differences between steps·day^{-1} and activity mins·day^{-1} for all single health indicator categories and health profiles (‘healthy’ vs. at ‘unhealthy’). Therefore the fundamental requirements for application of the contrasting group method to establish criterion (health) referenced standards are not satisfied (Berk, 1976) (e.g. the assumption of the existence of dichotomised groups cannot be met). Similarly, results of the ROC analysis show the AUC was not significantly different from 0.5 (0.59, 0.55, 0.59, 0.46 for steps·day^{-1} and 0.58, 0.58, 0.59 and 0.45 for activity mins·day^{-1} for BMI, WC, %BF and BP respectively; 0.56, 0.54 for steps·day^{-1} and 0.58, 0.57 for activity mins·day^{-1} for health profiles 1 and 2 respectively). Consequently cut points could not be determined for daily steps and activity time.

Pearson correlations showed no significant relationship between health status and daily step counts (steps·day^{-1}), daily activity time (mins·day^{-1}) and maturation status for health defined by BMI, WC, %BF, BP, HP1 and HP2 respectively (see table 7.5). Further no significant relationship was seen between maturation status and daily step counts (steps·day^{-1}) ($r = -0.01$ $p = 0.925$), and daily activity time (mins·day^{-1}) ($r = 0.01$ $p = 0.865$).

6.3.3 Comparison of current step recommendations

A comparison of previously published step count recommendations for BMI, %BF and health profiles 1 (Cluster score of Body Mass Index, Waist Circumference and Blood Pressure) and 2 (Cluster score of % body fat, Waist Circumference and Blood Pressure) are presented in table 7.5. The step cut point of 10,000 (Laurson et al., 2008) consistently produced the highest Se and Sp values, which were maximised best in health profile 1 when compared to the single health indicators of BMI, %BF and Health profile 2. The step cut point of 13,000 (Duncan et al., 2006) resulted in low Se and Sp values for both single and profile health indicators. The percentage of girls (separated into age groups of 12 (n=69, 13, (n=38), 14 (n=47) and 15 (n=14) years) achieving the recommended steps·day^{-1} for each step cut point (Vincent and Pangrazi 2002; Tudor-Locke et al., 2004b; Duncan et al., 2006; Laurson et al., 2008; McCormack et al., 2011) are presented in Table 7.6. For all age groups at least 50% achieved the recommendation of 10,000 steps·day^{-1} (BMI-referenced cut point) (Laurson et al., 2008). Approximately 40% (44), 30% (30) and 20% (23) achieved, 11,000 (Vincent and Pangrazi 2002), 12,000 (Tudor-Locke et al., 2004) and 13, 000 steps·day^{-1} (Duncan et al., 2006) respectively. A small percentage (4%) of the girls achieved the step recommendation of 16,000 steps·day^{-1} (McCormack et al., 2011). Split by age group a greater percentage of the 14 (8%) and 15 (14%) year olds achieved 16,000 steps·day^{-1} compared to the younger adolescent girls 12 (0%), and 13 (5%) years).

Table 6.5. Result of the Pearson correlations for the relationship between health status, daily step counts (steps·day⁻¹), daily activity time (mins·day⁻¹) and maturation status for health each health category

	Daily step counts		Daily activity time		Maturation status	
	r	***p***	***r***	***p***	***r***	***P***
BMI	-0.01	0.39	-0.06	0.43	0.13	0.07
WC	-0.04	0.55	-0.11	0.15	0.15	0.06
%BF	-0.002	0.98	-0.03	0.71	0.05	0.59
BP	0.12	0.14	0.13	0.11	-0.64	0.45
HP1	-0.12	0.13	-0.12	0.14	-0.05	0.50
HP2	0.53	0.57	-0.08	0.43	0.03	0.73

BMI = Body mass index, WC = Waist circumference, %BF = Percentage body fat, BP = Blood pressure, HP1= Health profile 1, HP2= Health profile 2

Table 6.6. Evaluation of previously published step count recommendations for two health indicators (BMI and %BF) and health profiles

Health reference	Step Cut point (steps·day^{-1})	Sensitivity (Se)	Specificity (Sp)
BMI	10,000[a]	0.64	0.46
	11,000[b]	0.35	0.24
	12,000[c]	0.28	0.18
	13,000[d]	0.17	0.14
	16,000[e]	0.38	0.63
%BF	10,000[a]	0.58	0.49
	11,000[b]	0.46	0.34
	12,000[c]	0.35	0.26
	13,000[d]	0.26	0.17
	16,000[e]	0.49	0.57
HP1	10,000[a]	0.60	0.50
	11,000[b]	0.47	0.36
	12,000[c]	0.32	0.27
	13,000[d]	0.26	0.18
	16,000[e]	0.40	0.68
HP2	10,000[a]	0.58	0.47
	11,000[b]	0.46	0.35
	12,000[c]	0.33	0.29
	13,000[d]	0.22	0.27
	16,000[e]	0.49	0.59

BMI= Body Mass Index, %BF= Percentage Body fat, HP1= Health profile 1, HP= Health Profile 2

Step cut points a= Laurson et al., 2008 (5-12yr olds), b=Vincent and Pangrazi 2002 (5-11yr olds), c= Tudor-Locke et al., 2004 (6-12yr olds), d=Duncan et al., 2007c (5-12yr olds), e=McCormack et al., 2011 (7-16yr olds)

Table 6.7. Percentage (%) of the girls meeting selected step defined cut points

Step cut point (steps·day^{-1})	All girls (n=168)	12 (n=69)	13 (n=38)	14 (n=47)	15 (n=14)
10,000[a]	57	63	52	55	50
11,000[b]	44	49	42	38	42
12,000[c]	30	31	26	31	35
13,000[d]	23	18	26	26	28
16,000[e]	4	0	5	8	14

Step cut points a= Laurson et al., 2008 (5-12yr olds), b=Vincent and Pangrazi 2002 (5-11yr olds), c= Tudor-Locke et al., 2004 (6-12yr olds), d=Duncan et al., 2007c (5-12yr olds) e=McCormack et al., 2011 (7-16yr olds)

Step cut points - a, c and e= BMI referenced, b= Norm referenced, d= % Body fat referenced.

6.4 Discussion

In an attempt to inform how much walking should be advocated for good health in adolescent girls the current study has examined daily step counts and activity time values relating to different health indicators (BMI, WC, %BF and BP) and 2 separate health profiles. Although daily step recommendations have previously been defined by BMI, in children and adolescents (Tudor-Locke et al., 2004b; Laurson et al., 2008; Dollman et al., 2010; McCormack et al., 2011) and %BF in children (Duncan et al., 2007c), there are not currently any step recommendations that specifically relate to adolescent girls. As well, this is the first study to attempt to identify step recommendations according to WC and BP as single health indicators, and according to health profiles (cluster risk scores) of BMI, WC, %BF and BP in an adolescent population.

6.4.1 Adolescent appropriate health reference standards

Results of the current study indicated that individuals classified as 'healthy' defined by each of the single health indicators and health profiles did not take significantly more steps·day^{-1} or spent more time in moderate intensity activity (i.e. more steps at or above the pre-specified threshold, MPA mins·day^{-1}) than individuals classified as at health risk or with poor health profiles. This is not consistent with the findings of prior youth studies (Tudor-Locke et al., 2004b; Duncan et al., 2007c; Laurson et al., 2008; Dollman et al., 2010; McCormack et al., 2011), who reported that individuals with a healthy body composition defined by BMI (Tudor-Locke et al., 2004b; Laurson et al., 2008; Dollman et al., 2010; McCormack et al., 2011) and %BF (Duncan et al,. 2007c) took more steps·day^{-1} than their overweight counterparts. In the current study, the smallest difference between 'healthy' and 'unhealthy' girls was

442 steps·day^{-1} and 4 minutes activity time when health was defined by HP1. Although probably only equivalent to 400-500m walking distance, in terms of energy expenditure this still relates to extra calories burned and more importantly a reduction in sedentary time. It is also likely that these small differences may be accumulated through incidental activity, which has been deemed to be equally important to achieving moderate intensity activity targets (Levine et al., 2006).

However, this study suggests it is unlikely that these small differences in walking behaviour might impact on health. The difference in steps and activity time between health groups was not statistically significant and therefore the fundamental requirements for the application of the contrasting group method were not met (Berk et al., 1976). Similarly, results of the ROC analysis show the area under the curve (AUC) were not significantly different from 0.5 for each single health indicator and health profile indicating that the predictive ability of classifying an individual as 'healthy' or 'unhealthy' with regard to daily step counts and activity time was no better than chance. These results suggest that daily step counts and activity time values do not discriminate between girls classified as 'healthy' or 'unhealthy'. The findings are consistent with those of Dollman et al., (2010), the only other study to consider adolescent girls as a separate subsample of the youth population with respect to evaluating 'healthy' walking behaviour.

Dollman et al., (2010) examined health referenced recommendations in four age and gender groups (5-12yr old girls and boys and 13-16yr old girls and boys). Daily BMI defined steps targets of 12,000 steps·day^{-1} and 10,000 steps·day^{-1} for boys and girls respectively were identified for 5-12yr olds. Among adolescent boys (13-16yr old) 11,000 steps·day^{-1} was associated with healthy body composition defined by BMI. However daily step values did not discriminate between individuals classified as healthy or at health risk as defined by BMI (e.g. healthy weight vs overweight/obese) among adolescent girls. Dollman et al., (2010) suggested that the poor association between steps·day^{-1} and health status (BMI derived weight categories) in adolescent girls (13-16yr olds) may be attributed to changes in body composition that occur during maturation. As BMI cannot discriminate between fat and lean mass, increases in height and muscle mass can also lead to increased BMI and therefore inappropriate weight (health) classifications are more likely to arise during maturation (Maynard et al., 2001). Thus maturation status may be viewed as a confounding variable in this population. However in the current study Pearson's correlations showed no significant associations between health status, maturation status, and daily step counts (steps·day^{-1}) and daily activity time (mins·day^{-1}). This suggests that maturation status was not a confounding factor in the current study.

It is difficult to explain why it is that walking behavior does not predict health status in this population, when this is not the case for children, and indeed adolescent boys (Dollman et al., 2010). It is feasible that in fact daily step counts and activity levels of the girls were essentially too low for even the more active to achieve health benefits. In comparison to the mean daily step count values for the adolescent boys in the study by Dollman et al., (2010), the girls in the current study took approximately 800 fewer steps·day^{-1} (10,287 compared to 11,150 steps·day^{-1}), which may be the equivalent to approximately 6-7minutes of MVPA per day (assuming a MVPA step rate of 120 steps·min^{-1}). Similarly in comparison to the younger girls (5-12yr olds) the girls in the current study took approximately 1300 fewer steps·day^{-1} (10,287 compared to 11,666 steps·day^{-1}), equivalent to approximately 10minutes MVPA per day. However it should be noted that the mean daily step values and step cut points reported by Dollman et al., (2010) are lower than those proposed by other youth studies with the exception of Laurson et al., (2008), thus the difference in the number of steps·day^{-1} between younger and older girls may in fact be greater.

It is also possible that the health indicators adopted here did not appropriately represent health risk. Other than BMI (discussed above), percentage body fat (%BF) is the only other health indicator (criterion) that has been previously employed to reference daily step recommendations in youth (Duncan et al., 2007c). Duncan et al., (2006) suggested that %BF may be a more appropriate health indicator to reference step recommendations against as it is more strongly associated with steps·day^{-1} than BMI. However Andersen et al., (2006) stated that health outcomes are often unclear in the youth population, as the association between physical activity and single health risk indicators are often weak. They also suggested that a more appropriate measure of health status would be to calculate the level of health risk, by clustering disease risk factors, specifically cardiovascular risk factors (Andersen et al., 2006). Therefore in the current study two separate health profiles (cluster risk score) were calculated in addition to the single health indicators. The health profiles consisted of either BMI or %BF as weight components, WC and BP as cardiovascular risk factors. Although no fitness related components or blood risk factors such as total cholesterol and HDL ratio were considered, Andersen et al., (2008) stated that lower intensity activities, such as walking have a greater effect on energy expenditure and insulin levels, than fitness per se. Therefore the health indicators used in this study, although mainly weight related should have been appropriate health indicators for activities such as walking.

6.4.2 Steps and Activity time

A further factor considered in the current study was whether the number of steps taken (volume of walking) or time in activity (intensity of walking/active stepping) was a better predictor of health status. It was hypothesised that the inclusion of activity time would be more likely to influence health status, as there is evidence to suggest that time spent in vigorous physical activity better predicts adiposity than the total volume of activity (Ruiz et al., 2006), and that additional health benefits are gained from more vigorous activity (Department of Health 2011). However the current study demonstrated that as with the daily step counts, there was no difference in activity time between those classified as healthy and unhealthy among adolescent girls. Despite this, the current study is the first to consider active stepping (activity time) in addition to volume of walking (daily step counts) and such outcome measures may be worth considering in other populations

Further it is acknowledged that activity time was determined by pedometer (NL-1000) in the current study and therefore time in different intensities is unquantifiable (only activity at or above the 3.6 METs (NL-1000- level 4) was accumulated). While walking activity is unlikely to be undertaken at a pace that will promote higher intensities (METs), it remains unclear whether individuals classified as healthy continually walked at a higher intensity for similar periods of time as unhealthy individuals. This is considered a limitation to the current study.

6.4.3 Comparison of current step recommendations

The inability to be able to suggest a step count threshold that is relevant for adolescent girls returns the question as to whether current thresholds recommended for young people are at all appropriate for this population. The ability for currently published guidelines to be able to correctly discriminate between girls that were 'healthy' and 'unhealthy' was therefore examined. The lowest step cut point of 10,000 steps $\cdot day^{-1}$ (Laurson et al., 2008) consistently produced the greatest Se and Sp values for BMI, %BF, HP1 and HP2 compared to the other recommendations (Vincent and Pangrazi 2002; Tudor-Locke et al., 2004b; Duncan et al., 2006; McCormack et al., 2011) and thus could be considered the most appropriate recommendation to use in adolescent girls. However, even using this 'best case' threshold, 34% of girls classified as 'healthy' according to BMI did not meet the recommendation and 46% of 'unhealthy' girls did meet the recommendation.

In a recent review of all previously published step recommendations, and whilst acknowledging the weaknesses of published thresholds, Tudor-Locke et al., (2011a) suggested that 10-11,700 steps $\cdot day^{-1}$ may be an appropriate recommendation for daily steps for adolescent boys and girls. Interestingly, this was considered to be intermediate to the recommended steps $\cdot day^{-1}$ for children and adults, and is inherently logical. Whilst this study has demonstrated that such a threshold may be misleading, 10,000 steps $\cdot day^{-1}$ appears to be the best informed guideline to use to date.

6.4.4 Strengths and Limitations

The current study had several strengths. It is the first study to consider time spent in activity (mins·day^{-1}) in addition to steps·day^{-1} to explore how much walking is required for health. It is also the first to report step based data relating to WC and blood pressure as single health indicators and to use health profiles in order to categorise health status, and thus avoid the limitations of any one indicator alone

Limitations of this study are the relatively small number of participants classified in each health category, compared to previous youth studies, which resulted in the fundamental properties of the contrasting group method not being met. Further participants excluded from final analysis (reasons outlined in figure 6.1) were significantly heavier and had significantly greater BMI than those included in the final analysis, suggesting that the study has selected a healthier sample. Furthermore other lifestyle factors that may contribute to health status, such as diet were not accounted for in this study. It is also acknowledged that pedometer determined PA is limited and as such may not provide enough information to discriminate health status (Beets et al., 2008). However this limitation could be easily overcome by employing an accelerometer based measurement device, if deemed practical and feasible. Further, and as indicated in previous youth studies (Laurson et al., 2008 and Dollman et al., 2010), it is not possible to determine if health status is an outcome or cause of pedometer determined steps and activity time due to the cross sectional design of the current study.

A further limitation to this study may be the inclusion of underweight, overweight and obese individuals in the 'unhealthy' classification. Laurson et al., (2008) reported improved accuracy of their step cut points with the removal of individuals classified as overweight, from a sample which included normal, overweight and obese individuals (e.g. Comparison of steps $\cdot day^{-1}$ between normal and obese individuals was more accurate than normal vs. overweight + obese). However in the current study there were no real (minimal) differences in step$\cdot day^{-1}$ and activity time (mins$\cdot day^{-1}$) for all health indicators and profiles between unhealthy individuals further classified as underweight, overweight and obese (see appendix 2). Further Dollman et al., (2010) suggested it may be viable that being underweight could also be related with pathologies that limit physical activity. Therefore in the current study, as in Dollman et al., (2010) underweight participants were separated from normal weight participants and classified as 'unhealthy' (being at health risk) along with those classified as overweight and obese.

6.5 Conclusion

In conclusion results of the current study indicate that in terms of walking activity, 'healthy' adolescent girls do not walk significantly more in term of steps$\cdot day^{-1}$ or time spent in activity (e.g. mins$\cdot day^{-1}$ spent at 3.6METs or above) than girls classified as 'unhealthy'. This suggests that in general adolescent girls may not walk enough to stratify health and health related outcomes and as a result, the data could not be used to suggest an appropriate step guideline for this population. Considering previously defined thresholds, it appears that the best guideline to adopt might be 10,000 step$\cdot day^{-1}$. However, even this guideline may be misleading.

Chapter 7 : Summary, conclusions and practical recommendations for future research direction

7.1 Introduction

The overall objective of this thesis was to identify both the quantity and quality of walking required for health in adolescent girls and how best to assess walking activity with regard to current physical activity guidelines, with the aim of providing step based guidelines to inform walking interventions in adolescent girls. Together, the four studies that comprise this thesis have added to the limited body of knowledge in this area of research.

The aim of this chapter is to provide a summary of the research findings from the four studies (chapters 3-6), discuss the findings in relations to the original research aims, provide practical recommendations with regard to the research findings and highlight potential future research direction. The Chapter concludes with an overall summary of the thesis findings in relation to the paradigm for validation of walking research (Bassett et al., 2008) (see figure 1.1) which provided a framework for this thesis.

7.2 Revisiting study one chapter 3

Study one addressed whether walking on a treadmill accurately replicates walking overground in adolescents. This is of particular importance when establishing any step based recommendation, as the intended application of such recommendations is overground in a real world setting. However the treadmill is often utilised in this area of research as a matter of convenience. The findings of this study support prior research highlighting differences between the two modes in an adult population (Dal et al., 2010; Berryman et al., 2011). The findings also indicate that treadmill walking does not replicate walking overground in adolescent girls. Consequently step count recommendations translated from treadmill walking may therefore underestimate the step rate required to promote health enhancing overground walking. Any future walking research with the aim of exploring step based recommendations would therefore benefit from focusing on overground walking, as this would generalise more accurately to real-life walking behaviour.

Further the findings from study one, which was conducted under controlled conditions, little is currently known about walking on other surface e.g. grass, gravel paths and pavement with curbs, under free living conditions. Subsequent research in this area may therefore wish to explore the energy cost and step rate equivalence with regard to other overground walking conditions. Further research is required into natural and moderate intensity walking speed and step rates over such surfaces and may be particularly important with regard to implementing step based recommendations and walking interventions within the youth population.

7.3Revisiting study two chapter 4

Guided by the findings of study one, study two focused on identifying the quality of walking (steps per min) required to achieve moderate intensity physical activity overground. Overall the findings of study two successfully advanced the research knowledge in this area as the methodological limitations of prior youth studies were addressed, by directly assessing relative exercise intensity (METS derived from oxygen uptake) and steps taken (real time direct observation) to determine the minimum step rate required to achieve moderate intensity activity, generating a step based translation of minimal amount of MVPA (minimum number of steps required to achieve 60minutes of MVPA) in adolescent girls. In line with previous research (Graser et al., 2009) this study highlighted the ‘one size doesn’t fit all’ with regard to moderate intensity stepping (walking). The findings also suggest that promotion of a step rate range may be beneficial for use with adolescent girls and where feasible individual step rate recommendations should be considered according to weight status.

In light of these finding further research is required into ways of implementing individualised step rate recommendations that correspond to various intensities into a public health setting. With the recent advancement in technologies of body worn instruments, such as pedometers and affordable accelerometers, some of which are now able to provide feedback on time spent in MVPA, this may be possible.

7.4Revisiting study three chapter 5

The focus of study three was to identify the most appropriate step measurement instrument to assess free-living walking. Of the five commercially available instruments (activPAL™, Omron HJ-720-ITC, Omron HJ-304-E, New Lifestyles NL-1000, Yamax CW-701) assessed during continuous (study 3a) and incidental (study 3b) walking, the instrument deemed to be the most appropriate for use within the adolescent population was then utilised in study 4, chapter 6 where the focus of the thesis further built on the translation of current PA guidelines into daily step defined physical activity and desired health outcomes. The findings of this study highlighted the differences with regard to step accuracy and detection of ‘moderate intensity stepping’ (activity time) among the competing technologies during both continuous and incidental overground walking. Also highlighted is that prior assessment with the population of choice and consideration of additional feature are essential. With regard to these findings the New Lifestyles NL-1000 was deemed to be the most appropriate instrument to assess free living walking activity in adolescent girls.

Further the findings of this study have successfully added to this area of research by providing information on criterion validity of the five step measurement instruments within an adolescent population. Additionally the instrument detected step counts were compared to real time direct observation handtally step counts during continuous and incidental walking and activity time was compared to real activity time measured by $\dot{V}O_2$ during the continuous overground walking. Furthermore assessment of the instruments during incidental overground walking has provided insight into accuracy of these instruments during incidental stepping, incidental activity time and its impact on PA targets in a group of adolescent girls. However more research is required into the benefits of being incidentally active. Further research in this area (incidental walking) may provide insight into its impact on sedentary behavior patterns, whether individuals naturally walk at a pace that benefits their health, how to provide more opportunities to be incidentally active within daily life and how to promote it.

7.5 Revisiting study four chapter 6

Study four explored the quantity of walking (steps·day^{-1}) required for health in adolescent girls. This study has successfully added to the limited body of knowledge in this area of research by considering time spent in activity (mins·day^{-1}) in addition to steps·day^{-1} to explore how much walking is required for health. It is also the first to report step based data relating to WC and blood pressure as single health indicators and to use health profiles in order to categorise health status, and thus avoid the limitations of any one indicator alone. Despite this specific thresholds for the quantity of walking required for health could not be defined for this population as the findings indicated that in terms of walking activity, 'healthy' adolescent girls do not walk significantly more in term of steps·day^{-1} or time spent in activity than girls classified as 'unhealthy'. This finding however supports that of previous research with adolescent girls. In light of these findings further research is required to explore the relationship between walking and health in this population before we can promote an appropriate threshold of walking that is conducive to good health in adolescent girls. However it appears that the best guideline to adopt might be 10,000 step·day^{-1}

7.2 Summary and main conclusions of Thesis findings

The overall findings of this thesis suggest that walking activity should be assessed overground using an appropriate measurement instrument which has been previously assessed within the population of choice. With regard to the quality of walking a step rate of 120 steps·min^{-1} and 7200 steps in 60 mins may be advocated to achieve MPA in adolescent girls, and thus may be used as a guide to communicate intensity of walking. However specific thresholds for the quantity of walking required for health could not be defined for this population, thus step based guidelines to inform walking interventions in adolescent girls cannot be reported at this time. Further research is therefore required to explore the relationship between walking and health in this population before we can promote an appropriate threshold of walking that is conducive to good health in adolescent girls.

With regard to the three stage paradigm for the validation of walking research from Bassett et al., (2008) (see figure 1.1), which provided a framework for this thesis. The overall findings have addressed the first two stages (definitional and confirmatory respectively). The definitional stage refers to defining the characteristics of healthy walking in adolescent girls and confirmatory stage refers to how this definition is accurately assessed and used to identify step count targets. Also outlined in this model is an interactive process in which each stage of the research builds directly on relevant research from the earlier stages (definitional), however later stages of the research process can inform the need to return to the earlier stages.

The overall findings of this thesis have added to the limited body of knowledge in this research area by addressing a number of limitations of prior youth studies and building on the limited knowledge with regard to walking in adolescent girls. Specifically the characteristics of healthy walking were defined with regard to intensity of walking required for health in adolescent girls, as was the most appropriate methods for the assessment of walking in light of physical activity guidelines (confirmatory stage). However step based guidelines with regard to the quantity of walking required for health cannot be reported at this time, highlighting the need for further research to return to the earlier (definitional) stages of the research process.

Regarding this, specific research questions that should be explored are:

Why step rate does not discriminate health status among adolescent girls?

What impact walking on different surfaces has on step rate and energy expenditure of adolescent girls?

Does the purpose of walking (e.g. commuting/active travel, health/ leisure walk) influences step rate and energy expenditure in adolescent girls?

What are the differences if any in self-selected walking speed (step rate) when walking alone or with a group and what impact does this have on energy expenditure?

What is the practical implementation of individualised step rates by manipulation of music? Can adolescents match their step rate to music and or change tempo?

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Appendix 1

Standard instructions for incidental walking circuit

1. Stand with both feet on the start line and walk at a pace you would normally walk
2. Walk forward to the door and then turn right into the corridor
3. At the end of the corridor turn right and walk down the stairs
4. At the bottom of the stairs head toward the main reception area, turning left to join the adjacent corridor
5. At the end of the corridor turn right
6. Walk towards the bench on the left hand side of the corridor, when you reach it, have a seat.
7. Once you are seated, sit and relax and I will signal for you to move by giving you a five second count down, when I say one, stand up and head back down the corridor in the direction that you have just come from.
8. OK 5, 4, 3, 2, 1 lets go
9. At the end of the corridor turn left and this time head straight along to the steps at the end.
10. Continue up the stairs and at the top I want you to stand as still as you can until I say.
11. Again I will give you a five second count down and on one if you continue to follow the corridor round to the next set of stairs
12. Once you reach the stairs, go up them and follow the corridor round to gym hall 2
13. When you reach the door of gym hall 2, stop and stand as still as you can.
14. Once again I will signal when I want you to move by giving you a five second count down
15. OK 5, 4, 3, 2, 1 lets go
16. Follow the corridors round and down both sets of stairs retracing our foot steps back towards the bench we sat on earlier for another seat.
17. Have a seat and I will signal when I want you to move
18. This time we are going to head back to the gym hall we started in, so when you reach the end of the corridor I want you to go right towards the stairs and PE corridor
19. OK 5, 4, 3, 2, 1 lets go
20. When you get into the gym hall I want you to stop at the line you stated at and stay as still as you can while I not down the steps for the pedometers and time for the activPAL™

Appendix 2

Information sheet and consent form (Studies 1-3)

Walking for Health in Adolescent Girls

Parent(s)/guardian Information Sheet

Dear Parent/Guardian:

The teenactive research group based at Heriot Watt University are carrying out a research project to find out how much walking young girls need to benefit their health. Your daughter has been invited to take part in this research project because she is in the age range we are interesting in studying. Before agreeing for your daughter to take part in this project it is important for you to understand why the research is being done and what it will involve. Please read the information sheet thoroughly and carefully before deciding to give your permission for your daughters' participation in this project. Participation is completely voluntary and only those children who have parental permission and who want to participate will take part.

Why is the research important?

Walking is a popular and common form of exercise that can improve your health and well being. Unlike other forms of exercise, walking is part of everyday life for most people, it can take place almost anywhere, and there is no special clothing or skill involved, just one foot in front of the other. The government recommends that young people should take part in 60minutes of moderate intensity activity a day. Moderate intensity activity is often described as activity that will increase your heart rate so that you can feel your pulse; make you breathe a bit harder and make you feel warm. Walking has been identified as a good activity to help increase physical activity towards recommended levels for health. However there is limited information available on the amount of walking (number of steps/day) and speed of walking (steps/min) that young girls need to take to benefit their health. It is also not known how to best measure walking. Therefore we are carrying out a study to help advise the government about the amount of walking needed to benefit the health of adolescent girls.

What will your daughter be asked to do?

1. Return the attached Consent Form with your permission to be involved in the study.
2. Your daughter also needs to sign the form to let us know that she is happy to be involved
3. Your daughter will be asked to meet with the researcher on 3 separate days for up to 1 hour each time
4. Each meeting will take place during the school day between October and December.
5. As meetings will take place during school hours, your daughter may be removed from her timetabled class for the allocated meeting time with the agreement of the school.
6. During each meeting your daughter will be ask to undertake different activities. Activities include: sitting quietly while watching a DVD, walking in a straight line at different speed and incidental walking. Incidental walking will involve a circuit of walking, standing and sitting. This will reflect activity during the school day.
7. Body measurements will be taken and include measures of her height, seated height and waist circumference.
8. Some sessions will involve wearing and breathing into a mask, this allows us to measure how much energy is expended.
9. Your daughter will also be asked to wear a number of step measurement devices (Pedometers and an ActivPAL) during the walking activities.
    - Pedometers are small devices that clip on to the waist band and measure steps taken.
    - ActivPAL is a discrete device (about the size of a match box) that attaches to the thigh underneath clothing. ActivPAL provides information about your body position (e.g. are you sitting, standing or walking) and the pace at which you are walking.

How will the information that is collated be used?
All information obtained will be kept entirely confidential. Only the researchers named below will have access to the information obtained. In any subsequent use of the information collected and publication any details that could identify your daughter will be removed. All your daughters' results and information will be made available to you on request.
If you have any questions or enquiries at any time before, during and after the study please feel free to contact us: Mhairi MacDonald, PhD student carrying out the project (E-mail mm450@hw.ac.uk; 0131-451-4269); Project supervisor; Dr Samantha Fawkner (Email: S.Fawkner@hw.ac.uk; 0131-451-8365).

Participants are free to withdraw from the study at any time without being disadvantaged in any way. If your daughter decides to withdraw, please let Mhairi or Sam know as soon as possible.

Walking for Health- One foot in front of the other, it's simple!

Pupil Information Sheet

We would like to invite you to take part in a research project to help us find out how much walking young girls need to benefit their health. Before you decide if you want to join in it's important to understand why the research is being done and what it will involve for you. Please read the information sheet thoroughly and carefully before deciding whether or not to volunteer for this project.

Why is the research important?

Walking is a popular and common form of exercise that can improve your health and well being. Unlike other forms of exercise, walking is part of every day life for most people, it can take place almost any where, and there is no special clothing or skill involved, just one foot in front of the other.

The government recommends that young people should take part in 60minutes of moderate intensity activity a day. Moderate intensity activity is often described as activity that will increase your heart rate so that you can feel your pulse; make you breathe a bit harder and make you feel warm. Walking has been identified as a good activity to help increase physical activity towards these recommended levels for health. However there is limited information available on the amount of walking (number of steps/day) and speed of walking (steps/min) that young girls need to take to benefit their health. It is also not known how to best measure walking. Therefore we are carrying out a study to help advise the government as to what to promote for your health.

If I choose to participate, what will I be asked to do?

1. Speak to your parents about the project ask them to sign the form to say they are happy for you to take part; you also need to sign the form to say that you are happy to take part.

2. Return the a completed consent form within a week of receiving it, if possible
3. You will be asked to meet with me (Mhairi) on 3 separate days for up to 1 hour each time.

4. Each meeting with me will take place during the school day between October and December.

5. You will have some body measurement taken these include height, leg length and waist size.

6. During each meeting you will be ask to undertake different activities. Activities include: sitting quietly while watching a DVD, walking on a treadmill at different speeds and other walking activities.

7. There is no need for you to change or bring PE kit to any of the sessions.

8. Some sessions will involve you wearing and breathing into a mask, this allows us to measure how much energy you are using up.

9. You will also be asked to wear a number of step measurement devices (Pedometers and an ActivPAL) during the walking activities.
    - Pedometers are small devices that clip on to the waist band and measure steps taken.
    - ActivPAL is a discrete device (about the size of a mobile phone battery or match box) that attaches to the thigh underneath clothing. ActivPAL provides information about your body position (e.g. are you sitting, standing or walking) and the pace at which you are walking.

How will the information that is collated be used?

All information obtained will be kept entirely confidential. Only the researchers named below will have access to the information obtained. If we use any of the information collected in reports or publication any details that could identify you will be removed. All your results and information will be made available to you on request.

If you have any questions or enquiries at anytime before, during and after the study please feel free to contact us: Mhairi MacDonald, PhD student carrying out the project (E-mail mm450@hw.ac.uk; 0131-451-4269); Project supervisor; Dr Samantha Fawkner (Email: S.Fawkner@hw.ac.uk; 0131-451-8365).

If you do not want to join in or you want to stop being involved at any time during the study, don't worry the school and university will not mind, just let Mhairi know as soon as possible.

Sport and Exercise Science
School of Life Sciences

Walking for Health

Please complete sections 1 and 2.

<u>Section 1 (parent/guardian)</u>

I **agree/do not agree (delete as appropriate)** to…...............................(child's name) participating in a research project in collaboration with Heriot-Watt University, the nature of which has been explained to me by letter. I have discussed the children's information sheet with my child and explained to her what she will need to do if she chooses to participate in the project.

I understand my child will have various body measurements taken and will be asked to undertake walking activities whilst wearing a number of monitoring devices including the use of pedometers and breathing into a face mask.

I understand that this research project will take place during school hours and my child may be removed from timetabled classes to take part. My child is free to withdraw from the study at any stage without giving a reason and without affecting her relationship with the school or the University.

Signed...parent/guardian

Date..Name of School……………………………………

<u>Section 2 (child)</u>

I,..(your name) agree to take part in the project described above and I understand what it is about and what I will be asked to do. I understand I can stop participating in the project at any time and the school and the University will not mind.

Signed……………………………………………(child)

Date………………………………

Sport and Exercise Science
School of Life Sciences
Heriot-Watt University

Tel: 0131 451 4269
email: mm450@hw.ac.uk

Appendix 3

Information sheets and consent form (Study 4)

Walking for Health in Adolescents

Parent/guardian(s) Information Sheet

Dear Parent/Guardian:

The teenactive research group based at Heriot Watt University are carrying out a research project to find out how much walking young people need to benefit their health. Your child has been invited to take part in this research project because she is in the age range we are interesting in studying. Before agreeing for your child to take part in this project it is important for you to understand why the research is being done and what it will involve. Please read the information sheet thoroughly and carefully before deciding to give your permission for your Childs' participation in this project. Participation is completely voluntary and only those children who have parental permission and who want to participate will take part.

Why is the research important?

Walking is a popular and common form of exercise that can improve your health and well being. Unlike other forms of exercise, walking is part of everyday life for most people, it can take place almost anywhere, and there is no special clothing or skill involved, just one foot in front of the other. The government recommends that young people should take part in 60 minutes of physical activity a day. Walking has been identified as a good activity to help increase physical activity towards recommended levels for health. However there is limited information available on the amount of walking (number of steps/day) that young girls need to take to benefit their health. Therefore we are carrying out a study to help advise the government about the amount of walking needed to benefit the health of adolescents.

What will your child be asked to do?

1. Return the attached Consent Form with your permission to be involved in the study.

2. Your child also needs to sign the form to let us know that she is happy to be involved

3. Your child will be asked to meet with the researcher on 2 occasions for up to hour each time

4. Each meeting will take place during the school day between September and October.

5. As meetings will take place during school hours, your child may be removed from her timetabled class for the allocated meeting time with the agreement of the school.

6. Your child will have body measurements taken and include measures of her height, weight, waist circumference and percentage body fat. This information will allow us to get a general picture of the body measures of the adolescent population.

7. Your child will be given a pedometer (a step counter) and asked to wear it on their waistband for seven consecutive days. She should wear it all day other than when showering, swimming or sleeping. After seven days, your child will return the pedometer to the researcher. This will give us information on how active your child has been over the seven days.

8. Your child may also be asked to wear an ActivPAL, this is a discrete device (about the size of a match box) that attaches to the thigh underneath clothing. ActivPAL provides information about your body position (e.g. are you sitting, standing or walking) and the pace at which you are walking. The ActivPAL like the pedometer should be worn all day.

9. Your child has the option of receiving a daily text reminder, reminding her to put the pedometer on each morning and return the pedometer on the correct day. The text reminder will be a standard message sent to the girls involved in the study that week. In order to receive this reminder your child will need to let the researcher know her mobile number (if she has one). All numbers will be saved to a mobile phone used only for the purpose of the study. All numbers will be subject coded to ensure confidentiality and deleted after the data collection period.

10. If your child is absent from school on the day she is due to return the pedometer, please ensure she continues to wear it until it is possible to return the pedometer, this means that no data will be lost.

11. All researchers involved in this study are enhanced disclosure checked. This means that they have been checked by the police and other government bodies and are deemed safe to work with children and young people.

How will the information that is collated be used?

All information obtained will be kept entirely confidential. Only the researchers named below will have access to the information obtained. In any subsequent use of the information collected and publication any details that could identify your child will be removed. All your child's results and information will be made available to you on request.

If you have any questions or enquiries at anytime before, during and after the study please feel free to contact us: Mhairi MacDonald, PhD student carrying out the project (E-mail mm450@hw.ac.uk; 0131-451-4269; 07870610738); Project supervisor; Dr Samantha Fawkner (Email: S.Fawkner@hw.ac.uk).

Participants are free to withdraw from the study at any time without being disadvantaged in any way. If your child decides to withdraw, please let Mhairi MacDonald know as soon as possible by email, phone or text.

Walking for Health- One foot in front of the other, it's simple!

Pupil information Sheet

We would like to invite you to take part in a research project to help us find out how much walking young people need to benefit their health. Before you decide if you want to join in it's important to understand why the research is being done and what it will involve for you. Please read the information sheet thoroughly and carefully before deciding whether or not to volunteer for this project.

Why is the research important?

Walking is a popular and common form of exercise that can improve your health and well being. Unlike other forms of exercise, walking is part of everyday life for most people, it can take place almost anywhere, and there is no special clothing or skill involved, just one foot in front of the other. The government recommends that young people should take part in 60 minutes of physical activity a day. Walking has been identified as a good activity to help increase physical activity towards recommended levels for health. However there is limited information available on the amount of walking (number of steps/day) that young people need to take to benefit their health. Therefore we are carrying out a study to help advise the government about the amount of walking needed to benefit the health of adolescents.

If I choose to participate, what will I be asked to do?

1. Speak to your parent/guardian(s) about the project ask them to sign the form to say they agree for you to take part; you also need to sign the form to say that you agree to take part.

2. Return the completed consent form.

3. You will be asked to meet with me (Mhairi) on 2 occasions.

4. During the 1st meeting you will have some body measurement taken these include height, weight, waist size and % body fat.

5. You will be given a pedometer (a step counter) and asked to wear it on your waist band for seven days. You should wear the pedometer all day (even if you are not at school) except when showering, swimming or sleeping. After seven days you will return the pedometer to me (Mhairi).

6. You may also be asked to wear an ActivPAL device, which is a discrete device (about the size of a mobile phone battery or match box) that attaches to the thigh underneath clothing. ActivPAL provides information about your body position (e.g. are you sitting, standing or walking) and the pace at which you are walking.

7. To remind you to put your pedometer on every morning and return it to me on the correct day, you will receive a standard text message from me (Mhairi).

8. In order to receive your (optional) daily reminder message, I (Mhairi) will need to have your mobile number. Your number will be saved in the teenactive phone under a unique subject code to ensure confidentiality. All numbers will be deleted after the data collection period of two weeks.

How will the information that is collated be used?

All information obtained will be kept entirely confidential. Only the researchers named below will have access to the information obtained. If we use any of the information collected in reports or publication any details that could identify you will be removed. All your results and information will be made available to you on request.

If you have any questions or enquiries at anytime before, during and after the study please feel free to contact me: Mhairi MacDonald, PhD student carrying out the project (E-mail mm450@hw.ac.uk; 0131-451-4269; 07870610738).

If you do not want to join in or you want to stop being involved at any time during the study, don't worry the school and university will not mind, just let Mhairi know as soon as possible.

Sport and Exercise Science
School of Life Sciences

Walking for Health

Please complete sections 1 and 2.

<u>Section 1 (parent/guardian)</u>

I **agree/do not agree (delete as appropriate)**......................................(child's name) participating in a research project in collaboration with Heriot-Watt University, the nature of which has been explained to me by letter. I understand that if I have any questions or enquiries at anytime before, during and after the study I can contact the researchers named in the letter. I have discussed the children's information sheet with my child and explained to her what she will need to do if she chooses to participate in the project.

I understand my child will have various body measurements taken and will be asked to wear a step measurement device for seven consecutive days.

I understand that part of this research project will take place during school hours and my child may be removed from timetabled classes to take part. I understand that my child may receive a daily text reminder during the time she has the pedometer and that her number will be coded to ensure confidentiality and deleted after the data collection period.

My child is free to withdraw from the study at any stage without giving a reason and without affecting her relationship with the school or the University.

Signed..parent/guardian

Date..Name of School……………………………………

<u>Section 2 (child) overleaf</u>

Section 2 (child)

I.. (name) **agree/do not agree (delete as appropriate)** to participate in a research project in collaboration with Heriot-Watt University, the nature of which has been explained to me by letter. I understand that if I have any questions or enquiries at anytime before, during and after the study I can contact the researchers named in the letter. The children's information sheet has been explained to me by my parent/guardian and I understand what is involved if I choose to participate in the project.

I understand that I will have various body measurements taken and will be asked to wear a step measurement device for seven consecutive days.

I understand that I may receive a daily text reminder during the time I have the pedometer and that my number will be coded to ensure confidentiality and deleted after the data collection period.

I understand that I am free to withdraw from the study at any stage without giving a reason and without affecting my relationship with the school or the University.

Signed.. (child)

Date...I