The objective measurement of moderate-to-vigorous physical activity during commuting, and its association with metabolic markers: an observational study

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Table of contents

List of figures

List of tables

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Declaration

I declare that I have written this entire thesis on my own and that the work has not been submitted for any other degree or professional qualification. I confirm that the work submitted is my own, except where work that has formed part of jointly authored publications has been included. My contribution and those of the other authors to this work have been explicitly indicated below. I confirm that appropriate credit has been given within this thesis where reference has been made to the work of others

Some parts of this thesis have been published and approval has been sought to be reproduced in this thesis. Study One (Gbadamosi et al., 2020) has been published in the Journal for the Measurement of Physical Behaviour in 2020. The paper entitled, "The contribution of commuting to total daily moderate-to-vigorous physical activity" was jointly written with three other authors. I did the data processing and analysis and wrote the first draft for all authors to edit.

Study Two has been published in the Special issue of the Sensors Journal and this paper was written alongside three other authors that supported the analysis, editing of the manuscript and writing up of the final draft for submission. I supported the analysis in Microsoft Excel and statistical analysis in SPSS, I wrote the first draft and distributed to the co-authors for feedback, where necessary. Study Three is being written up for publication alongside three other authors.

Abbreviations

AACE	American Association of Clinical Endocrinology
AHA/NHLBI	American Heart Association/National Heart, Lung, and Blood Institute
aOR	Adjusted Odds Ratio
BMI	Body mass index
CI	Confidence Interval
CVD	Cardiovascular diseases
DHSC	Department of Health and Social Care
DfT	Department for Transport
DH	Department of Health
EGIR	European Group for the study of Insulin Resistance
HR	Hazard ratio
HSCIC	Health and Social Care Information Centre
IDF	International Diabetes Federation
LIPA	Light-intensity physical activity
METs	Metabolic equivalents
MVPA	Moderate-to-vigorous physical activity
NCEP ATP III	National Cholesterol Education Program Adult Treatment Panel III
NHANES	National Health and Nutrition Examination Survey
NHS	National Health Service
NICE	National Institute for Health and Care Excellence
NIHR	National Institute of Health Research
NTS	National Travel Survey
ONS	Office for National Statistics
OR	Odds Ratio
PHE	Public Health England
RR	Relative Risk
SD	Standard Deviation
UK	United Kingdom
UKHLS	UK Household Longitudinal Study
WHO	World Health Organisation

Abstract

Introduction: There is evidence showing that physical activity during commuting improves various health outcomes; however, the results are mixed due to differences in methodologies and measuring tools used in studies. Many commuting studies have focused on the use of self-reported measures only in quantifying physical activity.

Aim: The overall aim of this thesis was to explore the contribution of objectively measured moderate-to-vigorous physical activity (MVPA) during commuting towards total MVPA and its association to metabolic markers.

Methods: Three cross-sectional, observational studies were undertaken to address the main aim of the thesis. **Study One** (n=23) recruited a sample of staff members at the University of Salford. The participants wore an accelerometer-based device (activPAL™) for seven days continuously and completed an activity diary, with information regarding their commute duration and mode to determine the contribution of MVPA time during commuting towards total MVPA. **Study Two** (n=24) used the same study population as Study One to explore a novel methodological approach of combining short interruptions of time between walking events based on an average walking cadence. The definition of MVPA used was a minimum walking cadence of either 76, 100, or 109 steps/minute. These novel MVPA measures were tested in Study Three**. Study Three** (n=40) recruited a sample of staff and postgraduate research students at the University of Salford to wear the activPAL™ and filled out an activity diary to collect data on commute duration, mode, and demographic and diet questions. In addition, specific metabolic markers were measured to investigate the associations between commute MVPA outcomes and metabolic markers.

Results: Commuting contributed 31% of total time spent in MVPA, with walking and mixed-mode commuters accumulating 37.6 and 26.9 minutes of MVPA respectively which was significantly higher compared to car commuters (5.8 minutes). Seventeen out of the 23 participants achieved more than 30 minutes of MVPA per day, with five achieving this in their commute alone. When short interruptions between walking events were combined (using an average cadence of 100 steps/minute), the average total time in MVPA before grouping was statistically significant than after grouping (123.1 vs. 126.3 minutes) ($p<0.001$) but the difference was very small. Using these new MVPA outcomes, the median total steps increased from 6,661 to 7,984 steps for a cadence of 76 steps/minute: 4,187 to 4,851 steps at 100 steps/minute, and 2,795 to 3,752 steps at 109 steps/minute. Grouping increased compliance with physical activity guidelines both for the 2011 and 2019 guidelines. Sixteen out of 40 participants were compliant with the 2011 guidelines, with an additional 10 participants meeting the guidelines after grouping; and twenty-nine out of the 40 participants were compliant with the 2019 physical activity guidelines, with two additional participants being compliant after grouping. Commute time in MVPA, before and after grouping, was significantly negatively associated with BMI; however, the associations were attenuated after adjusting for confounders except for grouped commute time in MVPA at 109 steps/minute where significance remained. Non-commute and total time in MVPA did not give any significant results before and after adjusting for confounding factors.

Conclusion: Commuting can be a major contributor to total daily MVPA, with the mode of commute playing a significant role: active commuting may provide a protective effect against metabolic syndrome. A robust and practical methodological approach to combining short interruptions between walking events into continuous walking events by considering the intensity and duration of the activities was developed. Therefore, this thesis provides a novel robust methodological contribution on which future epidemiological study designs can be based upon.

Covid Impact Statement

The impact of the Covid-19 pandemic was very harmful and disruptive to my PhD research and life in general. The original recruitment target number for Study Three was 80; however, the study ended up with 40 participants. The recruitment started in June 2019 and throughout the summer holidays: I was hoping for an improvement in recruitment numbers when the new session began in September 2019. When the new session began in September 2019, there were a few more people who signed up for the study (n=11). In December 2019[1], the WHO[2] was notified of a series of pneumonia cases of unknown origin in Wuhan city, Hubei Province, China, and how fast it was spreading. By the 9th of January 2020, the novel virus had been identified as SARS-CoV-2 and the associated disease as COVID-19. The WHO declared the virus as a Public Health Emergency of international concern in January 2020, coupled with the panic created by media outlets and social media. The news was terrifying because of the novelty of the virus and the alarming rate of spread, with both adults and children getting infected. My supervisors and I decided that since the data collection for Study Three involved collecting finger-prick blood samples I should put data collection on hold until there was more information about the Covid-19 virus. As a result of this, recruitment had to be stopped due to the uncertainty surrounding the Covid-19 pandemic. The total number of participants recruited could have been greater than the final sample population and in turn, had a greater impact on measuring the associations between commute time in MVPA and metabolic markers.

Due to the number of increasing cases of Covid-19 in the UK, the whole country had to go on lockdown. By the time the lockdown was announced in March 2020 in the UK, the university had moved to working from home and having meetings on Microsoft Teams. I was able to use the collection service by the University to pick up my work desktop and important documents. While I was adjusting to caring for my three-year-old daughter, working from home, and my husband working from home at the same time while trying to finish up a PhD, I and my husband tested positive for Covid-19 in May 2020. I was distraught because I was very scared

[1] https://www.gov.uk/government/publications/wuhan-novel-coronavirus-background-information/wuhan-novel-coronavirus-epidemiology-virology-and-clinical-features#:~:text=On%2031%20December%202019%2C,as%20COVID%2D19

[2] https://apps.who.int/iris/bitstream/handle/10665/330776/nCoVs.itrep31Jan2020-eng.pdf

of my entire family. My daughter had a fever for days but thankfully, no shortness of breath. I recovered in a matter of days; however, the virus affected my husband differently as he was in bed for two weeks. We couldn't go into the hospital because he tested positive for Covid-19, yet I couldn't understand any of the symptoms he had as they were not listed as Covid-19 symptoms. During this period, my research was greatly affected as I had to take time off. By the time I came back, it was scary to send my daughter to nursery because of how fast the virus was spreading, even among children and the likelihood of developing into a bigger health problem. Shortly after, in October 2020, I received news of civil unrest[3] in my home country (Nigeria) where people were either being kidnapped or killed by an arm of the Nigerian Police[4]. This was another very difficult time because I could not visit my family because of COVID and the unrest; therefore, impacting greatly on my research progress. In November, I also started having knee pains (as a result of prolonged sitting) and I expressed these concerns to my supervisors. I attend a virtual appointment with the Salford injury clinic, and they advised that I should move around more. However, it was extremely difficult leaving my home because of my caring responsibilities. These pains continued and have affected all aspects of my life.

By December 2020, I was seriously tired mentally as I felt completely drained from all the events of the year; however, I had worked so hard to get to this point, from moving from my home country to study for my Master's in Public Health in the UK, to having a baby at the beginning of my PhD second year to a pandemic that completely shut down the entire world. Although I kept in touch with my supervisors and updated them regularly regarding the progress of my PhD thesis, the progress with my thesis was slow and the impact of the situation seriously affected my productivity. I put in for an extension to ensure that I produce a thesis of an appropriate standard. I knew in my heart that I wanted to make it to the finish line, standing tall as a survivor.

[3] https://en.wikipedia.org/wiki/End_SARS
[4] https://www.bbc.co.uk/news/world-africa-54666368: https://www.aljazeera.com/news/2017/12/15/nigerians-want-polices-sars-force-scrapped/

Chapter 1: Introduction

1.0 Chapter Overview

This chapter provides an overview of the definition and domain of physical activity, recent physical activity guidelines, the burden of physical inactivity, and the benefits of physical activity. This chapter also discusses the role of commuting in contributing to physical activity and inactivity, its associations with health-related outcomes, and a brief overview of the assessment methods of commuting physical activity are discussed. The final section presents the framework for active commuting and concludes with the structure of this thesis.

1.1 Definition of Physical Activity and Physical activity guidelines

1.1.1 Definition and Domains of Physical activity

Physical activity is defined as "any bodily movement produced by skeletal muscles that require energy expenditure" (Caspersen, Powell, & Christenson, 1985, p.126; World Health Organisation [WHO], 2018, para. 1). Energy expenditure is an intricate part of physical activity because it is the amount of energy required to carry out all physical functions (Caspersen et al., 1985). Total daily energy expenditure comprises resting energy expenditure[5], thermic effect of food[6] (food digestion), and physical activity-related energy expenditure (PAEE)[7]; the latter being the most variable part of the total energy expenditure (McArdle, Katch, & Katch, 2006). Energy expenditure can be quantified by metabolic equivalents (METs), and it is used to express physical activity intensity (Ainsworth et al., 2011). One MET is equivalent to resting energy expenditure, which is equivalent to 3.5 ml of oxygen consumption per kilogram of body weight per minute while at rest (Strath et al., 2013; WHO, 2020). Within the overall definition of physical activity, sleep is defined as an energy expenditure at the level of 0.9 METs (where 1 MET is equivalent to resting metabolic rate), sedentary activities that include sitting and lying are at an energy expenditure of not more than 1.5 METs, light-intensity physical activity (LIPA) has been defined as those activities that increase energy expenditure at the level of 1.6–2.9 METs, moderate-intensity physical activity is defined as activities with an energy expenditure of between 3 to 6 METs (Ainsworth et al., 2011) and vigorous-intensity

[5] Resting energy expenditure is the energy required to maintain vital bodily functions, such as breathing, blood circulation, temperature control, needed for the body to function at rest

[6] Thermic effect of food is the energy required for breaking down food and to aid digestion

[7] Physical activity related energy expenditure is the energy required to do all movements above resting conditions

activity is with an energy expenditure of at least 6 METs (Table 1.1). Sedentary behaviour has been used interchangeably with physical inactivity, therefore, the Sedentary Behaviour Research Network (SBRN) (2012) recommends a much more specific definition "as any waking behaviour characterized by an energy expenditure of ≤1.5 METs while in a sitting or reclining posture (p. 540)". Therefore, this definition differentiates sedentary behaviour from physical inactivity which is simply defined as not meeting up with physical activity recommendations (Tremblay et al 2017).

Table 1.1: Classification of Physical Activity Intensity

Intensity	Energy Expenditure (METs)	Examples
Sleep	0.9	-
Sedentary	1.0-1.5 (or ≤1.5)	Sitting, lying down, watching television, sitting at a computer
Light activity	1.6–2.9	Cooking and washing dishes
Moderate activity	3.0-5.9	Swimming, walking, lifting weights
Vigorous activity	≥6	Running at 4 miles per hour (mph), Cycling

Physical activity can be characterised into four dimensions:

- type (structured or incidental),
- frequency (number of activity bouts which can be continuous or intermittent),
- duration (minutes or hours performing an activity), &
- intensity (rate of energy expenditure) (Strath et al., 2013).

Three of these four dimensions can be combined as a single metric to form an important variable, the total volume of physical activity (Figure 1.1) (Bassett et al., 2015). In addition to dimensions of physical activity, there are domains where physical activity can occur: these domains are occupational, leisure, transportation, and household chores; and each domain contributes to the total volume of physical activity (Figure 1.1). These domains of physical activity are central to understanding the assessment of physical activity (Bassett et al., 2014;

Strath et al., 2013). The transportation domain is the domain of interest and some of the reasons why people travel are shopping, personal business, leisure, or commuting (DfT, 2018). In this thesis, commuting was studied and investigated extensively because it is an important domain that involves regular, repeated, and non-discretionary activity.

Dimensions of PA	**Domains of PA**
Frequency } **Total**	Occupational
Intensity } **Volume of PA**	Transportation-Related
Duration }	Household Chores
Type	Leisure-time
Posture	**Context of PA**
Lying	Location
Sitting	Indoor vs. Outdoor
Standing	Purposeful vs. Incidental
Ambulating	Individual vs. Group
Health Benefits of PA	**Gait Characteristics**
Aerobic	Speed
Bone Building	Step Length
Muscle Strengthening	Step Frequency (Cadence)
Flexibility Enhancing	Step-to-step Variability
	Stance Time, Swing Time

MEDICINE & SCIENCE IN SPORTS & EXERCISE

Figure 1.1: The Multidimensional construct of physical activity, showing method of classifying physical activity, PA= physical activity (Adapted from Bassett et al., 2015)

1.1.2 Physical Activity guidelines

The guidelines for physical activity are adapted from scientific evidence available on the amount and frequency of physical activity needed to obtain optimal health benefits. These evidence-based guidelines inform healthcare professionals, policymakers, and individuals to make the best choices to reduce physical inactivity and, therefore, reduce the risk of ill health. In the United Kingdom (UK), the most used physical activity guideline was published in 2011. Recently, these guidelines were updated in September 2019, to take into account up to date evidence (DHSC, 2019). The 2011 guidelines were based on self-reported questionnaires and since then, there have been increasing use of objective measuring devices including accelerometers that can accurately capture and quantify physical activities. In addition, the removal of the bout length requirement in the 2019 guidelines was based on accumulating evidence on the importance of any walking as the evidence in the literature show that there were similar effects of bouts accumulated less than 10 minutes and greater than 10 minutes on health outcomes (Glazer et al., 2013; Saint-Maurice et al., 2018). Therefore, the update was based on the evidence in literature from a more accurate measurement standpoint. The update of the physical activity guidelines included recommendations for activity during pregnancy, post-partum, and disabled adults. The guidelines provide recommendations on the frequency, intensity, duration, and types of physical activity for children (early years, under 5s, and 5 to 18 years), adults (19 to 64 years), and older adults (65+ years).

The 2011 physical activity guidelines for adults recommend that adults should accumulate at least 150 minutes of moderate-intensity activity over a week or at least 30 minutes of moderate-intensity over five days a week, in bouts of 10 minutes or more (DHSC, 2011). The updated 2019 UK guidelines for adults stated that:

- "For good physical and mental health, adults should aim to be physically active every day. Any activity is better than none, and more is better still.
- Adults should do activities to develop or maintain strength in the major muscle groups. These could include heavy gardening, carrying heavy shopping, or resistance exercise. Muscle-strengthening activities should be done at least two days a week, but any strengthening activity is better than none.
- Each week, adults should accumulate at least 150 minutes (two and half hours) of moderate-intensity activity (such as brisk walking or cycling); or 75 minutes of vigorous-intensity activity (such as running); or even shorter durations of very vigorous-intensity activity (such as sprinting or stair climbing); or a combination of moderate, vigorous, and very vigorous-intensity activity.
- Adults should aim to minimise the amount of time spent being sedentary, and when physically possible should break up long periods of inactivity with at least light physical activity (DHSC, 2019, p. 30)."

Other countries have similar guidelines: the USA's guidelines include clear recommendations to undertake higher levels of physical activity compared to the UK (300 minutes or 5 hours of moderate-intensity physical activity per week) (US Department of Health and Human Services, 2018). The Canadian's movement guidelines have a different approach offering a

24-hour guideline on the integration of physical activity, sedentary behaviour, and sleep: the main messages from the guidelines are much clearer in that in addition to engaging in 150 minutes of MVPA per week and muscle-strengthening exercise on two days a week, adults are recommended to move more, which includes light physical activity, limit sedentary time to up to eight hours per day, and sleep well between seven to nine hours (Canadian Society for Exercise Physiology, 2012; Tremblay et al., 2016). The WHO has also recently updated physical activity and contains similar health promotion messages to the UK, USA, and Australia's physical activity guidelines. The guidelines include a strong recommendation on the accumulation of aerobic and muscle-strengthening physical activity every week, that is, 150-300 minutes of moderate-intensity or 75-150 minutes of vigorous-intensity physical activity or an equivalent of both, regardless of bout length (Bull et al., 2020; WHO, 2020). In summary, physical activity guidelines are health promotional messages that provide people of all ages the information they need to make well-informed decisions on the type and amount of physical activity they should undertake to improve their health (Bull et al., 2020; US Department of Health and Human Services, 2018; WHO, 2020).

The lengths of walking bouts were included in the 2011 UK physical activity guidelines, and compliance was based upon meeting the recommended duration (30 minutes), intensity (moderate intensity), and frequency of activity (at least for five days a week). Commuting is important because it is a repeated and non-discretionary activity and therefore, provides the frequency needed for achieving the recommended guidelines. Rafferty et al. (2016) reported that five out of 26 participants recruited in their cross-sectional study achieved their recommended physical activity guidelines in their commute alone; however, the Rafferty study did not measure lengths of walking bouts. All the components for defining compliance with physical activity guidelines are important measures in studying the effect of physical activity on different health outcomes.

1.2 Benefits of Physical Activity

Physical activity can be an important factor in reducing the risk of disease (Lee et al., 2012; WHO, 2010): the health benefits of physical activity have been well documented (Warburton, Nicol, & Bredin, 2006). Physical activity has been associated with a reduction in various health outcomes including cardiovascular diseases, diabetes, cancers, and increased risk of premature mortality (Warburton et al., 2006; WHO, 2010; Department of Health [DH], 2011; Garber et al., 2011; Lee et al., 2012); improved mental wellbeing (Biddle et al., 2000; Anokye et al., 2012; Cooper & Barton, 2015), and reduced anxiety (Anderson & Shivakumar, 2013). Therefore, to explore the potential benefits of physical activity on health, it is essential to evaluate these benefits across different types and domains of activities performed within daily-life routines such as commuting.

1.3 Physical inactivity and the burden of physical inactivity

Physical inactivity is the fourth most important risk factor for chronic, non-communicable diseases, after high blood pressure (13%), tobacco use (9%), and high blood glucose (6%) (Scholes & Mindell, 2013; WHO, 2009; WHO, 2010). Physical inactivity is responsible for 6% of global mortality, 6% of the global burden of disease from coronary heart diseases, 7% of type 2 diabetes and 10% of breast and colon cancers (WHO, 2009; Lee et al., 2012). Physical inactivity has been estimated to cause global mortality of 3.2 million preventable deaths per year (WHO, 2009, WHO, 2010). It has been reported that these deaths could be avoided if the global population were more active (Guthold et al., 2018).

Non-communicable diseases account for nearly half of the global burden of diseases, and cardiovascular diseases (CVD) are responsible for one-third of all deaths worldwide. It has been estimated that 17.9 million people worldwide died from CVD in 2016, with 85% of these deaths attributed to heart attacks and strokes (WHO, 2020). Some of the underlying risk factors are metabolic dysfunction, including dyslipidemia (elevated triglyceride levels and low levels of HDL-cholesterol), high blood pressure, high blood sugar, and abdominal obesity. The clustering together of these factors results in metabolic syndrome (Kassi et al., 2011). According to the National Health Service (NHS), metabolic syndrome is estimated to affect one in four adults in the UK, and it increases the risk of developing coronary heart disease, stroke, and other conditions that affect blood vessels (Kassi et al., 2011; NHS, 2016). There is evidence to suggest that total physical activity has beneficial effects on metabolic risk factors (Glazer et al. 2013); in addition, commuting physical activity is also beneficial to metabolic risk (Steell et al., 2017). Therefore, the individual metabolic markers that contribute to metabolic syndrome as a health outcome were the focus of this thesis.

In the Health Survey for England 2016, it was reported that 21% of men and 25% of women aged 19 years and over did not meet the recommended physical activity guidelines; these estimates were based on self-reported data (Scholes & Naeves, 2017), which may be subject to response and social-desirability bias. A previous Health Survey for England in 2008, which measured subjective and objective physical activity, found significant differences in the results from these two methodologies: only 6% of men and 4% of women met the physical activity recommendations based on objective measures using accelerometer-based body-worn activity monitors, compared to 39% of men and 29% of women based on self-reported physical activity (Craig, Mindell, & Hirani, 2009). Similarly, data from Canada (Canadian Health Measures Survey [CHMS]) and America's Health Survey (2003/2004 National Health and Nutrition Examination Survey [NHANES]) reported that 85% and 95% of the population respectively do not meet recommended guidelines when using objectively-measured physical activity (Colley et al., 2011; Larouche, Faulkner, & Tremblay, 2016; Troiano et al., 2008).

In the UK, in 2006/2007, the financial burden of treating health-related outcomes directly attributable to physical inactivity (direct costs) has been estimated to have cost the NHS £1.06 billion (Scarborough et al., 2011; Scholes & Mindell, 2013). Indirect costs of physical inactivity to society – such as production losses due to mortality and morbidity, workdays lost to sickness absence, private healthcare costs – has been estimated to be £7 billion annually (Allender et al., 2007; Scholes & Mindell, 2013; PHE, 2019). Therefore, increasing physical activity will not only improve the health of the population but also provide financial benefits. Consequently, there is a need to reduce physical inactivity and increase physical activity.

Some factors contributing to physical inactivity may include the increase in technological advancements, for example, labour-saving devices such as computers that have impacted occupations that previously involved high levels of LIPA and MVPA (Church et al., 2011; Guthold et al., 2018). Another contributory factor to lower levels of physical activity has been the increase in car use that has resulted in a decline in active modes of transport (WHO, 2009). In the UK, since the 1960s, there has been an increase in car ownership per household (PHE, 2016; WHO, 2018), and the proportion of households without a car has fallen from 69% in 1961 to 24% in 2017 (PHE, 2016; Department for Transport [DfT], 2017).

1.4 Commuting and modes of commuting[8]

Commuting falls under the transportation-related domain of physical activity: unlike other purposes of travel, commuting is an important aspect of a working individual because, in most circumstances, it is for non-discretionary purposes, it cannot be eliminated, and it is undertaken regularly. Commuting can be defined as travel to and from a place of employment (King & Jacobson, 2017; DfT, 2017). It can be active or non-active, and active commuting can include walking, cycling, and public transport because they involve physical activity (Shannon et al., 2006; Lorenzo et al., 2020; Millett et al., 2013). Although many studies have classified walking and cycling only as active modes of commuting (Mytton et al., 2018; Rissel et al., 2014), the use of public transport (train, bus, tram, or metro) almost invariably involves both elements of walking or cycling and can be classified as an active mode of commute (Flint et al., 2014; Laverty et al., 2013; Panter et al., 2018). Some other studies have defined active commuting as involving any walking or cycling done as part of a commuting journey (Lorenzo et al., 2020). This may be a better definition for active commuting since it incorporates the use of more than one mode of commute: for example, journeys that involve driving to the train station, taking the train, then a walk, or cycling to work. The UK physical activity guidelines for adults suggest that activity can be incorporated into daily life by replacing a car drive or bus ride with walking or cycling (DH, 2011). For example, a person who drives to and from work can drive to the train station, board a train, and walk the rest of the distance to work; by doing this, activity can be incorporated into the journey rather than being sedentary throughout the entire journey. Hence, replacing a whole or a part of a journey with walking or cycling will increase the level of physical activity carried out during commuting.

Although the literature has defined commuting as active and non-active modes, it is evident that it can be more complex since even car travel can have an active component. While travelling by public transport might not involve the same degree of physical activity as walking

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[8] This paragraph was written up before the pandemic that required a large number of people to work from home and all studies included in this thesis were pre-Covid.

and cycling only, recent studies have shown an association between commuting by public transport and obesity reduction (Flint et al., 2014). This links into the complexity of these definitions, as in some instances, those who use public transport may have a longer walk than those who primarily walk to work. Therefore, a better-suited definition for active commuting may be involving any walking or cycling done as part of a commuting journey (Lorenzo et al., 2020) because it incorporates the use of more than one mode of commute, for example, journeys that involve driving to the train station, taking the train, then a walk, or cycle to work. This definition will be adopted in this thesis because it allows the mixed-mode journeys to be quantified as they involve some walking or cycling as part of their commuting journey.

1.4.1 Current statistical trends in commuting

The NTS is the primary source of data on travel behaviours in the UK, and at least 16,000 individuals in 7,000 households participate in the survey every year (DfT, 2018). According to the NTS 2017, the most common mode of travel in England is by car, which accounts for 61% of all trips (NTS defines a trip as a one-way journey with a single main purpose), including commute trips; and 76% of households own at least one car (DfT, 2018). Walking accounted for 27% of all trips made and only 3% of average distances travelled; however, these trips were defined as short distances (<1 mile) (DfT, 2018). Meanwhile, public transport accounted for 5% of all trips, and cycling accounted for only 2% of all trips made in 2018 (DfT, 2018).

Shopping and personal business were the most common reasons for travelling (26% and 19% respectively); however, they accounted for a smaller share of total distances travelled (11% and 14% respectively). Commuting was also one of the most common reasons for travelling (19% of trips per person), and it accounted for 20%, which was the largest proportion of total distances travelled (1,309 average commuting miles per person per year) (DfT, 2018). There were variations in commuting trips by mode, with 62% being by car, 13% by walking, and 6% by public transport (DfT, 2018). Car mode accounted for the largest number of trips and longest distances travelled to work (55% of trips and 62% of distances travelled), followed by rail (7% of trips and 16% of distances travelled), and then by walking (11% of trips and 1.1% of distances travelled). The average time spent on a one-way commute was 31 minutes (DfT, 2017), and similarly, data from the American Community Survey data for 2012–2016 reported an average one-way commute of is 26 minutes in the United States (Christian, 2012, United States Census Bureau, 2017).

According to the DfT (2019), there has been a downward trend in the number of commuting trips from 164 trips per person per year in 2002 to 144 trips per person per year in 2018. Also, the average distances travelled have decreased by 9%, from 1,400 miles per person per year in 2002 to 1,277 miles per person per year in 2018 (DfT, 2019). Some factors responsible for the decline in the number of commuting trips include workers commuting on fewer days of the week or combining two or more trips in one, consequently reducing the number of miles travelled. Although there has been a decline in the number of trips and average distances travelled during commuting, it is important to study this kind of travel behaviour since it is regular and repetitious; and thereby serves as an avenue to incorporate physical activity as part of a commuting journey. In addition, for the economically active that make up approximately 30 million (65%) of the entire population in the UK (Office for National Statistics [ONS], 2017), incorporating physical activity during commuting may be a way to effect change in a large proportion of the population.

In summary, commuting is one of the main purposes why people travel, and it is an important domain of physical activity because it is regular, repeated, and a non-discretionary activity that can serve as an opportunity to increase total physical activity, which in turn can improve health. Therefore, there is the need to consider the available evidence on the role of commuting in increasing levels of physical activity and, in so doing, contribute to addressing the health problems caused by low levels of physical activity in the UK.

1.4.2 Assessment methods of Commuting Physical Activity Behaviour

Total time spent commuting, type of commute mode, distance travelled, and amount of physical activity accumulated are the most common variables measured in commuting studies (Dinu et al., 2019; Ferrer et al., 2018). Information on mode of commuting and total time spent commuting are usually measured using a travel diary or physical activity questionnaires on the different domains of physical activity with different response options recorded as part of these assessments (Audrey et al., 2014). Physical activity can also be measured objectively using a body-worn device capable of quantifying the amount and intensity of physical activity (Audrey et al., 2014; Rafferty et al., 2016). Global positioning systems (GPS) have also been used to identify the domains in which physical activity occur in combination with accelerometers to measure physical activity (Audrey et al., 2014; Cooper et al., 2010; Panter et al., 2014; Rafferty et al., 2016). The different methods of measuring physical activity will be discussed in more detail in the literature review (Section 2.1).

The use of self-reported measures for measuring physical behaviour has been well established in commuting studies (Audrey et al., 2014); e.g. questionnaires and travel activity diaries can give contextual information that most objective measurement tools do not provide (Atkin et al., 2012). However, self-reported tools cannot provide information on the intensity of physical activity and tend to be subject to recall and social desirability bias, leading to over-reporting of time spent in physical activity and under-reporting of time spent in sedentary activities (Prince et al., 2008; Scheers et al., 2012). Few commuting studies have used objective measures, such as accelerometer-based devices, to measure physical behaviour (Audrey et al., 2014; Costa et al., 2015; Rafferty et al., 2016; Yang et al., 2012). However, these studies are lacking in considering mixed-mode journeys: they have either primarily focused on walking (Audrey et al., 2014), or walking and cycling only (Ferrer et al., 2018), or just measured the total time spent commuting (Rafferty et al., 2016; Sahlqvist et al., 2012; Yang et al., 2012).

The outputs and interpretation from accelerometer-based devices can differ depending on the measuring instrument (Iveson et al., 2020). One of the most common objective devices used in commuting studies has been the waist-worn ActiGraph (Audrey et al., 2014; Costa et al., 2015; Ferrer et al., 2018; Sahlqvist et al., 2012), which provides information on activity intensity using cut-point thresholds (Freedson et al., 1998). Activity counts are one of the outcomes from the ActiGraph, aggregated by a proprietary algorithm based on the amount of acceleration accumulated over specified epochs (Chen & Bassett, 2005; Welk, 2002). Calibration studies were developed to relate the counts' outcome to objectively measured energy expenditure and convert these counts outcomes into thresholds for physical activity intensities (Bassett, Rowlands, & Trost, 2012; Matthews, 2005); for example, the Freedson cut-point thresholds are common in defining physical activity intensities (Freedson et al., 1998). The activPAL™ is another example of an accelerometer-based device that has been used in commuting studies (Rafferty et al., 2016; Gbadamosi et al., 2020): it has been validated for measuring step count and rate of stepping (cadence) (Grant et al., 2006). The acceleration data from the activPAL™ is classified by the proprietary software into activities: sitting, standing, stepping, and cycling (activPAL™ manufacturing guide). The events files from activPAL™ provide insight into the patterns of activity undertaken as it provides a second-by-second output of continuous periods of a single activity (Granat, 2012; Granat et al., 2015)

Cadence, defined as the rate of stepping, has been used as an alternative method of estimating the intensity of physical activity, MVPA (Slaght et al., 2017). MVPA has been defined as a cadence of 100 steps/min (Marshall et al., 2009; Rowe et al., 2011; Tudor-Locke et al., 2005), and as high as 109 steps/min within healthy populations (Chastin et al., 2009; Rafferty et al., 2016). Also, an average cadence of 76 steps/minute in free-living settings in a healthy population measured using the activPAL™ (Dall et al., 2013) was considered as a proxy for a cadence threshold for MVPA. Only one commuting study to date has used cadence to quantify MVPA in commuting (Rafferty et al., 2016): other previous studies have quantified MVPA based on cut-points derived from the ActiGraph accelerometer (Audrey et al., 2014; Panter et al., 2012; Sahlqvist et al., 2012; Yang et al., 2012). Cadence has been used interchangeably with step accumulation – which is referred to as the number of steps within a minute – and this is seen in Tudor-Locke's definition of cadence (Tudor-Locke et al., 2005) where the ActiGraph accelerometer collected the number of steps taken at minute-by-minute intervals (Dall et al., 2013). Tudor-Locke's definition of cadence, which is also reported as steps/minute includes any other events (that is, sedentary events) that were included within that minute. On the contrary, the cadence from the activPAL™ is defined as steps/minute – and it only looks at the number of steps taken in a stepping event. Therefore, the activPAL™ was used to quantify MVPA based on cadence for this thesis.

1.5 The impact of commuting on health outcomes

Several health benefits are associated with active commuting (Hamer & Chida, 2008; Larouche et al., 2016; Saunders et al., 2013). In terms of benefits to mental health, active commuting has been associated with a reduction in cortisol levels (related to stress) and an increase in endorphins levels (related to mood) (Avila-Palencia et al., 2017; Olsson et al., 2013;

Zijlema et al., 2018). Active commuting has been associated with a reduction in body mass index (BMI) and percentage body fat (Flint & Cummins, 2016; Flint et al., 2014; Flint et al., 2016; King & Jacobson, 2017; Martin et al., 2015; Mytton et al, 2016; Mytton et al., 2018), reduced levels of hypertension and diabetes (Honda et al., 2015; Laverty et al., 2013), reduced risk of cardiovascular risk (Celis-Morales et al., 2017; Gordon-Larsen et al., 2009; Hamer & Chida, 2008; Lerssrimongkol et al., 2016; Panter et al., 2018), and reduced risk of metabolic syndrome (Garcia-Hermoso et al., 2018; Kuwahara et al., 2016; Lorenzo et al., 2020; Sandaragani et al., 2018; Steell et al., 2017; Vaara et al., 2020). These studies are discussed in more detail in the literature review (Section 2.7) and suggest that active commuting has a wide range of benefits to the physical health of the population.

Despite the benefits of active commuting, travel distance from home to work, and ineffective public transportation system, and convenience can act as barriers to the uptake of active commuting (Jones & Ogilvie, 2012; Shannon et al., 2006). Also, lengthy commute journeys have been linked to poorer health outcomes (Halonen et al., 2019): the impact of spending long periods in commuting can encourage certain unhealthy behaviours such as, not participating in physical activity, having enough time to prepare a nutritious meal, and not having a good sleep; these unhealthy lifestyle behaviours have been associated with increased risk of obesity (Christian, 2012). Longer commutes may be impractical for walking or cycling and therefore can increase the uptake of non-active modes of commute which can lead to adverse health consequences, and potential exposure to overcrowding on public transport that can impact mental health (Rafferty et al., 2016; King & Jacobson, 2017; Norgate et al., 2020). Despite these unfavourable outcomes associated with lengthy commute journeys, it is important to consider the benefits of active commuting listed above and encourage the use of mixed-mode journeys by incorporating active modes of commuting as part of the journey among these groups of people. Therefore, commuting presents an opportunity to influence many working-age individuals and implement evidence-based interventions to encourage active commuting to improve workers' physical and mental health.

1.6 Framework for Active commuting

Sallis et al. (2006) designed an ecological model of four domains of active living. An ecological model can illustrate the multiple determinants of health, relating to the individual and interactions with their social and physical environments in which behaviours take place (Dahlgren & Whitehead, 1991). According to Sallis et al. (2006), "Ecological models are well-suited for studying physical activity because physical activity is done in specific places." The centre of the ecological model for active living represents individual lifestyle factors, followed by layers of interacting factors: perceived environment, behaviour settings, and the influences of policies. The information environment, the natural environment, and the socio-cultural environment interact with the different levels in the model. The four active living domains as shown in the figure below are recreation, transport, occupation, and household (Figure 1.2).

The socio-ecological model is built on several clusters of factors that can interact with active commuting: the demographic characteristics being at the core are important in influencing active commuting and the health benefits (Mytton et al., 2018). Some demographic factors such as age have been found to impact the contribution of commuting physical activity to total physical activity (Shannon et al., 2006; Ferrer et al., 2018). Therefore, demographic and lifestyle factors, such as age, gender, level of education, total physical activity, and fruit and vegetable intake are included as covariates in this thesis. Another important demographic factor is the choice of mode of commute, which has been shown in previous studies to play an important role in contributing to total physical activity and reducing the risk of several health risk factors (Flint et al., 2014; Flint et al., 2016; Patterson et al., 2020). The mode of commute is a correlate that influences physical activity outcomes such as volume and intensity (Ferrer et al., 2018; Lachapelle & Noland, 2012): the use of more than one mode of commute is very typical of everyday commute journeys in real-life settings, therefore, mixed-mode journeys will be considered in this thesis. The robust characterisation of free-living physical behaviour is essential to understanding the association between commuting physical activity and health outcomes (Granat, 2012).

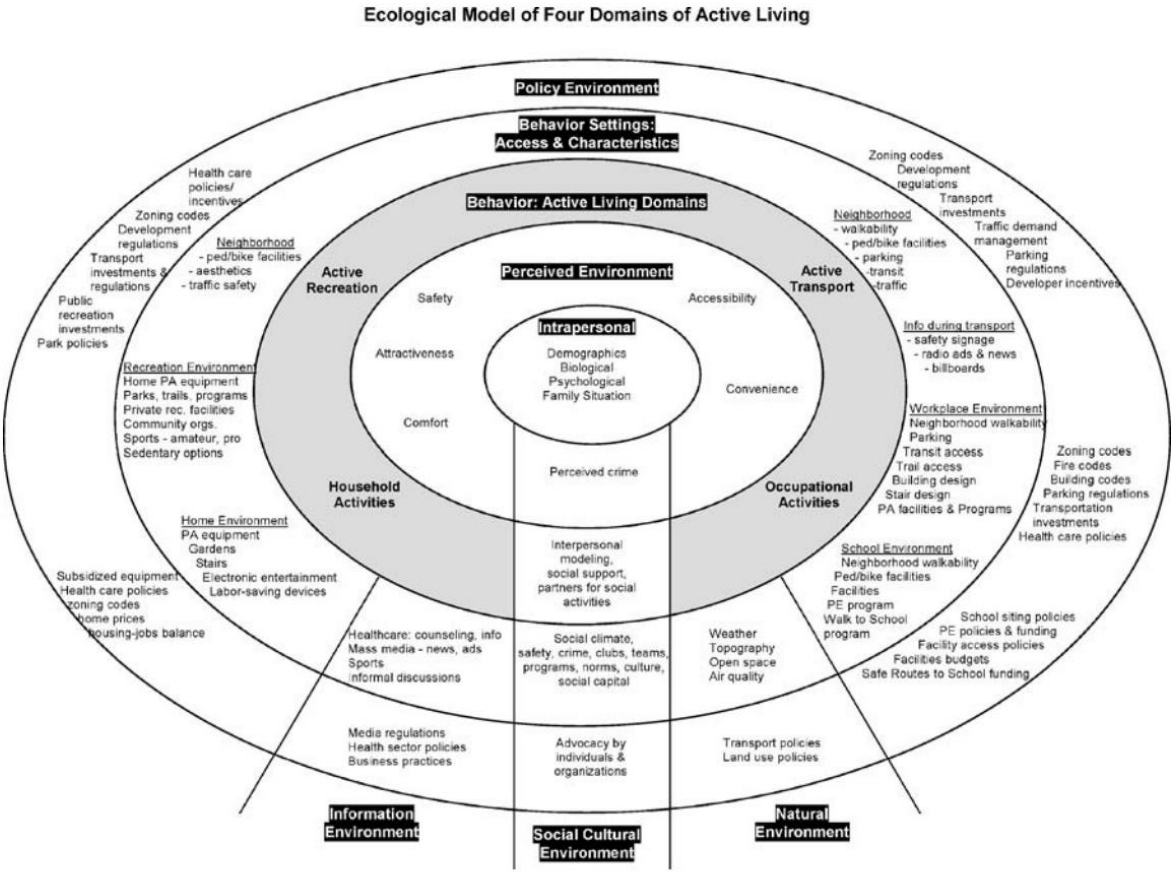

Figure 1.2: The Socio-ecological model of physical activity and sedentary behaviour (Adapted from Sallis et al., 2006)

The quality of the environment, psychological factors and policies are other correlates of active commuting. The environmental factors are positive correlates in previous studies (Ferrer et al., 2018; Shannon et al., 2006; Smith et al., 2017); however, the methods used to assess commuting physical activity rely on subjective data. The most important areas of measurement for physical behaviour appears to be the physical activity dimensions of active commuting: intensity, duration, and frequency (Panter et al., 2012). The combined use of objective and subjective measures in measuring the contribution of commuting physical activity in terms of intensity, duration, and frequency is important to examine the dose-response relationships between physical activity and health outcomes, identify and monitor population-level physical activity, and assess the effectiveness of interventions aimed at increasing physical activity level (Atkin et al., 2012; Edwardson et al., 2017; Freedson et al., 1998; Rennie & Wareham, 1998). Therefore, the use of objective measures accelerometer-based devices and self-report measures (activity diary on commuting) in quantifying the contribution of commuting MVPA to total physical activity and its association with metabolic markers will be explored in this thesis.

1.7 Chapter Summary

Physical activity is important for health improvement and incorporating activity in commuting can increase compliance with physical activity guidelines. There is a body of evidence that active commuting contributes to total physical activity; however, study outcomes are dependent on the study design and how physical activity during commuting is measured. Most studies that have looked at the relationship between commuting and physical activity have focused on the volume and intensity of physical activity accumulated. Little is known about the role mixed-mode journeys play in accumulating physical activity. In addition, commuting studies have mostly used self-reported measures of physical activity, which are known to overestimate physical activity. Regarding compliance with physical activity guidelines, commuting studies have not reported on the length of walking bouts of activities: this is a gap in the literature since some studies report that walking bouts greater than 10 minutes are more beneficial on health outcomes than walking bouts less than 10 minutes. Therefore, it is important to explore the importance of walking bouts on health outcomes.

Although there is evidence of the protective effect of active commuting against obesity and cardiovascular diseases, comparability between studies is difficult due to the differences in the measuring tools used in previous commuting studies. There is no evidence to date on the effect of continuous walking, and the effect on metabolic markers, in commuting studies. Therefore, it is imperative to use appropriate objective measurement tools and methods to avoid underestimating or overestimating the true effects of MVPA during commuting on health outcomes.

1.8 Overall aim of thesis and summary of studies included in the thesis

This thesis aimed to explore the contribution of objectively measured MVPA during commuting towards total MVPA and its association to metabolic markers. This was achieved first by objectively quantifying the contribution of MVPA during commuting to total MVPA by using cadence to define MVPA. Also, the length of walking bouts and how this affect compliance to 2011 and 2019 UK's physical activity guidelines were explored. After the exploration of the lengths of walking bouts in Study One, it was observed that long periods of continuous walking in a free-living environment were not very practical. Therefore, Study Two sought to re-define continuous walking in free-living activities by combining walking events and short interruptions between them based on an average cadence threshold (the process is known as grouping). This study was conducted to introduce a novel approach that did not assume the maximum duration of interruptions as in the case of previous studies; however, the only criteria needed was the cadence threshold. The impact of this grouping process was tested on compliance with 2011 and 2019 UK's physical activity guidelines. Lastly, the final study (Study Three) sought to investigate these novel commute times in MVPA outcomes with their association with metabolic markers.

1.9 Structure of Thesis[9]

This thesis is divided into the following chapters, **Chapter One: Introduction** provides a background to physical activity, the role of commuting to contributing to physical activity, an overview of methods used in measuring commuting physical activity, and its association with health outcomes. For navigation through this entire thesis, at the beginning of every chapter, Table 1.2 will illustrate the details of the content and objective of each chapter.

Chapter Two: Literature Review describes the literature review of current evidence on commuting physical activity and its association with health outcomes, particularly metabolic markers. The chapter also provides a detailed overview of methods used in measuring physical activity and commuting. At the end of this chapter, a detailed description of the aims and objectives are presented (Section 2.10).

Chapter Three: Methodology I describes the methods for Study One and Study Two (Commuting and MVPA and Gap analysis study) and the methodologies used in data collection, data cleaning and processing, and statistical tests used to achieve objectives one to six (Section 2.10.1 and 2.10.2). The methods for Commuting and MVPA have already been

[9] The studies included in this thesis contains data that were collected pre-COVID and therefore, focuses on commuting pre-COVID. The impact of COVID on commuting and physical activity is discussed in section 7.5.

published in the Journal for Measurement of Physical Behaviour (Gbadamosi, Clarke-Cornwell, Sindall, & Granat, 2020).

Chapter Four: Results I present the findings for Study One and Study Two (Commuting and MVPA, and Gap analysis study) that address objectives one to six (Section 2.10.1 and 2.10.2). The results for Commuting and MVPA have already been published (Gbadamosi et al., 2020).

Chapter Five: Methodology II describes Study Three and the methods used in the data collection, data cleaning and processing, and the statistical tests used to achieve objectives seven to eleven (Section 2.10.3).

Chapter Six: Results II presents the results for Study Three that address objectives seven to eleven (Section 2.10.3).

Chapter Seven: Discussion summarises the findings from each study presented in this thesis, discusses the strengths and limitations of each study. Also, a reflective commentary on the impact of Covid-19 on commuting.

Chapter Eight: Conclusion presents a concluding summary of the thesis and implications for policy and future research.

Table 1.2: Overview of the structure of the thesis

Chapter	Summary of each chapter
1- Introduction	A background to physical activity, the role of commuting to contributing to physical activity, an overview of methods used in measuring commuting physical activity, and its association with health outcomes.
2- Literature review	A critical review and discussion of the literature surrounding measuring commuting MVPA, and its association to various health outcomes, especially metabolic risk factors
3- Methodology I – Methods for Study One and Two	Describes the methods for Study One:(*Commuting and MVPA)*; and Study Two: (*Gap analysis*) **Aim of Commuting and MVPA study**: To objectively determine the contribution of MVPA during commuting to total MVPA, using cadence to define MVPA, and explore how minimum walking bout length affects adherence to physical activity guidelines. **Aim of Gap analysis study**: To use an event-based approach to define continuous walking events, by combining walking events with short interruptions based on an average cadence threshold.
4- Results I – Results for Study One and Two	Presents the results for objectives one to six: 1. To objectively quantify MVPA during commuting using the definition of cadence. 2. To determine the difference between modes of commute and time spent in MVPA during commuting. 3. To determine the level of compliance to physical activity guidelines by examining the volume of MVPA and length of walking bouts accumulated. 4. To combine short interruptions between walking events to form a new continuous walking event called "grouped event" 5. To examine how grouping walking events changes total time walking and total time in MVPA 6. To ascertain whether combining walking events with short interruptions between them impacts compliance to physical activity guidelines.
5- Methodology II – Methods for Study Three	Describes the methods used in Study Three to address objectives seven to eleven **Aim**: To investigate the association between MVPA during commuting physical activity and metabolic markers.
6- Results II – Results for Study Three	Presents the results for objectives seven to eleven: 7. To determine the difference between the different modes of commute and time spent in MVPA during commuting and non-commuting periods. 8. To objectively quantify MVPA, using different cadence thresholds for MVPA, for both commuting and non-commuting stepping. 9. To explore the patterns of commuting and non-commuting stepping at different lengths of walking bouts, before and after grouping walking events. 10. To determine the compliance to the 2011 and 2019 UK physical activity guidelines for all participants before and after grouping walking events. 11. To investigate associations between commuting time in MVPA (before and after grouping walking events) and metabolic markers.
7- Discussion	This chapter summarises the findings from Study One to Three, highlights their strengths and limitations within this thesis; Reflection on the impact of COVID-19 on commuting physical activity.
8- Conclusion	This chapter gives a concluding summary of the thesis and implications for policy and future research.

Chapter 2: Literature review

Chapter	Summary of each chapter
1- Introduction	A background to physical activity, the role of commuting to contributing to physical activity, an overview of methods used in measuring commuting physical activity, and its association with health outcomes.
2- Literature review	A critical review and discussion of the literature surrounding measuring commuting MVPA, and its association to various health outcomes, especially metabolic risk factors
3- Methodology I – Methods for Study One and Two	Describes the methods for Study One:(*Commuting and MVPA)*; and Study Two: (*Gap analysis*) **Aim of Commuting and MVPA study**: To objectively determine the contribution of MVPA during commuting to total MVPA, using cadence to define MVPA, and explore how minimum walking bout length affects adherence to physical activity guidelines. **Aim of Gap analysis study**: To use an event-based approach to define continuous walking events, by combining walking events with short interruptions based on an average cadence threshold.
4- Results I – Results for Study One and Two	Presents the results for objectives one to six: 1. To objectively quantify MVPA during commuting using the definition of cadence. 2. To determine the difference between modes of commute and time spent in MVPA during commuting. 3. To determine the level of compliance to physical activity guidelines by examining the volume of MVPA and length of walking bouts accumulated. 4. To combine short interruptions between walking events to form a new continuous walking event called "grouped event" 5. To examine how grouping walking events changes total time walking and total time in MVPA 6. To ascertain whether combining walking events with short interruptions between them impacts compliance to physical activity guidelines.
5- Methodology II – Methods for Study Three	Describes the methods used in Study Three to address objectives seven to eleven **Aim**: To investigate the association between MVPA during commuting physical activity and metabolic markers.
6- Results II – Results for Study Three	Presents the results for objectives seven to eleven: 7. To determine the difference between the different modes of commute and time spent in MVPA during commuting and non-commuting periods. 8. To objectively quantify MVPA, using different cadence thresholds for MVPA, for both commuting and non-commuting stepping. 9. To explore the patterns of commuting and non-commuting stepping at different lengths of walking bouts, before and after grouping walking events. 10. To determine the compliance to the 2011 and 2019 UK physical activity guidelines for all participants before and after grouping walking events. 11. To investigate associations between commuting time in MVPA (before and after grouping walking events) and metabolic markers.
7- Discussion	This chapter summarises the findings from Study One to Three, highlights their strengths and limitations within this thesis; Reflection on the impact of COVID-19 on commuting physical activity.
8- Conclusion	This chapter gives a concluding summary of the thesis and implications for policy and future research.

2.0 Chapter Overview

This chapter is divided into two main sections: the first section describes the different methods for measuring physical activity, the objective measures that have been used in commuting studies, and the rationale for the primary objective measure that will be used in this thesis. The second section discusses the current evidence available on commuting physical activity and health-related outcomes. The final section summarises the entire chapter and a detailed list of the aims and objectives of the studies included in this thesis.

2.1 Measurement of Physical Activity

The accurate assessment of physical activity is important to examine the dose-response relationships between physical activity and health outcomes, identify and monitor population-level physical activity, and assess the effectiveness of interventions aimed at increasing physical activity level (Atkin et al., 2012; Edwardson et al., 2017; Freedson et al.,1998; Rennie & Wareham, 1998). In measuring physical activity, the following four dimensions need to be considered: frequency, duration, intensity, and type of physical activity (Strath et al., 2013). In addition, the domains of physical activity in which activity occurs such as leisure, occupation, household/domestic, and transportation differ by the dimensions of physical activity (Sallis, Owen, & Fischer, 2015; Strath et al., 2013). More recently, there have been recommendations to consider the different domains in which physical activity occurs because they are central to understanding physical activity and creating interventions that effect change (Sallis, Owen, & Fischer, 2015; Strath et al., 2013) as well as the research questions to be answered (Edwardson et al., 2017).

Figure 2.1 shows a range of commonly used physical activity measures with increasing validity and reducing practicality (Dugdill & Stratton, 2007): subjective measures, such as the activity diaries and self-report questionnaires have a low validity but high practicality in terms of cost and availability. On the other hand, objective measures such as pedometers, heart monitors, accelerometers, have high validity and low practicality due to the cost ineffectiveness and burden to the participants. However, since this report by Dugdill and Stratton, accelerometers have been employed in many large-scale population studies (NHANES 2003-2004, UK Biobank, 1970 British Birth Cohort Study UK, The Maastricht study, The Netherlands, The

Nord-Trondelag Health Study, HUNT4, Norway) and they could be considered to have higher feasibility (Dall et al., 2018; Doherty et al., 2017; Stamatakis et al., 2020); therefore, making the relationship described in Figure 2.1 in need of modification. The use of an objective measure combined with self-report measures (activity diaries, questionnaires) provides more details on the domain and purpose of behaviour (Healy et al., 2011). There are a variety of methods for measuring physical activity in research (Dowd et al., 2012), each with its advantages and disadvantages that need to be considered in conjunction with the most valid, accurate, and reliable instrument (Dugdill & Stratton, 2007; Welk, 2002). In the following sections (Section 2.2 and 2.3), the different methods for measuring physical activity and their advantages and disadvantages will be linked to frequency, duration, intensity, type, domain, and research questions relevant to this thesis: some of the physical activity measurement tools available for each method are discussed, highlighting their specific features and limitations.

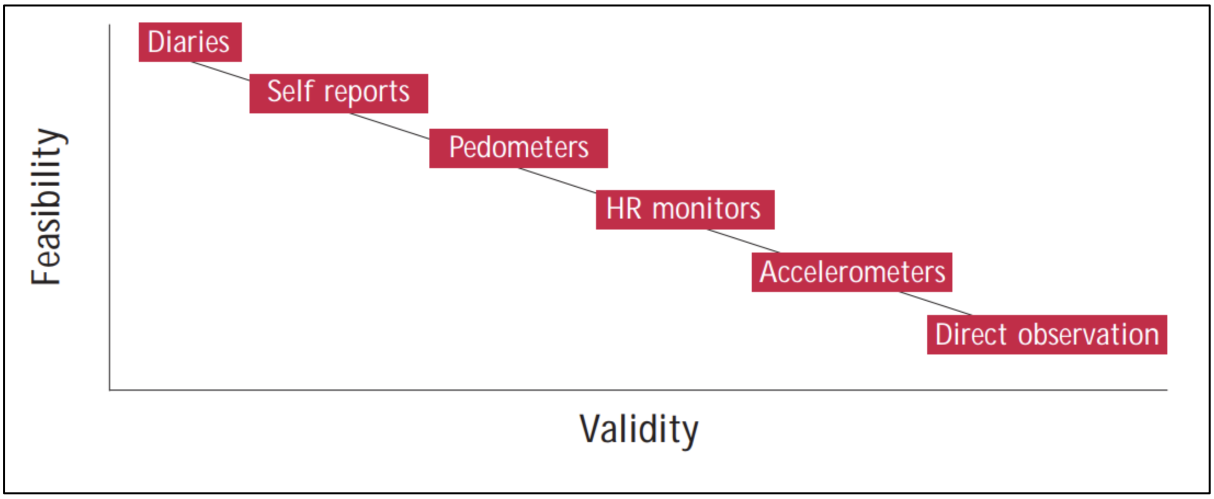

Figure 2.1: Feasibility and validity of measures of physical activity (Adapted from Dugdill & Stratton, 2007)

2.2 Self-reported measures

Self-reported measures (for example, activity diaries and questionnaires) are one of the methods used in assessing physical activity and they rely on participants either to recall activity that has previously occurred or record the activities as they occur (discussed in more detail in Sections 2.2.2). Self-reported tools are low-cost, can have a low to moderate participant burden, and provide information that the other measures cannot (Atkin et al., 2012). They are subject to limitations, including reporting bias: reporting bias is the error in reporting events when survey questions involve recalling past events which may result in a difference in response (Bailey, 2005; Bowling, 2014; Setia, 2016). Another is social desirability, which involves the participants responding to questions based on how they think the researcher wants them to report it (Bowling, 2014). Although self-reported measures are susceptible to influence by cultural norms, perceived social desirability, recall, and reporting bias, they are useful in collecting data from large samples and are readily accessible to most of the population (Atkin et al., 2012). This method of data collection can also provide contextual information on the different dimensions and domains of physical activity and sedentary behaviour (Loveday et al., 2016).

2.2.1 Activity diaries and logs

Activity diaries are used to obtain detailed information on a recurrent type of activity throughout the day or at specific time points. They are often time-dependent, and they can be self-administered or interviewer-administered, in which case, they may be expensive for researchers (Crosbie, 2006). They can be in the form of a booklet, or a list of questions programmed on a mobile phone (Stansfield et al., 2012). Activity diaries can be used in combination with objective measures for detailed data collection (Dowd et al., 2012; Hamer, et al., 2014). An example of a well-known activity diary is the Bouchard activity record (Bouchard et al., 1983). The Bouchard activity record is a three-day activity record that asks participants to recall their main activity out of nine types of physical behaviour every 15 minutes over a 24-hour period. Each of the nine behaviours is given a numeric approximate energy expenditure value, ranging from 1 being the least intense activity to 9 being the extremely intense activity (Bouchard et al., 1983; Hart et al., 2011). Although activity diaries provide a great deal of information, they can be misleading with under-reporting sedentary behaviour and over-reporting physical activity (Scheers et al., 2012). The main advantage of activity diaries is that they can be used to record information that cannot be inferred from objective data (Atkins et al., 2012; Strath et al., 2013), such as sleep time, waking periods, commuting times, and other specific events during the day, depending on the research questions being answered (Edwardson et al., 2017).

Activity diaries that focus on information on travel have been referred to as travel diaries in the literature (Kenyon, 2006), which are designed to capture information on the mode of travel, the departure time, arrival time, and distance travelled (Kenyon, 2006). Some travel diaries have been used in commuting/travel studies and are sometimes incorporated as part of the individual or household survey questionnaire (Harms et al., 2018). Examples of some travel diaries include Australian Bureau Statistics Time use diaries, National Household Travel Survey (NHTS) for American residents, and the NTS in England. The Australian Bureau Statistics Time Use Diaries was used as a part of the Australian Bureau Statistics Time Use survey that collected information on the domains of physical activity on two consecutive days of the week: respondents recorded their main and secondary travel activity in five-minute intervals (Tudor-Locke et al., 2005). In America, NHTS is the only source of national data that collects data on personal and household travel, including daily non-commercial travel by all modes, characteristics of the people traveling, their household, and their vehicles (Federal Highway Administration, 2019). The daily travel diary collects information on all trips taken within a 24-hour period for each trip, and for each trip, the respondents report the purpose of the trip, the mode of transportation used, the time of the day of travel, the day of the week and the vehicle occupancy. The NTS in England uses a travel diary to collect data on travel patterns of all age groups, including children: approximately 16,000 individuals in 7,000 households in England take part in the survey annually (Stratford et al., 2003). The NTS data collection consists of a face-to-face interview and a seven-day self-completed written travel diary, which collects information on the travel journeys' purpose, duration, mode of transport, and distance (Stratford et al., 2003).

2.2.1.1 Advantages and Disadvantages of activity diaries

The advantages of activity diaries are somewhat like that of self-reported measures. They are easy to use and relatively inexpensive to administer (Atkins et al., 2012; Strath et al., 2013). They can provide information on activity patterns and serve as an alternative for assessing different dimensions of physical activity (Vanroy et al., 2014). A disadvantage of activity diaries is the burden they can place on the participant, requiring regular engagement by the participant for the duration of the study. Also, they can be labour-intensive and burdensome for the researcher during data reduction and cleaning (Edwardson et al., 2017; Strath et al., 2013). Reporting bias may present an issue with activity diaries as participants may underestimate sedentary behaviour, overestimate physical activity or forget to record the actual events that took place during the reporting period (Bailey, 2005; Bowling, 2014; Setia, 2016).

2.2.2 Self-reported questionnaires

Self-reported questionnaires can be used to assess physical activity by identifying domains and dimensions of physical activity based on self-reported responses (Strath et al., 2013). Questionnaires can be administered as self-reported surveys or administered by an interviewer (Strath et al., 2013; Sylvia et al., 2014). Questionnaires are often validated using objective measurement tools among different population groups (Wareham et al., 2002). Questionnaires vary in the domain they estimate, how the data are reported (activity scores, times, energy expenditure), and how data are obtained (paper and pencil assessment, computerised questionnaire, interview) (Welk, 2002).

Some examples of commonly used questionnaires include the International Physical Activity Questionnaire (IPAQ) (Bauman et al., 2009; Chastin et al., 2014, Craig et al., 2003), Global Physical Activity Questionnaire (GPAQ) (Bull et al., 2009; WHO, n.d.), European Prospective Investigation into Cancer Study- Norfolk Physical Activity Questionnaire (EPAQ2), and Recent Physical Activity Questionnaire (RPAQ). The IPAQ is one of the most widely used physical activity questionnaires (Dyrstad et al., 2014; van Poppel et al., 2010).

The IPAQ was developed as a surveillance tool for comparing physical activity prevalence across countries (Bauman et al., 2009; Craig et al., 2003): it has a long (IPAQ-Long Form) and short-form (IPAQ-S) (www.Ipaq.ki.se) is used for 18-69-year-olds and asks questions about various physical activities carried out in the previous seven days. The long version assesses duration and frequency in moderate and vigorous-intensity physical activity exceeding 10 minutes per bout across four different domains over the last seven days: transportation, while the IPAQ short version does not separate the activity domains (Sjöström, Oja, Hagströmer, Smith, & Bauman, 2006). Test-retest reliability for the IPAQ-Long Form and IPAQ-S versions has demonstrated acceptable to high levels of repeatability (Craig et al., 2003). However, in terms of criterion validity using the ActiGraph 7164 accelerometer, the correlation coefficient ranged from 0.26 to 0.39 for the long-form and 0.23 to 0.36 for the short-form (Craig et al., 2003). In a systematic review, which included 23 studies, the correlation between total physical activity measured by the IPAQ-S and objective measures, the correlation coefficients reported were low (r=0.09 to 0.39) (Lee, Macfarlane, Lam, & Stewart, 2011). The authors recommended further validation studies and exploration of demographic or cultural differences. Despite the validation issues, the IPAQ has gained acceptance and is mainly used in its short form, which does not ask any specific questions on transport/travel (Bauman et al., 2009).

The GPAQ is a validated surveillance tool developed by the WHO for monitoring and evaluating physical activity levels at national and international levels (WHO, 2005). For example, the GPAQ was used in the Chilean National Health Survey (CNHS) data collection process, a nationally representative household survey, to collect information on transport, adiposity outcomes, and sociodemographic factors (Medina et al., 2020; Steell et al 2017). The GPAQ consists of 16 questions that estimate physical activity levels in three domains: work, travel, and recreation. It is validated for people aged 16-84 years and asks respondents to recall over a typical week the activities carried out in each domain assessed (Bull et al., 2009).

Many physical activity questionnaires are designed to measure total physical activity, and in addition, estimate the amount of physical activity undertaken in the different domains of physical activity – leisure, occupational, household/domestic, and transportation-related physical activity (or commuting) (Strath et al., 2013). The most frequently used method to collect physical activity data during commuting is the use of activity diaries and questionnaires: this is because information on the mode of commute and distances travelled can be estimated from the information recorded either in the activity diary or the questionnaire (Section 2.2.2.1). The Recent Physical Activity Questionnaire (RPAQ) has been used in large-scale commuting studies: a National Institute of Health Research large-scale intervention study in Cambridge titled 'Commuting and Health in Cambridge' (Ogilvie et al., 2010; Panter et al., 2014). The RPAQ contains questions about physical activity in four sections: activity at home, during leisure, during transport, and at work (Besson, Brage, Jakes, Ekelund, & Wareham, 2010). In each section of this questionnaire, the questions are closed rather than open-ended; as a result, this questionnaire can be used to complete and facilitate large-scale data entry (Besson et al., 2010). The RPAQ users are presented with closed questions with a choice of answers to select from: these categories of answers were provided based on early versions of the open-endedly structured questionnaire (Besson et al., 2010). The RPAQ has been validated in a healthy population of 21-57-year-olds and has shown a good test-retest repeatability (intraclass coefficient (ICC)=0.76)) with a criterion validity of r=0.39 for total physical activity energy expenditure (PAEE) against the doubly labelled water technique (Besson et al., 2010). These results also suggest that the RPAQ may be used to estimate absolute TEE, PAEE, time spent sedentary, and time spent in vigorous physical activity in groups of healthy adults (Besson et al., 2010).

Physical activity questionnaires (for example, the RPAQ) used in studies of active commuting classify commuting based on the most used mode of commute; thus, indicating limitations with the questionnaire (Panter et al., 2014). The usual mode of travel does not reflect the reality of commuting for some commuters who may either combine modes of commute. For example, walking to the train station and taking the train to work, or people who may use alternative modes on different days (for example, cycle to work on some days and drive on other days) (Goodman et al., 2012; Panter et al., 2014). Commuters who adopt these commute patterns may be incorrectly classified as 'passive' commuters when they do undertake some 'active' commuting. Such classifications also result in comparisons being drawn between individuals who cycle or walk for the entire journey to work with individuals who primarily drive to work. Whilst such comparisons have a role, many journeys to work are too far to be undertaken solely walking or cycling (the average commute in the UK in 2014 was 8.7 miles). Therefore, a more practical approach should be adopted in comparing different modes of commute to reflect the reality of commuting.

2.2.2.1 Advantages and disadvantages of self-reported questionnaires

Physical activity questionnaires are relatively inexpensive and convenient to use, they can be applied to sampling large numbers of individuals and usually have a low participant burden. They can be used to capture qualitative and quantitative physical activity information and can record activities that are not captured by accelerometers and other objective measures (Strath et al., 2013; Welk et al., 2002). Despite the advantages, physical activity questionnaires are subject to reporting bias based on the accuracy and completeness of recorded responses.

Social desirability bias can occur in the use of questionnaires, with participants/respondents reporting events based on cultural norms (Shephard, 2003; Sylvia et al., 2014); for example, comparing travel times reported by self-reported questionnaires vs. objective measures (GPS), Kelly and colleagues (Kelly et al., 2013) discovered that self-reported trip lengths were overestimated by between 2.2 and 13.5 minutes per trip. The authors reported that the overestimation of trip length from self-reported measures was because of indirect trips to work and sometimes reporting the travel time to include non-travel activities, such as loading of the vehicle (Kelly et al., 2013). They are less robust in measuring light or moderate activity compared to objective measures and can result in under or over estimation of energy expenditure (Welk, 2002).

2.3 Objective measures of Physical Activity

Objective measures involve the use of wearable monitors that directly measure acceleration, heart rate, or energy expenditure. Objective measures include accelerometer-based devices (also referred to in the literature as accelerometers), pedometers, inclinometers, and heart rate monitors (Bassett, 2012). Objective measures are an effective method of quantifying physical activity as well as sedentary behaviour (Chastin et al., 2009; Chastin & Granat, 2009). To better understand the methods used in this thesis and for answering the stated aims and objectives, a brief overview of some physical activity measurement tools will be discussed in the following sections (2.3.1 – 2.3.5). Section 2.3.5 provides a detailed, critical narrative on accelerometers, as this was the chosen assessment method for the studies within this thesis to accurately quantify commuting time in MVPA without the risk of overestimating physical activity, as seen in the case of self-reported commuting studies.

2.3.1 Direct Observation

Direct observation is a valid method for obtaining physical activity data in a natural setting with little interference (Mckenzie, 1991): it involves a trained observer watching or recording specific physical activity behaviour (sitting, walking, running) in real-time. The observers must be trained to use a specified direct observation coding system to obtain the most accurate results. Direct observation is mostly used to study children’s physical activity (Dugdill & Stratton, 2007). This method can be used to generate contextual information and data on type, duration, and intensity of physical activity (Strath et al., 2013); however, it is very labour intensive, requiring researchers to observe in real-time and code activities, whether in real-time or by watching video recordings (Sirad & Petrucci Jr, 2019). It can also be time-intensive for the training of the observers, the data collection processing, and analysis (Dale et al., 2002). Also, the use of this method is limited to smaller studies over a short period.

2.3.2 Heart rate monitors

Heart rate monitors measure physiological responses to physical activity by detecting electrical impulses from the heart and converting them to beats per minute (Dugdill & Stratton, 2007). They can be worn as a fitted belt around the chest or as small wristwatches: they have a low participant burden when recording periods are short, they are easy and quick for data collection (Sirad & Pate, 2001). They can provide detailed data on frequency, intensity, and duration, and estimate energy expenditure (Strath et al., 2000; Welk, 2002). These devices can be affected by non-activity stimuli that can increase heart rate, such as emotional state, temperature change (Strath et al., 2013). Also, there is a strong relationship with moderate to vigorous intensity activities; however, there is a weak relationship with low-intensity activities. Furthermore, the cost of this instrument may prohibit assessments with large sample sizes (Welk, 2002). An example of a commercially available heart rate monitor is the Actiheart sensor (Brage et al., 2005; Crouter et al., 2008), which was used in the Commuting and Health in Cambridge study as one of the objective measurement tools to quantify energy expenditure (Ogilvie et al., 2010).

2.3.3 Pedometers

Pedometers are small motion sensors that are placed on the hip using a belt or a waistband. They are used to measure steps using a mechanical lever, which is activated when the subject's hip moves vertically (Sirard & Petrucci Jr, 2019). Pedometers are best for recording running and brisk walking because these behaviours occur in a vertical position; however, they are unable to record activities such as sitting, standing, or solely upper body movements (Tudor-Locke et al., 2002). Some pedometers can estimate distance walked, if the stride length is known, and can be used to estimate physical activity energy expenditure by estimating the energy cost associated with walking (Dale et al., 2002).

Pedometers are easy to use, inexpensive, and specifically designed to assess walking (Strath et al., 2012). They have a behavioural feedback function that displays the number of steps accumulated: this can alter the true behaviour of the participants by over-estimating physical activity and under-estimating sedentary behaviour (Scheers et al., 2013). Pedometers cannot distinguish between intensity, frequency, or duration and therefore, this limits their ability in predicting energy expenditure correctly (Freedson & Miller, 2000; Tudor-Locke et al., 2002).

There are various commercially available pedometers, including the Yamax Digi-Walker (Crouter et al., 2003), and the StepWatch (Coleman et al., 1999; Karabulut et al., 2005). These pedometers are available in different models and the models vary in cost and measurement accuracy. For example, the Yamax Digi-Walker underestimates step counts at slow activity speeds; however, the StepWatch-3 model is sensitive to walking at slow speeds (Sylvia et al., 2014).

2.3.4 Global positioning systems

Global positioning systems (GPS) are satellite-based navigation systems that can provide a time-precise location at any point on the surface of the Earth (Krenn et al., 2011; Maddison & Mchurchu, 2009). GPS can be used in providing objective information on the context of activity without direct observation (Loveday et al., 2016): they provide a good spatial resolution of location (Maddison & Mchurchu, 2009) and have the potential of estimating the distance travelled (Krenn et al., 2011). GPS has been used in combination with accelerometers to measure the contribution of commuting to physical activity (Cooper et al., 2010; Rafferty et al., 2016; Panter et al., 2014). An example of a commonly used GPS receiver is the QStarz BT1000XT used in commuting studies that have objectively measured location (Audrey et al., 2014; Ferrer et al., 2018; Panter et al., 2014; Rafferty et al., 2016).

The use of GPS can be used to address a limitation posed by self-reported measures in terms of reporting bias, social desirability bias, and under- and over-reporting of physical behaviours (Costa et al., 2015; Panter et al., 2014). A systematic review that included eight studies comparing self-report and GPS duration of travel journey times reported that the self-reported measures overestimated journey times by 2.2 to 13.5 minutes per journey (Kelly et al., 2013). However, GPS is limited in its ability to measure indoor location due to satellite signal loss (Loveday et al., 2016). The data cleaning and reduction process require technical and software expertise – the use of Geographical Information Systems (GIS) and machine learning – and it is often not reported in most travel research; therefore, making it difficult to be reproduced (Panter et al., 2014). Also, there are issues surrounding the need to charge the GPS device daily, either due to the high power consumption of the device, or the participants forgetting to recharge the battery regularly (Krenn et al., 2011). These are some of the issues that make it impractical to be used for a seven-day monitoring in conjunction with accelerometer and therefore, this device was not considered in this study.

2.3.5 Accelerometer-based devices

Accelerometer-based devices are motion sensors that measure body movements in terms of acceleration; these accelerations can be translated into physical activity intensity, frequency, and duration over time intervals (Chen & Bassett, 2005). They can be worn on different parts of the body but are generally designed to be worn on either the hip, thigh, or wrist (Troiano, Stamatakis, & Bull, 2020; Welk, 2002). Depending on the accelerometer model, acceleration of body movements can be detected in one (uniaxial) to three (tri-axial) orthogonal axes – anteroposterior, mediolateral, and vertical (Chen & Bassett, 2005; Strath et al., 2013; Sylvia et al., 2014).

The acceleration generated from accelerometer-based devices is often converted into units of measurement called activity counts (Chen & Bassett, 2005). These counts are the estimated intensity of an activity collected over a specific time called an epoch, this has often been one minute (Atkin et al., 2012). The data obtained from accelerometer-based devices can also be translated into time spent in different postures (sitting, standing, or energy expenditure units – METs per hour or minute, counts per minute or total counts, depending on the device used and the site of placement (Bassett et al., 2015; Crouter et al., 2006; Granat et al., 2006). There are fundamental differences between the models of accelerometers-based devices, making it difficult to compare results between studies (Migueles et al., 2017; Strath et al., 2013).

Measuring physical activity and sedentary behaviour using accelerometers can be broadly categorised into those that estimate energy expenditure and those that classify postures (Granat, 2012). There is a wide range of accelerometer-based devices that have been validated and tested in various populations and different age groups (Migueles et al., 2017; Strath et al., 2013; Sylvia et al., 2014). Some of the available accelerometer-based devices are: the ActiGraph (Troiano et al., 2008; Welk et al., 2000), the activPAL™ TM (Grant et al., 2006), the ActiCal, the AX3 (Duncan et al., 2018), the Tritrac (Nichols et al., 1999). Specifically, some accelerometer-based devices that have been used to measure commuting physical activity are, the ActiGraph GTX3 (Audrey et al., 2014; Costa et al., 2015; Panter et al., 2012; Yang et al., 2012), the AX3 (Celis-Morales et al., 2017) and the activPAL™ (Rafferty et al., 2016). The two most common accelerometer-based devices in commuting studies are the ActiGraph (Actigraph GT3X, figure 2.2), and the activPAL™ (figure 2.3). The ActiGraph is an example of an energy expenditure device, while the activPAL™ TM is an example of a postural classification device: these devices will be discussed in more detail in sections 2.3.5.2 and 2.3.5.3

2.3.5.1 Advantages and Disadvantages of Accelerometers-based devices

Accelerometer-based devices are small, devices that can provide objective information on the amount, frequency, intensity, and duration of physical activity (Plasqui & Westerterp, 2007). They allow for the collection of data over long periods and storage of large amounts of activity information without the presence of the researcher; thus, saving time and cost (Trost et al., 2005). Accelerometers can have a low burden on participants due to their size and weight; however, it depends on the orientation and placement site of the accelerometer-based devices and the aspects of physical activity measured. For example, the waist-worn devices have been validated for measuring energy expenditure; however, they are limited in classifying postures and distinguishing between different activity types: similarly, the wrist-worn sites increase compliance, but errors may occur due to hand movements and distinguishing between different activity types (Crowley et al., 2019; Kerr et al., 2017), while thigh-worn sites allow estimation of postural classification (Crowley et al., 2019). Similarly, the ActiGraph may not be convenient to sleep with around the waist and the activPAL™ attached to the thigh may irritate some participants (Edwardson et al., 2017; Kerr et al., 2017). However, due to advancement in the use of accelerometers in physical activity research, algorithms have been developed that can differentiate between sitting and lying (Lyden et al., 2017), and classify time spent in cycling in posture-based devices (Speirs et al., 2019)

2.3.5.2 The ActiGraph – Energy expenditure device

Accelerometers that estimate energy expenditure are generally worn on the hip or the wrist (Chen & Bassett, 2005). The ActiGraph[10] (ActiGraph LLC, Pensacola, Florida) was first developed as a uniaxial accelerometer, that can measure the vertical acceleration of body movements. One of the first-generation accelerometers was the ActiGraph 7164 (size: 51x41x15mm, weight: 43g), and the activity counts needed to be translated into meaningful physical activity intensity levels for adults (Freedson et al., 1998). The recent models of the accelerometer are tri-axial monitor accelerometers (ActiGraph GT3X+, size: 38x37x18mm, weight: 27g, Figure 2.2). They can be worn either on the hip by using an adjustable belt or on the wrist with a strap and integrate a tri-axial sensor to measure acceleration in three axes at sampling rates up to 100 Hz, using activity counts that reflect the duration and intensity of movements in each epoch. 2002). The ActiGraph has been used in large scale population studies worldwide including the ongoing National Health and Nutrition Examination Survey (NHANES) (Troiano et al., 2008; Troiano et al., 2014).

Figure 2.2: The ActiGraph accelerometer (ActiGraph GT3X, ActiGraph LLC, Pensacola, FL) (Source: Bassett, 2012)

The proprietary algorithms (ActiLife software) for the ActiGraph accelerometer are used to convert the acceleration data into a count outcome (activity counts per minute, cpm), that can be defined over specified epochs (Chen & Bassett, 2005; Welk, 2002). Consequently,

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[10] It has been previously called Computer Science and Applications, Inc (CSA) and Manufacturing Technology, Inc (MTI)

researchers have developed thresholds of activity counts data to classify physical activity intensities using calibration studies (Bassett et al., 2012): these calibration studies were developed to make a meaningful representation of the activity counts data (Kim et al., 2012; Welk, 2002). For example, the Freedson cut-point thresholds were developed from a regression equation using the ActiGraph 7164 (Freedson et al., 1998). The Freedson cut-point thresholds are one of the common approaches to defining physical activity intensities: light: 100-1951 cpm, moderate: 1952-5724 cpm, vigorous: 5725-9498 cpm (Freedson et al., 1998). The cut-points by Freedson et al. (1998) were estimated with treadmill walking and running; they tend to overestimate light-and moderate-intensity activities and underestimate vigorous activities (Crouter et al., 2006; Berntsen et al., 2010). The use of Freedson cut-off points thresholds has been widely used in the literature (Matthews et al., 2008; Ridgers et al., 2012); however, there have been other cut-point thresholds from regression equations for different intensities of physical activity that have been developed over the years (Brage et al., 2003; Hendelman et al., 2000; Leenders et al., 2003; Yngve et al., 2003). The other regression equations that have been developed from the same device (ActiGraph 7164) have produced multiple different cut-off thresholds to define intensity categories (moderate-intensity cut-points range from 191 to 2743 cpm, and vigorous-intensity cut-points range from 4945 to 7526 cpm), showing a lack of agreement and comparison between studies (Bassett, 2012; Crouter et al., 2006).

In validating the ActiGraph for estimating sedentary time, Kozey-Keadle et al. (2011) tested the validity of an ActiGraph accelerometer using the arbitrary threshold value of 100 cpm (Matthews et al., 2008): they found that the ActiGraph under-estimated total sedentary time by 4.9% compared to direct observation. A recent study suggested that step outputs gained from ActiGraph accelerometers at waist and wrist placement sites are not equivalent under both laboratory and free-living conditions (Tudor-Locke et al. 2015). Although much progress has been made in the assessment of physical activity with accelerometers, there are several limitations when using hip-based accelerometers to assess sedentary time. Recent models of the ActiGraph such as GT3X and GT3X+ contain an inclinometer algorithm, mimicking the activPAL™, that can be worn on the thigh and classify posture: sitting/lying, standing, and stepping (Steeves et al., 2015); however, when this device is worn at the hip, there is misclassification of standing as sitting time (Atkin et al. 2012; Carr & Mahar 2012; Lyden et al.

2012). In addition, the ActiGraph is bulky in terms of dimensions and wearing it in the thigh could cause compliance problems and increase participant burden (ActiGraph GT3X, size: 53x35x7mm, weight: 15g; ActiGraph GT3X+, size: 46x33x15mm, weight: 19g, Figure 2.2) (Radtke, Rodriguez, Braun, & Dressel, 2021)

2.3.5.3 The activPAL™ – Posture classification device

Accelerometers that classify postures are another category of devices that can be used to quantify physical activity and sedentary behaviour. The attachment of these devices to the thigh to determine the inclination along the three orthogonal planes is to derive postural classification using proprietary algorithms (Granat, 2012). The activPAL™ (PAL Technologies Ltd, Glasgow, Scotland) activity monitor is worn on the front mid-line of the thigh and classifies posture as sitting/lying, standing, and stepping. The activity monitor has been validated for stepping (that is, walking and running) and cadence, which is defined as steps per minute over the time in which the steps are accumulated (Dahlgren et al., 2012; Grant et al., 2006). Although the activPAL™ can misclassify walking at slow walking speeds (that is., < 0.5 metres per second (m/s)) (Stansfield et al., 2015), it remains a valid and reliable device for measuring physical activity in a different range of populations – children aged between three to five years old (Davies et al., 2012), working-age adults (Godfrey et al., 2007, Dahlgren et al., 2010, Grant et al., 2006, Ryan et al., 2006), and older adults aged between 65 to 87 years old (Grant et al., 2008). There are different models of the activPAL™, and the newer models (activPAL3™ micro (23.5x43x5 mm), 9.5g, Figure 2.3) are lighter in weight than the earlier models (activPAL3™ (53x35x7 mm, 15g) (Edwardson et al., 2017; Steeves et al., 2015); therefore, reducing the burden on participants.

Figure 2.3: The activPAL™ micro accelerometer, with the figure on the front indicating the direction of attachment

Grant et al. (2006) determined the validity of the activPAL™ compared to direct observation to measure sitting time in a laboratory environment. The mean percentage difference between sitting time between the accelerometer and direct observation was 0.3%; the inter-observer reliability was >0.97 for all postures (Grant et al. 2006). The authors reported that the number of sit-to-stand and stand-to-sit transitions recorded by the activPAL™ and through direct observation were identical (Grant et al. 2006). The activPAL™ has a high test-retest reliability for treadmill walking at 4.5 kilometres (km) per hour (intraclass correlation coefficient (ICC)=0.94) and stairs walking (ICC=0.88,0.81, and 0.70). In adults, the activPAL™ is a reliable and valid measure of step counts at varying walking speeds (0.90,1.12,1.33,1.56, and 1.78 m/s) (Ryan et al., 2006); however, it is less accurate for slower walking speeds (<0.5 m/s) (Stansfield et al., 2015). Using the more recent models, the activPAL3™ has been evaluated to determine the validity and reliability of measuring stepping and posture detection in 20 adults and eight young people performing standardised activities and activities of daily living (Sellers, Dall, Grant, & Stansfield, 2016). The authors reported that compared to video observation, the activPAL3™ was accurate in detecting standardised activities and purposeful stepping; however, similar to Stansfield et al., (2015), the detection of slower stepping movement was poor and decreasing step detection accuracy with increasing cadence above 150 steps/minute. Also, the activPAL3™ demonstrated excellent inter-device reliability (ICC (1,1) > 0.90) for all outcomes (Sellers et al., 2016). In comparing the agreement between the activPAL™ and the activPAL3™ models in detecting posture and stepping in adults and young people, Sellers et al. (2016) reported that both models detected all standardised activities with less than 5% of agreement. During activities of daily living, the activPAL3™ recorded more steps than the activPAL™ in both adults and young people; however, the activPAL™ detected more steps during jogging than the activPAL3™. When the results were compared to the video observation, it was observed that both models underestimate stepping during jogging, with less accuracy at detecting steps at increasing cadences. The agreement between the activPAL™ and the activPAL3™ model for second-by-second posture detection was greater than 90% for all standardised and activities of daily living in both adults and young people. Currently, the activPAL™ generates an output of step counts, based on the proprietary algorithm. Recently, the activPAL™ proprietary software has been updated to distinguish between periods of walking and cycling (Speirs et al., 2019).

2.3.5.4 Comparison of the ActivPAL™ and ActiGraph accelerometers

Steeves et al. (2015) compared the thigh-worn ActiGraph and activPAL™ during controlled and free-living conditions. For the controlled activities, participants were fitted with both accelerometers and asked to perform 18 different activities (six sitting, two standing, nine stepping, and one cycling), and standing while writing on a whiteboard with intermittent stepping; for the free-living activities, participants were also asked to wear both accelerometers for three days during waking hours only and were to carry on with normal routine activities; and recorded using a smartphone the duration when the device was taken off and put back on. Under laboratory conditions, both accelerometers correctly classified standing time; however, for sitting postures, the activPAL™ correctly classified >95% of the time spent in four out of the six sitting postures and the ActiGraph correctly classified 100% of the time spent in five of the six sitting postures. Both devices misclassified sitting on a laboratory stool (ActiGraph 14% vs. activPAL™ 95%): the activPAL™ misclassified 14% of sitting time with legs elongated, while the ActiGraph classified this sitting activity correctly. For all stepping activities, the activPAL™ correctly classified the time spent more than 95% of the time; the ActiGraph was accurate for six out of the nine stepping activities: however, the ActiGraph was less accurate for descending stairs (86%), ascending stairs (92%), and running at 2.91 miles per second (93%). The two accelerometers categorised time spent writing on a whiteboard with intermittent standing differently (ActiGraph: 85% standing and 15% stepping vs. activPAL™: 98% standing and 2% stepping). In terms of time spent in upright cycling, the activPAL™ categorised 93% of cycling time as stepping while the ActiGraph categorised more than 99% of cycling time as sitting and the rest (<1%) of cycling time as stepping. Although the ActiGraph may have classified the posture correctly as sitting, the activPAL™ recognised cycling as an activity. In free-living conditions, the two accelerometers were similarly accurate in correctly classifying activities (86% observed). Both the activPAL™ and the ActiGraph did not differ in their estimation of the total time spent sitting (ActiGraph 64% vs. activPAL™ 62%). However, there were significant differences between the two devices for the time spent standing (ActiGraph 21% vs. activPAL™ 27%) and stepping (ActiGraph 15% vs. activPAL™ 11%). The ActiGraph may have presented as more sensitive to detecting steps, but this does not translate into actual stepping taking place: in the laboratory conditions, where there was a criterion measure – direct observation, it was observed that the activPAL™ was more sensitive to actual steps taken compared to ActiGraph (Steeves et al., 2015; Radtke et al., 2021). The authors concluded that although the ActiGraph presented as more sensitive to movement than the activPAL™, it is important for other studies to determine if the sensitivity translates to greater accuracy in detecting steps (Steeves et al., 2015; Radtke et al., 2021).

Although Radtke et al. (2021) also reported similar findings to Steeves et al. (2015) that the activPAL™ misclassified sitting with leg elongated, both studies did not report what the activPAL™ classified the activity (sitting with leg elongated) as. In contrast, Radtke and colleagues reported that both the ActiGraph and the activPAL™ classified all stepping tasks correctly while Steeves et al. (2015) reported that the ActiGraph misclassified some stepping activities (such as ascending and descending the stairs, and running at 2.9 m/s). The attachment of the activPAL™ with the inclination along the three orthogonal planes is to derive postural classification using proprietary algorithms (Granat, 2012); however, the waist-worn devices are limited in classifying postures and distinguishing between different activity types. The differences in classifying postures using thigh-worn monitors may be due to the proprietary algorithms for the devices, and therefore, there is a need for improvements in the algorithms to allow for accurate classifications of a wider range of postures and activities (Steeves et al., 2015).

A study by An, Kim, & Lee (2016) was carried out to observe the validity of the inclinometer functions of the ActiGraph GT3X+ positioned on the waist and the wrist and, and the thigh-mounted activPAL™ in measuring three different postures (sitting, standing, and stepping) (An, Kim, & Lee, 2016). Sixty-two participants were asked to complete 15 activities that included seven sitting, eight standing and stepping activities. Compared to direct observation, the activPAL™ was more accurate for measuring sitting and standing compared to the waist- and wrist-worn ActiGraph (An et al. 2016). The activPAL™ was accurate for detecting stepping time in both laboratory and free-living conditions, while the ActiGraph was accurate for detecting stepping on treadmill activities. The wrist-worn sites for the ActiGraph GT3X+ may increase compliance, but errors may occur due to hand movements and distinguishing between different activity types (Crowley et al., 2019; Kerr et al., 2017), while thigh-worn sites for the activPAL™ allows estimation of postural classification (Crowley et al., 2019).

2.3.5.5 The rationale for the accelerometer used in the studies included in this thesis

The main aim of this thesis was to explore the contribution of objectively measured MVPA during commuting towards total MVPA and its association to metabolic markers. To objectively measure commuting, the device needed to use classifies posture correctly, that is, to correctly distinguish between different modes of commute, for example, walking to the bus stop, sitting on a train, cycling, or driving a car. The activPAL™ has been regarded as the gold standard for measuring sitting and classifying postures correctly (Kozey-Keadle et al., 2011). Although the time in MVPA is not a standard output from the activPAL™ accelerometer, there are different options for converting the outputs from the activPAL™ into the time spent in MVPA: they include, classifying energy expenditure outputs from the activPAL™ into intensities (Lyden et al., 2017; Steeves et al., 2015), while the hip or waist-worn ActiGraph misclassifies standing activities and misclassifies some activity types (Radtke et al., 2021). According to Lee and Dall (2019), although the time in MVPA is not a standard output from the activPAL™ accelerometer, there are different options for converting the outputs from the activPAL™ into the time spent in MVPA: they include, classifying energy expenditure outputs from the activPAL™ into intensities (Lyden et al., 2017), the use of cadence of stepping periods (Dall et al., 2017; Rafferty et al., 2016), and the use of acceleration data from the activPAL™ to generate cut-points for MVPA (Dowd, Harrington, & Donnelly, 2016). The activPAL™ is comparable to the ActiGraph for measuring time spent in MVPA and suggests that activPAL™ may be suitable to use as a single device to measure both sedentary behaviour and MVPA (Lee & Dall, 2019).

The activPAL™ is validated for measuring steps count (Dahlgren et al., 2010): the second-by-second downloadable events file produced from the proprietary algorithm software classifies all steps taken and the duration in which the steps are taken; from this, the cadence can be calculated. The ActiGraph, on the other hand, although has been validated for quantifying time spent in MVPA, the selection of the cut-point used depends on the epoch length and varies from study to study. Also, the activPAL™ does not depend on derived thresholds of counts per minute from different regression equations to measure physical activity as in the case of the ActiGraph. This thesis focuses on the time spent in MVPA and using the events file produced from the activPAL™ proprietary algorithm, the activPAL™ was the device most suited for the quantification of MVPA, using the cadence of stepping periods, during commuting and non-commuting periods.

2.4 Quantifying intensity - MVPA

The intensity of physical activity is an important parameter because it reflects the rate of an activity or energy expenditure (Tudor-Locke et al., 2011). Both global and national physical activity guidelines recommend that activity be either moderate or vigorous (DHSC, 2019). The time spent in moderate- or vigorous-intensity activity can be used to determine whether the study population is meeting recommended physical activity guidelines (DHSC, 2019; Strath et al., 2013); furthermore, physical activity surveillance can help researchers monitor and investigate the dose-relationship of physical activity at different intensities with health-related outcomes (Tudor-Locke et al., 2011). In addition, research has shown that reaching recommended physical activity levels is associated with reduced risk of cardiovascular diseases, diabetes, cancers, and increased risk of premature mortality (Warburton et al., 2006; WHO, 2010; Garber et al., 2011; Lee et al., 2012); improved mental wellbeing (Biddle et al., 2000; Anokye et al., 2012; Cooper & Barton, 2016), and reduced anxiety (Anderson & Shivakumar, 2013). Also, physical activity intensity can help in understanding the dose-response relationships with health outcomes that can be used as a component of health promotional messaging in encouraging physical activity for health (Tudor-Locke et al., 2012).

Physical activity intensity can be estimated based on energy expenditure: accelerometer-based devices can be used to estimate intensity either by METs per minute/hour, counts per minute, or cadence (Strath et al., 2013). The counts per minute are a measure of total physical activity that are produced using proprietary algorithms (ActiLife software) for the ActiGraph accelerometer and can be expressed as the total number of counts for all valid days divided by wear time (Bassett et al., 2015). To identify the physical activity of different intensities, calibration studies were developed to translate acceleration data – activity counts – into specific cut-point thresholds corresponding to the energy expenditure of the given intensity (Section 2.3.5.2) (Freedson et al., 1998; Matthews, 2005). However, counts per minute represent the output from the ActiGraph accelerometer only, and they are dimensionless and arbitrary numbers (Chen & Bassett, 2003; Welk, 2002); they are not comparable since acceleration data are processed differently depending on the proprietary algorithm function (Strath et al., 2013).

Another method of estimating physical activity intensity is by the use of cadence (steps/minute) (Slaght et al., 2017). The cadence of stepping periods has been used to identify the intensity of different levels of activity (Chastin et al., 2009; Dall et al., 2013; Granat et al., 2015; Slaght et al., 2017). Research has suggested that cadence is a more prudent means of estimating MVPA (Chastin et al., 2009; Tudor-Locke et al., 2018) since it emphasizes the speed of the steps taken (Slaght et al., 2017). Cadence can be expressed as the number of steps divided by the time spent walking in that minute multiplied by 60 and this represents the actual rate/speed of stepping (Rafferty et al., 2016).

$$\boldsymbol{Cadence = \frac{Number\ of\ steps}{Duration\ of\ steps\ taken\ in\ that\ period} \times 60}$$

Figure 2.4: Formula for calculating cadence

2.4.1 True Cadence and Step accumulation

The cadence of walking in a free-living environment has often been estimated by measuring the number of steps taken within a period, usually one minute (Tudor-Locke et al., 2011); however, continuous periods of free-living walking activity occur within periods that are less than one minute in healthy individuals (Chastin et al., 2009; Orendurff et al., 2008). Tudor-Locke et al. (2011) used data from the NHANES from 2005-2006 using the ActiGraph accelerometer from a sample of 3744 participants to determine cadence patterns in free-living adults and data were presented as steps taken, at minute-by-minute intervals. The "cadence" presented in these studies was the number of steps taken within a minute, including non-stepping events; but the correct term should be "step accumulation." Step accumulation is not the same thing as cadence; cadence being the actual *rate* at which those steps are taken (Dall et al., 2013).

Cadence has been used interchangeably with step accumulation in several studies and it has been demonstrated that using step accumulation gives a completely, distorted picture of true cadence (Dall et al., 2013). The full characterisation of free-living walking cadence requires a description of the duration of walking events, and the number of steps accumulated within these events (Granat et al., 2015). Derived outputs from the activPAL™ accelerometer-based device can be used to estimate the duration of walking events, number of steps, and cadence of those steps.

2.4.2 Defining MVPA using cadence

There is a consensus in the literature that the minimum level of MVPA, based on three METs threshold for energy expenditure (Section 1.1.1), is a walking cadence of 100 steps/minute (Marshall et al., 2009; Tudor-Locke et al., 2005; Tudor-Locke & Rowe, 2012; Rowe et al., 2011); hence, the cadence threshold of 100 steps/minute was considered as an MVPA threshold in this thesis. However, these studies were completed in a controlled laboratory setting and measured energy expenditure using portable indirect calorimetry while participants walked on a treadmill or over-ground at a range of speeds (Marshall et al., 2009; Tudor-Locke, et al., 2005; Tudor-Locke & Rowe, 2012; Rowe et al., 2011). For each measurement point, participants walked for at least six minutes, and cadence was therefore assessed during continuous periods of stepping. More recently, another laboratory-based study performed five minutes treadmill walking tests separated by two minutes rest period with 76 participants aged between 21- and 40- years old, and measured intensity using portable indirect calorimetry while directly observing cadence. They reported that the optimal cadence threshold for moderate-intensity was 102 steps/minute and 129 steps/minute for vigorous-intensity (Tudor-Locke et al., 2018). Tudor-Locke and colleagues concluded that 100 and 130 steps/minute will be a reasonable estimate for moderate and vigorous intensities. While short walk tests can be used to estimate the cadence of walking periods, free-living walking is a better representation of individual performance levels in the real world (Granat et al., 2015). Another study defined MVPA as 109 steps/minute based on a previous study (Tudor-Locke et al., 2005), which demonstrated in a small treadmill-based study of 25 men reported that walking at 5 METs was at a cadence of 123.6 ±4.9 steps/minute (Chastin et al., 2009; Rafferty et al., 2016). Chastin and colleagues calculated a new threshold value (109 steps/minute) that was three standard deviations below the average walking cadence at this intensity (that is, 123.6 – (4.9*3) = 109), which would include anyone walking within the moderate-intensity range and include 99% of the population assuming that cadence is normally distributed. The

Rafferty's study (Rafferty et al., 2016) defined MVPA as 109 steps/minute and this is the only commuting study that has measured MVPA in terms of cadence. In addition, Dall et al. (2013) reported a mean cadence of 109 steps/minute when walking is continuous and purposeful. Therefore, due to the nature of commuting stepping being purposeful, the 109 steps/minute was considered as a cadence threshold for MVPA. Therefore, in this thesis, the use of more than one MVPA threshold was considered.

The main purpose of selecting more than one MVPA threshold was based on the two established cadence thresholds that have been previously used, that is, 100 steps/minute (Marshall et al., 2009; Tudor-Locke et al., 2005; Tudor-Locke & Rowe, 2012; Rowe et al., 2011) and 109 steps/minute (Chastin et al., 2009; Rafferty et al., 2016). An important aspect of this thesis was to explore the contribution of MVPA during commuting and how MVPA is defined plays a vital role in estimating the time spent in MVPA, its contribution to total physical activity and how it's associated with metabolic markers. Therefore, rather than rely on one definition for MVPA that has been widely used but open to different interpretations, the use of more than one MVPA threshold was explored for comparability between what was most attainable by a healthy adult population and the impact of varying thresholds on the accumulated duration in MVPA. Although there is a consensus in the literature that the definition of MVPA is a walking cadence of 100 steps/minute, the definition of MVPA used by Rafferty et al. (2016)

Additionally, this thesis explored the use of an additional threshold that had not been previously established –76 steps/minute – from a cross-sectional study by Dall and colleagues (Dall et al., 2013). The authors sampled a population of 117 participants aged between 30 to 62 years old in free-living settings using the activPAL™ and reported an average walking cadence of 76 (±6) steps/minute (Dall et al., 2013). Although this threshold is not a reflection of MVPA and it is a measure of central tendency from a cross-sectional study, the activPAL™ software provides an indirect estimate of METs based on steps using an in-built cadence-linear regression equation (PAL Technologies Ltd, 2010) (Figure 2.5) and the equation works out that three METs (moderate intensity) would be approximately 74 steps/minute. Therefore, the threshold of 76 steps/minute was considered as a cadence threshold for MVPA alongside other established thresholds.

$$\boldsymbol{Energy\ Expenditure\ (MET.h) = (1.4\ x\ d) + (4\ - 1.4) x \left(\frac{c}{120}\right) x\ d}$$

$$\boldsymbol{c = cadence\ (steps\ per\ minute),\quad d = activity\ duration\ (hours).}$$

Figure 2.5: Equation for estimating energy expenditure (METs) from the activPAL software

The studies included in this thesis will be defining MVPA as 76, 100, and 109 steps/minute. These different definitions of MVPA are fully explored in Studies Two and Three; however, Study One defines MVPA as 100 steps/minute and only explores the impact of the different definitions of MVPA based on adherence to physical activity guidelines. As a result of the initial exploration carried out in Study One, Study Two and Three fully explore the different definitions of MVPA (76, 100, & 109 steps/minute).

2.5 Quantification of continuous walking in physical activity

2.5.1 Update on the national physical activity guidelines on continuous walking

The updated version of the UK physical activity guidelines published in September 2019 removed the requirement of a minimum 10-minute bout of MVPA from the UK physical activity guidelines, suggesting that MVPA bouts of any duration of physical activity are better than none (DHSC, 2019). The updated guidelines also recommend that setting targets of achieving at least bouts of 10 minutes per activity may be an effective intervention for people with low levels of activity (DHSC, 2019). The United States physical activity guidelines report was recently updated stating that accumulating MVPA at any bout length is essential to all health outcomes (US Department of Health and Health Services, 2018). This statement is supported by a study conducted by Saint-Maurice et al. (2018) that found that the amount of MVPA accumulated in greater bouts of more than 10 minutes did not result in additional risk reduction for mortality.

As a result of this update, the prevalence of people who were meeting the new guidelines increased (Lyden, 2019). This update is quite important as it has been observed in several physical activity studies that continuous walking bout of 10 minutes may not be practical in free-living settings (Chastin et al., 2009). However, in America, as a result of the updated guidelines, a large number of people (8.5x) were meeting up with the 2018 guidelines (Lyden, 2019). Further analysis into volume and accumulation of steps showed that those who met the 2008 guidelines accumulated a high volume of steps through longer, continuous stepping bouts than those who met the 2018 guidelines that had a high volume of steps at bouts <1 minute (Lyden, 2019). There is a need for future research to consider the consequence of the bout length requirement on health outcomes. There is a need for physical activity studies to consider the consequences of the bouts of physical activity with health-related outcomes, that is, how short can continuous walking be to be health-enhancing?

2.5.2 Continuous walking studies

There have been limited studies that have looked at interruptions in continuous walking; however, these studies have assumed what the maximum interruption duration should be, ranging from 6 to 30 seconds (Ayabe et al., 2014; Barry et al., 2015; Harvey et al., 2017), without consideration for the intensity of the walking activity. The intensity of an activity is important because the physical activity guidelines recommend that activity should be either of moderate or vigorous intensity (DHSC, 2019), and cadence has been suggested as a practical way of estimating activity intensities (Tudor-Locke & Rowe, 2012). Furthermore, intensity can help in understanding the dose-response relationships to health outcomes that can be used as a component of a physical activity prescription.

Harvey et al. (2017) found, in a laboratory study using oxygen consumption, that a 10-second break during walking can be considered continuous; however, a break of 50 seconds or more was considered a break in continuous walking because oxygen consumption reduces. In another study, the varying effects of a maximum resting period (between 1-30 seconds) on the volume of walking and compliance to public health recommendations in 97 older adults were assessed (Barry et al., 2015). Ambulatory events were combined with standing events if the duration between two consecutive ambulatory bouts were below or equal to the maximum resting period. The authors concluded by saying increasing the maximum resting period will increase the duration spent walking as well as compliance with physical activity recommendations. This is not a surprising result and provides no physiological basis for the choice of the length of the interruption.

Looking at the impact of continuous walking on health outcomes, Robson and Janssen (2015) found that total MVPA embedded within bouts of light-intensity physical activities (such as standing) are strongly associated with cardiometabolic risk factors and metabolic syndrome: this association was found to be similar in MVPA accumulated in bouts of 10 minutes or more. In addition, some studies have shown that MVPA bouts of activity accumulated in fewer than 10 minutes are associated with cardiometabolic risk factors (Glazer et al., 2013). Robson and Janssen (2015), suggested that combining bouts of MVPA less than 10 minutes with light-intensity physical activity (non-sedentary bouts) is as beneficial as continuous activity of MVPA in 10 minutes or more. As there is currently no standardised method of defining continuous walking (Chastin et al., 2009), a definition of continuous walking is needed for comparison between similar studies in physical activity research. This definition will help to assess compliance to physical activity guidelines as well as translate into policies and practices for public health interventions.

Continuous walking periods of activity can be assessed by using an event-based approach (Granat et al., 2012; Granat, 2015). The event-based approach involves classifying activities as events, which are continuous periods in which an individual spends in a single activity: sitting, standing, or stepping (Granat, 2012). Figure 2.6 shows the primary events that represent the outputs (the postural classification) from the activPAL™ accelerometer: further analysis of stepping using the event file from the activPAL™ can be used to infer the stepping rate or intensity and the stepping bouts (whether it is short, medium, or long). From this kind of approach, further analysis can look at one event (stepping or sitting) in more detail and can be redefined by allowing defined gaps between them to be combined based on a user-defined rule (Granat, 2012). A user-defined rule, in this case, could be that two walking events separated by a standing event would be considered as one continuous walking event if the average cadence of the continuous walking event was above a certain threshold. This method was employed in the Gap analysis study included in this thesis (Section 3.4).

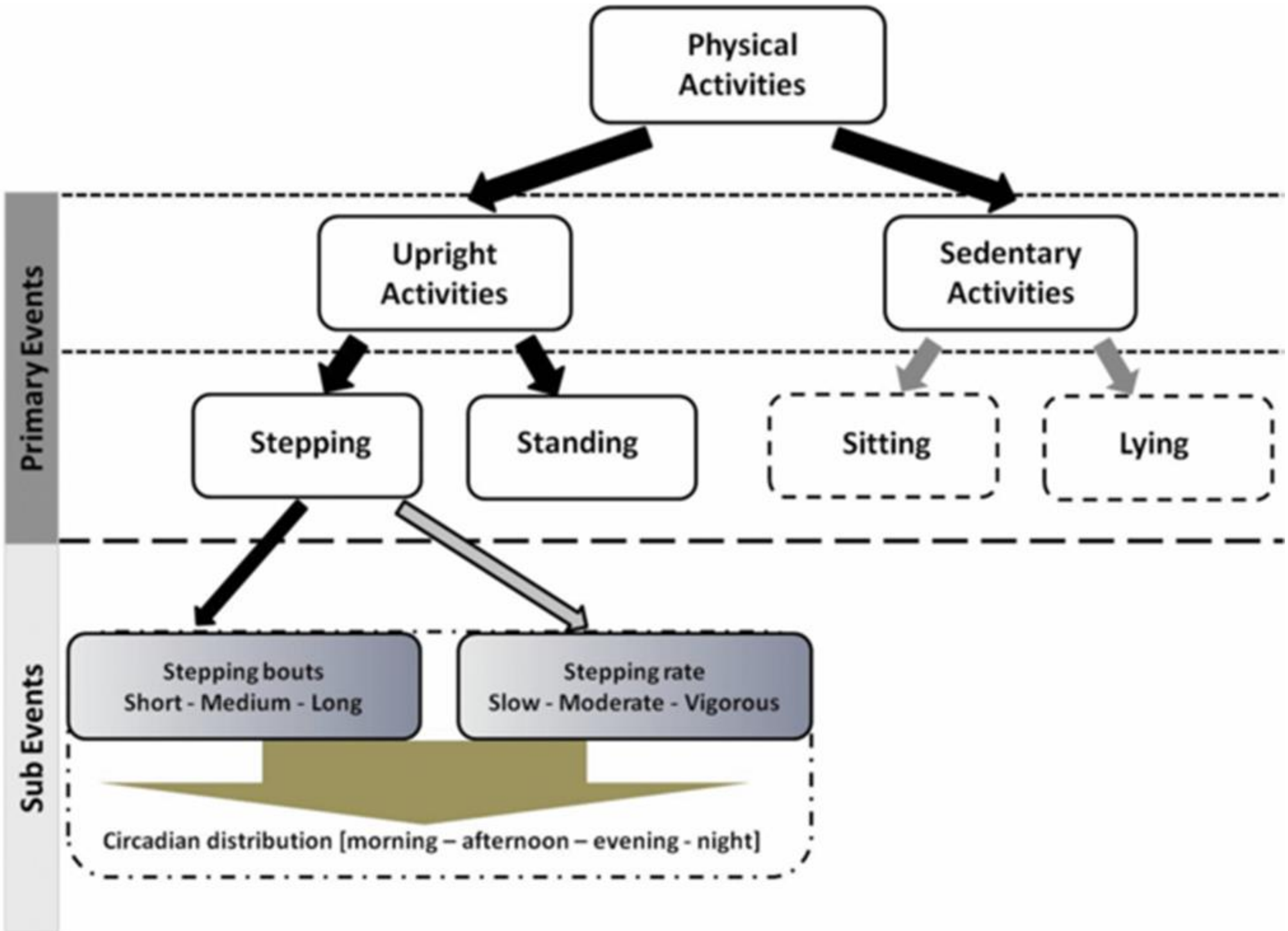

Figure 2.6: Classification of events (Source: Granat, 2012)

2.6 Contribution of Commuting to total physical activity

Active commuting (that is, a commuting journey involving any walking or cycling) may be an effective way of integrating physical activity into everyday routines thereby, increasing total MVPA levels (Audrey et al., 2014). Active commuting has been recognised by the National Institute for Health and Care Excellence (NICE) as a feasible way of incorporating greater levels of physical activity into daily life (NICE, 2012). In addition, active commuting can help to achieve recommended physical activity guidelines (Hamer & Chida, 2008), and can thus appeal to those less likely to participate in more structured activities (Guell et al., 2012). Although having a longer commute may result in greater opportunities for physical activity, lengthy commutes could also result in more time being spent in non-active modes of commuting (Rafferty et al., 2016; King & Jacobson, 2017). The studies discussed in this section have used a combination of both objective and subjective methods in quantifying physical activity during commuting.

A UK cross-sectional study with a larger sample size (n= 103) objectively measured commuting using GPS and a waist-worn ActiGraph GT3X+ accelerometer found that time spent in MVPA was 60% higher in participants who walked to work compared to those who drove to work (78.1 ± 24.9 vs. 49.8 ± 25.2 minutes per day) (Audrey et al., 2014). Similarly, the Commuting and Health study in Cambridge found that participants recorded 55 minutes of objectively measured MVPA per day using a waist-worn ActiGraph GT3X+, with active commuting accounting for 16% (nine minutes) of the daily time spent in MVPA and 30% of the recommended level of MVPA (that is, 150 minutes of MVPA per week) was accrued in commute (Yang et al., 2012). Ferrer et al. (2018) also measured using ActiGraph GT3X+ and GPS receiver (BT Q1000X) reported that only 11% of the study population were compliant with the physical activity guidelines. The authors reported that the people who walk and use public transport were more likely to meet up with physical activity recommendations: 39% of the walking commuters and 16% of the public transport commuters met with the guidelines compared to 5% of car commuters. The device used in studies by Audrey et al. (2014), Ferrer et al. (2018), and Yang et al., (2012) was the ActiGraph GT3X+ accelerometer, and researchers used Freedson cut-point thresholds to categorise activity intensities (Freedson et al., 1998). The cut-points were derived in laboratory conditions, and they have been reported to underestimate vigorous activities when compared to the free-living environment (Basset, 2012); Also, the laboratory-derived cut-points may not apply to different populations, especially when measuring physical behaviour in the free-living environment (Clarke-Cornwell et al., 2016).

Rafferty et al. (2016) used an activPAL™ activity monitor and a GPS receiver to give detailed information on physical activities undertaken in different domains in a small sample of working adults (n=26) employed in sedentary occupations. In the cross-sectional study, the authors considered the intensity of activity and defined MVPA as a period of walking at a cadence of 109 steps/minute (Section 2.4.2). Using data collected from the GPS receiver, the authors categorised activity within six domains: work, commute, work excursion (such as going for lunch during working hours), home, home excursion, and others (for example, going shopping). Figure 2.7 shows the percentage of steps taken in each domain and the percentage of time spent in MVPA in each domain. They found that 32% of total daily steps taken, with an average period of 22 minutes were spent in MVPA: 68% of total MVPA, were accrued during the commute. The study had limitations in that it did not report on modes of commute and there was no information on the bout length of MVPA, which was essential to assessing compliance to 2011 physical activity guidelines (Rafferty et al., 2016). Also, the sample size for Rafferty's study was small, making generalisability to the working population difficult; however, it adds to the literature the importance of commuting contributing to total daily physical activity.

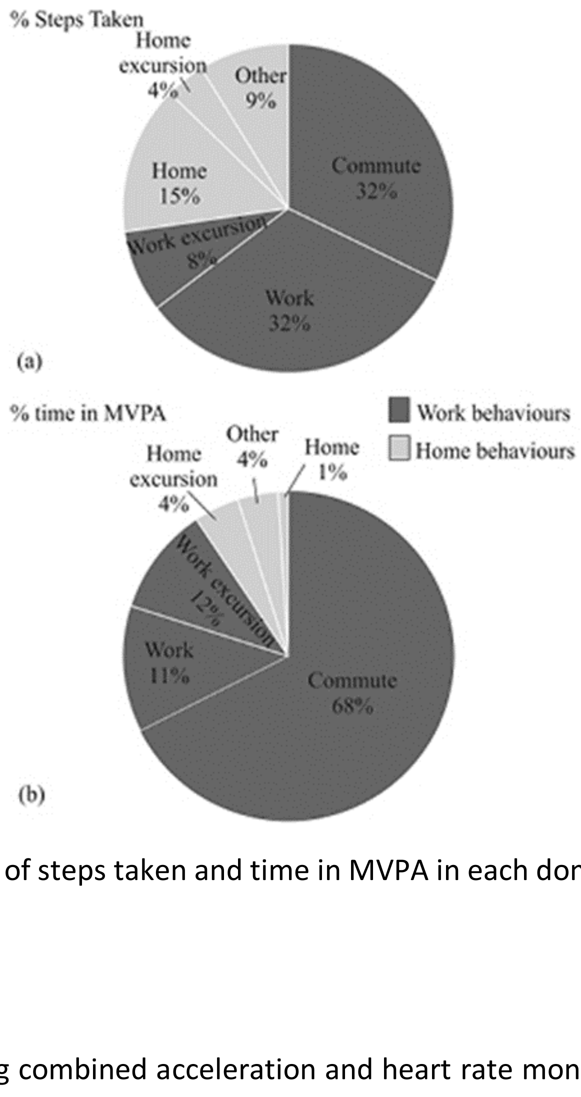

Figure 2.7: Percentages of steps taken and time in MVPA in each domain (Source: Rafferty et al. 2016)

Costa et al. (2015) using combined acceleration and heart rate monitoring (AccHR) and GPS receiver (BT Q1000X) in free-living participants reported that although walking or cycling alone to work involved a greater energy expenditure (that is, MVPA), commute car journeys combined with walking and cycling contribute to the total amount of MVPA accumulated.

Incorporating car journeys with walking or cycling to work accounted for 20% of the time spent in MVPA; meanwhile, for car journeys only, no MVPA accumulated and 59% of the total journey duration was spent sedentary (Costa et al., 2015). This study was robust in the use of the heart rate monitors and the accelerometer-based device and further provides more evidence on the importance of the use of mixed-mode journeys and its contribution to total daily physical activity. However, heart-rate monitors can be affected by non-activity stimuli that can increase heart rate, such as emotional state, temperature change (Strath et al., 2013); also, GPS has a high burden on participants and require technical knowledge on data processing methods.

Several studies have measured active travel to work using self-reported measures, including physical activity questionnaires and online surveys (Chris et al., 2013; Rissel et al., 2014; Sahlqvist et al., 2012). According to Chris et al. (2013), participants were more likely to meet physical activity recommendations if they travelled actively to work: this is consistent with Sahlqvist et al. (2012), who found that 65% of participants that travelled actively accumulated an average of 195 minutes of physical activity per week. These results indicate that commuting can be a major opportunity for increased levels of MVPA in the population. However, in both studies, physical activity was measured by self-report, which could lead to overestimation of the actual events (Chris et al., 2013; Scheers et al., 2012). Although physical activity questionnaires are relatively inexpensive and convenient to use, and usually have a low participant burden (Strath et al., 2013; Welk et al., 2002), they are less robust in measuring light or moderate activity compared to objective measures and can result in under or over-estimation of energy expenditure (Welk, 2002). Therefore, in combination with accelerometers, which are more robust in quantifying MVPA, the use of activity diary was employed in the studies included in this thesis because of its convenience, cost, and low burden on participants.

2.7 Literature review of commuting MVPA and health outcomes

2.7.1 Search Strategy

To achieve the overall aim of investigating the association between time spent in MVPA during commuting and metabolic markers, a systematic literature search was conducted to identify the specific gap and formed the basis of this thesis. A systematic literature search was conducted to identify relevant articles on the key concepts of 'commuting', 'physical activity' and 'metabolic risk factors'. A total of four electronic databases: CINAHL (Cumulative Index to Nursing and Allied Health Literature), MEDLINE (Medical Literature Analysis and Retrieval System Online), PsychINFO, and Web of Science were selected to reflect the breadth of the concepts of 'commuting', 'physical activity' and 'metabolic syndrome': databases were searched from the earliest record to August 2017, and they were updated until September 2021.

To identify studies to be included in the review, detailed search strategies for each of the three concepts (commuting, physical activity, metabolic risk factors) were developed for each database (Appendix 1) and only studies in the English language were included. The records were identified through the database searches and imported into the Endnote citation management database. The duplicates were removed, and the resulting articles were screened. Following a review of titles and abstracts based on key concepts, it was observed from the references of some of the resulting papers that some studies defined commuting as travel to work or transportation. So, these keywords were incorporated under the search strategy to include papers that may have not necessarily used the previously defined keyword of commuting. Also, some useful references were taken from the reference lists of relevant papers.

The remaining papers were screened further by reading the full-text articles according to the following criteria: studies that measured travel to work/ active transport/commuting, health outcomes associated with commuting, and commuting and physical activity/MVPA. All papers included were focused on adults as the sample population. The excluded papers included studies that measured active travel (all travel and not specifying commuting) and some studies where the population were children.

2.8 Commuting and Health Outcomes

The included studies are reviewed under this section, and they have been grouped according to the different health outcomes identified in the literature search. Active commuting has been associated with several health outcomes and they include:

i. Cardiovascular diseases risk and mortality (Celis-Morales et al., 2017; Dinu et al., 2019; Hamer & Chida, 2008; Lerssrimongkol et al., 2016; Panter et al., 2018; Raza et al., 2020)
ii. Metabolic syndrome
    a. Obesity (Flint & Cummins, 2016; Flint et al., 2014; Flint, Webb, & Cummins, 2016; King & Jacobson, 2017; Martin et al., 2015; Mytton et al., 2018; Mytton et al., 2016; Rissel et al., 2014)
    b. Other metabolic risk factors (Byambasukh et al., 2020; Garcia-Hermoso et al., 2018; Gordon-Larsen et al., 2009; Laverty et al., 2013; Lorenzo et al., 2020; Medina et al., 2020; Millett et al., 2013; Sadaragani et al., 2018; Steell et al., 2017; Vaara et al., 2020)

2.8.1 Cardiovascular diseases risk and mortality

Active commuting has been associated with a reduced risk of cardiovascular diseases and mortality (Dinu et al., 2019; Hamer & Chida, 2008; Raza et al., 2020). Dinu et al. (2019) conducted a systematic review with 23 included studies and found that active commuting was associated with a reduction in cardiovascular disease by 9%, and diabetes by 30%. The authors investigated walking and cycling only and found a significant reduction of 24% for all-cause mortality and 25% for cancer mortality among cycling commuters compared to non-active commuters; however, but there were no significant associations reported for walking. The authors reported the lack of consistency in the definition of active commuting among the studies included, while some defined active commuting in terms of time spent walking or cycling, some reported binary responses of ‘yes’ or ‘no’ for active commuting, other reported duration and intensity using estimated METs-hours per week. In addition, all the 23 studies assessed active commuting using self-reported responses which are prone to reporting and social-desirability bias (Bowling, 2014). The confounding variables adjusted for were limited to age, gender, leisure, and occupational physical activity from the included studies: there was no account for other confounding factors such as socio-economic characteristics, nutritional variables, and lifestyle factors like smoking, alcohol consumption, which are important factors that can serve as a potential mediator of the relationship between active commuting and health outcomes (Suyigama et al., 2013). Similarly, a systematic review with a meta-analysis of 173,146 participants from six prospective cohort studies and one case-control study reported that active commuting was associated with an 11% reduced risk of cardiovascular outcomes, especially in women (Hamer & Chida, 2008). However, the study was limited by the different range of cardiovascular endpoints (including hypertension, diabetes, stroke, coronary heart disease, myocardial infarction, and cardiovascular disease): there was no differentiation between walking and cycling, and the included studies did not include mixed-mode journeys.

Another recent systematic review with a meta-analysis of 59 included studies to estimate the risk-reduction of active commuting on various non-communicable diseases (Raza et al., 2020). The minimum amount of 11.25 METs-hours per week was derived from the estimated risk reduction of WHO minimum amount of physical activity developed for health economic assessment tool (Kahlmeier et al., 2017). The authors reported that an 18% risk reduction for myocardial infarction and a 22% reduction for type 2 diabetes for those spending 11.25 MET-hours per week in active commuting compared to spending 0.5 MET-hour per week and 2.2 MET-hour per week respectively. However, after adjustment of BMI, the percentage risk reduction reduces to 11% and 8% for myocardial infarction and type 2 diabetes respectively. All of the studies included in the systematic review were of prospective designs, thereby limiting the bias of reverse causation (Bailey, 2005). All of the included studies measured self-reported physical activity, and this may have resulted in social desirability bias (Bowling, 2014; Petticrew & Roberts, 2003).

A prospective cohort study that used data from a UK Biobank study with 263,540 participants aged 40 to 69 years old across the UK to investigate the association between different types of active commuting and incident cardiovascular disease, cancer, and all-cause mortality (Celis-Morales et al., 2017). Out of the 263,450 participants, 54,378 wore a wrist-worn accelerometer, AX3 (Open Lab, Newcastle University), to quantify physical activity. Mode of commuting was measured using an electronic questionnaire and responses were categorised as: car/motor vehicle, walk, public transport, and cycle. Outcome measures were all-cause cardiovascular diseases, cancer mortality, incident cardiovascular diseases and cancer outcomes (incidence and mortality). The authors found that commuting by cycling and walking was associated with a lower risk of incident CVD (cycling hazard ratio [HR]: 0.54, 95% CI 0.33-0.88, $p>0.001$; walking HR: 0.73, 95% CI 0.54-0.99, $p>0.001$) and CVD mortality (cycling HR: 0.48, 95% CI 0.25-0.92, p>0.001; walking HR: 0.64, 95% CI 0.45-0.91, p>0.001) compared to non-commuting. The study also found that mixed-mode commuting with a cycling component was associated with a lower risk of cancer incidence (HR: 0.64, 95% CI 0.45-0.91, p>0.001), cancer mortality (HR: 0.68, 95% CI 0.57-0.81, p<0.001), and all-cause mortality (HR: 0.76, 95% CI 0.58-1.00, p<0.05) after adjusting for confounding variables. The authors recommended that policies allowing for use of active modes of commute as well as providing easy accessibility to the population may present opportunities for improvement of public health. According to the authors, fitness and objectively measured physical activity were only available for a subset of the sample with active commuting data and in order not to increase the risk of bias in the results for those without objective measures of fitness and physical activity in the other categories; the variables were not included as covariates in the analysis.

Another prospective cohort study that also used data from the UK Biobank study with 358, 799 participants aged 37 to 73 years to investigate the associations between more active patterns of travel relative to exclusive car use and CVD, cancer, and all-cause mortality found similar results to Celis-Morales and colleagues (Panter et al., 2018); however, Panter and colleagues further stratified their participants into regular and non-regular commuters. The sample population was stratified as regular commuters, that is, those that reported being employed and travelled to work at least three times a week and non-regular commuters. Commuting was self-reported, and the responses were grouped as those who reported exclusive car use and those who reported other travel patterns including some walking, cycling, or use of public transport. Regular commuters with more active patterns of travel on the commute had a lower risk of incident CVD (HR 0.89, 95% CI 0.79–1.00) and fatal CVD (HR 0.70, 95% CI 0.51–0.95) and those who were not regular commuters with more active patterns of travel were associated had a lower risk of all-cause mortality (HR 0.92, 95% CI 0.86–0.99). This study used a large population dataset and adjusted for a comprehensive set of potential confounders, ranging from socioeconomic to behavioural characteristics including sleep, diet, and other forms of physical activity; however, the lack of accelerometer-measured physical activity may have led to an overestimation of physical activity accumulated during commuting (Bowling, 2014).

2.8.2 Metabolic Syndrome

Metabolic syndrome, as defined by Diabetes UK, occurs when a range of metabolic risk factors such as obesity and insulin resistance come together (Diabetes.co.uk, 2017). The risk factors are as follows: abdominal obesity, high triglyceride levels, low levels of HDL (high-density lipoprotein)-cholesterol, high blood pressure, insulin resistance, increased risk of developing blood clots, and inflammation of body tissues (NHS, 2016; Diabetes.co.uk, 2017). Having three of these risk factors means metabolic syndrome may be diagnosed in the UK (NHS, 2016; Diabetes.co.uk, 2017); however, there are no uniform criteria for defining metabolic syndrome and various definitions exist (Kassi et al., 2011). Kassi et al. (2011) reviewed the current definitions of metabolic syndrome and recommended that there is a need to develop a unified criterion for defining metabolic syndrome to encourage comparisons of studies and suggested that diagnosis and prevention should focus on established risk factors. Many international organisations and expert groups, such as the WHO, the European Group for the study of Insulin Resistance, the National Cholesterol Education Program Adult Treatment Panel III (NCEP ATP III), the American Association of Clinical Endocrinology, the International Diabetes Federation (IDF), and the American Heart Association/National Heart, Lung, and Blood Institute, have attempted to incorporate all the different parameters used to define metabolic syndrome (Appendix 2) such as insulin resistance, fasting blood glucose, waist circumference, triglycerides, HDL-cholesterol, and Blood pressure. While some of the organisations like NCEP ATP III and American Heart Association recommend any three of the risk factors, others like the IDF recommends abdominal obesity in addition to two more risk factors.

The two most widely used definitions are those of the: NCEP ATP III and IDF, which are focused on waist circumference as opposed to the definitions by AACE, EGIR, and WHO that is focused on insulin resistance (Kassi et al., 2011). The most used definition in commuting studies is the NCEP ATP III definition: according to the NCEP ATP III, the presence of three or more of the following using these cut-off points: waist >102 cm in men, >88 cm in women; triglycerides ≥1.70 mmol/l (150 mg/dL); high-density lipoprotein cholesterol (HDL-C) <1.03 mmol/l (40 mg/dL) in men, <1.29 mmol/l (50 mg/dL) in women; blood pressure ≥130/85 mm Hg and fasting plasma glucose ≥6.11 mmol/l (110 mg/dL) means metabolic syndrome can be diagnosed. However, a major concern with the NCEP ATP III definition is its applicability to different ethnic groups, especially when trying to define obesity thresholds (Kassi et al., 2011). The IDF recognised these problems and proposed a new definition in 2005 with ethnic-specific thresholds (Alberti et al., 2009). Considering the difficulties associated with defining metabolic syndrome, a joint interim statement (consensus definition) highlights the importance of the individual components of metabolic syndrome in risk prediction (Alberti et al., 2009). In the UK, the NCEP ATP III is an acceptable definition for metabolic syndrome (Diabetes.co.uk, 2017).

2.8.2.1 Obesity

A review found that the mode of travel to work had a significant impact on obesity trends (King & Jacobson, 2017). From the reviewed studies, it was found that commuting by public transport might be a potential intervention area for obesity reduction especially among non-active commuters (Reich et al., 2020): public transport can serve as a balance between actively commuting and driving to work (King & Jacobson, 2017). The findings from King and Jacobson (2017) are supported by other studies that have investigated the association between active commuting and BMI (Flint & Cummins, 2016; Flint et al., 2014; Mytton, Panter, & Ogilvie, 2016).

A population-based cross-sectional study examined the association between active commuting (walking and cycling) with objective measures of adiposity (body fat and visceral adipose tissue) in working adults aged 29-65 years in Cambridgeshire, UK (Mytton et al., 2018). The commute mode was assessed using the Recent Physical Activity Questionnaire (RPAQ) with the question "*how do you normally travel to work*?", and physical activity was measured objectively using a single-piece combined heart rate and movement monitor, ActiHeart (Cambridge Neurotechnology Ltd, Cambridge, UK). The authors of this study found that people who lived greater than five miles from work were more likely to be male, use the car for non-commuting journeys, and have a university degree. Those who reported regular cycling had a lower body fat percentage than those who only used car (women, − 1.74%, 95% CI: − 2.27% to − 0.76%; men, − 1.30%, − 2.26% to − 0.33%) while those that walked regularly had no reduction in body fat, after adjusting for potential confounders (age, education, alcohol consumption, smoking status, leisure-time physical activity, usual mode of commute and work type). A strength of this study was the use of both self-reported and objective measures of physical activity and the outcomes, body fat and visceral adipose tissue, which gave a detailed depth of the aim of the study. In addition, the authors did not use BMI as an indicator of obesity, percentage body fat has been reported to be a better indicator of obesity because it is not affected by muscle mass (Bozeman et al., 2012). However, due to the cross-sectional design of this study, causation could not be established between active commuting and adiposity measures because both variables were measured simultaneously; therefore, there is no way to determine if the exposure preceded the outcome or vice versa– reverse causation (e.g., obesity determining active travel may sometimes explain the observed associations).

Another cross-sectional study reported that walking to work was significantly associated with lower BMI in men and women after adjusting for overall physical activity per week, education, income, and nutrition variables (men: -2.47, 95% CI -4.43 to -0.51, women: -2.95, 95% CI -4.91 to -0.99) (Rissel et al., 2014). However, cycling to work was associated with lower BMI in men only (-2.15, 95% CI -4.11 to -0.19), which contrasts with Mytton et al. (2018) who found associations in men and women: this may have been as a result of different measures of adiposity used in both studies (that is, percentage body fat in Mytton et al's. (2018) study and BMI in Rissel et al's. (2010) study). Also, Rissel et al. (2010) reported that walking or cycling did not change significantly among the participants throughout 2005 to 2010. The association between active commuting and BMI cannot be used to determine the temporality of association due to the cross-sectional design of this study. This study used data from the New South Wales Continuous Health Survey, which is a telephone survey of health indicators collected all year round and therefore are not susceptible to weather changes, which is known to affect walking and cycling to work (Rissel et al., 2014). However, the self-reported mode of reporting BMI could result in measurement bias and social desirability bias as those who are overweight are more likely to report a lower BMI (Rissel et al., 2014). The study focused on walking and cycling as the main mode of commute that was reported and therefore did not capture mixed-mode journeys.

A cross-sectional study examining the association of active commuting with cardiovascular risk factors looked at the impact of the mode and duration of commuting in rural and urban areas in India (Millett et al., 2013). The authors reported that cycling to work was more common among rural dwellers (68.3%) while the private vehicle was the most common mode of commute among urban dwellers (44.5%). Commuting by private vehicle, cycling, and public transport was associated with a lower risk of being overweight or obese; however, in adjusted models, associations were attenuated but the significant relationship remained among those who walked to work (adjusted risk ratio [ARR] 0.72; 95% CI 0.58–0.88) and cycled to work (ARR 0.66; 95% CI 0.55–0.77) with a lower risk of being overweight or obese. The factors that were adjusted for were age, sex, tribe[11], the standard of living, occupation, factory location, leisure-time physical activity, fat intake, smoking status, and alcohol intake. Cycling to work was associated with a lower risk of developing hypertension (ARR 0.69; 95% CI 0.54–0.86) and diabetes (ARR 0.60, 95% CI 0.34–1.04) after adjusting for confounding factors. The results strengthen a causal interpretation between these associations; however, as a result of the cross-sectional design, causality cannot be established.

Another cross-sectional study investigated associations between active commuting, body fat and BMI, using data from the UK Household Longitudinal Study (UKHLS), which is a representative sample of 40,000 UK households (Flint et al., 2014). Active commuting was measured from responses to the question: *'How do you usually get to work?'*: participants (n=7,534) reported only their main mode of transport, thereby not capturing mixed-mode journeys. The modes of commute were categorised into private transport, public transport, and active transport (walking or cycling). The outcome measures were BMI and percentage body fat, and they were objectively measured by a trained nurse during a health assessment visit. The authors reported that men who commuted through active (walking or cycling) or public transport modes had lower BMI scores 1.10 (95% CI 0.53 – 1.67) and 0.97 (0.40 – 1.55) than those who used a motorised mode of commute, after controlling for confounding factors (Flint et al., 2014). Similar findings were reported for women as well. Although the obesity measures were objectively-measured, limiting social-desirability bias (Bowling, 2014; Gorber et al., 2007), the limitations of this study include not accounting for mixed-mode journeys and the cross-sectional design, which means causality cannot be established (Bowling, 2014; Petticrew & Roberts, 2003).

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[11] Tribes are identified by the Government of India and is classed based on socio-economic status

Although the study (Flint et al., 2014) was cross-sectional in design and collected self-reported data, the results were consistent with a longitudinal study that measured associations between active commuting and BMI (Mytton et al., 2016). Mytton and colleagues used data from the *Commuting and Health in Cambridge* study, a longitudinal study of commuters in Cambridge, UK, to examine the longitudinal associations of walking and cycling with BMI. The participants (n=809) reported their commute using a seven-day retrospective travel diary at baseline and after-one-year follow up. They found that those who maintained cycling commuting for a year reported a lower BMI (1.14kg/m^2, 95% CI 0.30 – 1.98, n=579) than those who never cycled to work. They also reported that an increase in walking was associated with lower BMI; however, there were no significant relationships between changes in weekly time spent walking or cycling during commute and change in BMI. Similarly, a study by Martin et al. (2014) explored the effects of switching between use of a private car and active transport or public transport for only journeys to and from work using data from the British Household Panel Survey from three timepoint periods: September 2004 to May 2005, September 2005 to May 2006, and September 2006 to March 2007. Participants were classified as having switched from one mode to another if they changed their baseline mode of commute at any point during the data collection period. The participants (n=4,056) aged 18 years and over, reported their usual main mode of commute at the different time points of data collection, and it was categorised as walking, cycling, public transport or private transport. The authors found switching from private transport to active transport or public transport was significantly associated with reduced BMI (self-reported) of −0.32 kg/m^2 (95% CI −0.60 to −0.05; p<0.05) after adjusting for confounders – age, gender, socioeconomic features, and changes in socioeconomic features between the baseline and follow-up time point. Switching from active travel to private transport were significantly associated with an increase in BMI of 0.34kg/m^2 (95% CI 0.05 to 0.64; p<005). The use of large sample size in determining changes in commuter behaviour and BMI over time is a strength of this study; however, the study is limited by not considering mixed-mode journeys, and the outcome measure (BMI) was self-reported, which may have led to an over-estimation of results obtained (Gorber et al., 2007; Mytton et al., 2016).

Another longitudinal study used data from the UK Biobank (a prospective cohort study with 500,000 participants aged 40-69 years that supports the investigation of risk factors for the major diseases of middle- and old-age) (Flint, Webb, & Cummins, 2016) examined the change in the mode of commute and objectively-measured BMI after a median follow-up period of four years and four months. Change in mode of commute was defined by switching to another mode of commuting between baseline and follow-up assessment. They found that those who transitioned from car to active commuting had a decreased BMI of -0.30kg/m^2 (95% CI -0.47 to -0.13; p<0.001) while those who transitioned from active to car mode had an increase in BMI of 0.32kg/m^2 (95% CI 0.13 to 0.50; p=0.008) (Flint et al., 2016). Flint and colleagues did not take mixed-mode journeys into account as participants only reported their main mode of commute. To address the limitation of not accounting for mixed-mode journeys, Flint and Cummins (2016) used cross-sectional UK Biobank data between 2006 to 2010 to examine the relationship between active commuting and objectively measured adiposity outcomes (BMI and percentage body fat). Participants were aged 40 to 69 years (n=156,994) who visited the 22 UK Biobank assessment centres between 2006 to 2010. The modes of commute were classified into seven different categories: car only, car and public transport, public transport only, car and other mixed-modes[12], public transport and active transport (walking and/or cycling), walking only, cycling only or walking and cycling; to capture various commute mode combinations. Compared to car commuters, the mixed and active transport had significantly lower BMI (men: β coefficient −1·00 kg/m^2, 95% CI −1·14 to −0·87, p<0·0001; women: −0·67 kg/m^2, –0·86 to −0·47, p<0·001), and cycling commuters (men: −1·71 kg/m^2, 95% CI −1·86 to −1·56, p<0·001; women: −1·65 kg/m^2, –1·92 to −1·38, p<0·001). Similar results were reported for associations between the mixed public and active commuters and percentage body fat: the cycling commuters had a significantly lower percentage body fat (men: −2·75%. 95% CI −3·03 to −2·48, p<0·001; women: −3·26%, –3·80 to −2·71, p<0·001) compared to the car commuters. The use of both objective measures of adiposity outcomes, BMI and percentage body fat reduced the risk of recall and social desirability bias (Bowling, 2014). The detailed classification of the commute modes allowed for derivation of mixed-mode categories; however, the modes of commute were self-reported, which may lead to a risk of response

[12] A heterogenous category comprising combinations of car

and recall bias (Bowling, 2014). As a result of the cross-sectional design of this study, causation could not be established between active commuting and adiposity measures because both variables were measured simultaneously; therefore, there is no way to determine if the exposure preceded the outcome or vice versa– reverse causation (e.g., obesity determining active travel may sometimes explain the observed associations) (Gorber et al., 2009).

2.8.2.1.1 Summary of Obesity papers

The studies reviewed above show an association between cycling commuting/walking/public transport modes of commute and reduced BMI or risk of obesity. There were a few limitations with the reviewed studies: study design, the imprecise measure of commuting or BMI, and the potential confounding factors. Most of the studies were cross-sectional, making it difficult to ascertain whether active commuting results in a reduced risk of obesity (causation) or that overweight/obese people tend to avoid commuting actively (reverse causation). The issue of the temporality of association from cross-sectional study designs was addressed using longitudinal study designs in establishing causation between active commuting and risk of obesity.

The use of BMI as a measure of adiposity was identified as a weak measure of assessment (Bozeman et al., 2012), and other methods were employed like the use of body fat percentage and visceral adipose tissue. However, some studies assessed obesity using BMI alone and this information was self-reported. In classifying commuting modes, most of the studies classified the modes into private/non-active, walking, cycling, and public transport: mixed-mode journeys, which is typical of a commuter’s journey were excluded from the classification (Flint et al., 2014).

In terms of controlling for confounding factors, modifiable lifestyle factors such as diet and physical activity are some of the predisposing factors to obesity; however, not all the obesity papers included adjusted for these factors. While some studies adjusted for leisure physical activity (Mytton et al., 2018; Rissel et al., 2014), others did not state if the association were independent of other forms of physical activity.

2.8.2.2 Other metabolic risk factors

Gordon-Larsen et al. (2009) used data from the 2005-2006 Coronary Artery Risk Development in Young Adults (CARDIA) in eight states in the US to examine cross-sectional associations of active commuting with cardiovascular risk factors. Active commuting was negatively associated with triglycerides (0.88, 95% CI 0.80 to 0.98), diastolic blood pressure (-1.54, 95% CI -3.07 to -0.01), and fasting insulin (0.84, 95% CI 0.77 to 0.92); and positively associated with HDL (1.05, 95% CI 1.00 to 1.10) in men only; however, these associations were attenuated with BMI adjustment and all outcomes became non-significant. This study was able to access a large amount of data, from a high-quality cohort study with objective physical activity and BMI recordings and a range of anthropometric measurements; however, the cross-sectional sample was based only on 18- to 30-year-olds; therefore, affecting the generalisability of the results (Bowling, 2014). Commuting data were based on any walking and cycling, therefore accounting for all walking, and cycling that takes place during commuting; however, the study did not report any public transport trips or mixed-mode journeys.

Another cross-sectional study examined the socio-demographic characteristics of active commuters and the association between active commuting and cardiovascular risk factors (hypertension, obesity, and diabetes) using data from a nationally representative survey of UK residents, Understanding Society, which is a household survey (administered by National Centre for Social Research): the study samples 40,000 households and includes approximately 1000 participants from the ethnic minority backgrounds (Laverty et al., 2013). The study excluded those aged above 65 years, those without valid travel data, and those that worked from home; resulting in 20,458 participants aged 16 to 65 years who participated in the survey between January 2009 and March 2011. Commuting data were collected using two questions: “And how do you usually get to your place of work? And “About how far, in miles, do you live from your usual place of work?”. Their responses were categorised into inactive, public transport, cycling, and walking: participants who walked or cycled were further classified into whether their commute to work was up to or greater than two miles one way. The authors found that women were more likely to use public transport or walk compared to men (adjusted odds ratio: aOR 1.22, 95% CI 1.11–1.35) after adjusting for age, gender, ethnicity, education level, area of residence[13], social class based on job type[14]. Participants aged 16 to 29 years were more likely to use public transport and those aged 50 to 65 years were less likely to cycle. Using public transport, walking, or cycling to work was associated with a lower likelihood of being obese (aOR 0.89, 95% CI 0.78–1.03 for public transport; aOR 0.80, 95% CI 0.70–0.91 for walking; aOR 0.69, 95% CI 0.54–0.88 for cycling) compared to private transport. Walking and cycling were associated with a reduced risk of diabetes (aOR 0.60, 95% CI 0.43–0.83 for walking; aOR 0.76, 95% CI 0.56–1.01 for cycling), and walking was associated with a lower risk of self-reported hypertension compared to private transport (aOR 0.83, 95% CI 0.71–0.97). In addition, those who actively commuted to work (by walking or cycling) for greater than or equal to two miles were less likely to have hypertension (aOR: 0.60, 95% CI 0.37–0.99) and a lower BMI (aOR: -1.25, 95% CI -1.76–0.71) but not significantly associated with type 2 diabetes (aOR: 0.33, 95% CI 0.10–1.05). Although the study by Laverty et al. (2013) used data from a representative data set in the UK, the study design was cross-sectional and causality could not be established. Reverse causality cannot be ruled out, that is, if the outcome is predicting the exposure and vice versa (Bowling, 2014). The exposure and outcomes were based on self-report and may have been underestimated the true association between active commuting and the risk factors (Gorber et al., 2009). In addition, other factors such as total physical activity or physical activity carried out outside of commuting and diet, which are potential mediators of the association between active commuting and cardiovascular risk factors were not controlled for (Suyigama et al., 2013)

A cross-sectional study used data from the Chilean National Health Survey (CNHS) from 2009 to 2010 with 2,864 participants to investigate the health benefits of active commuting with metabolic syndrome (Sadarangani et al., 2018). The CNHS is a large nationally representative household survey of 5434 participants aged 15 years and above that collects data on health risk factors and dietary status every six years. Physical activity was measured using the Global Physical Activity Questionnaire (GPAQ) and interviewers obtained demographic information.

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[13] Area of residence was based on regional classifications into London, South England (East and West), North England (East, West, and Yorkshire and the Humber), Central England (The Midlands and the East of England), Wales, Scotland, and Northern Ireland

[14] Social class was based on National Statistics Socio-Economic Classification [NS-SEC] in three groups: professional or managerial, intermediate, and routine.

The mode of commuting was collected using the GPAQ under the commuting domain. The trained nurses collected the metabolic outcomes and metabolic syndrome was defined according to the NCEP ATP III definition. They reported that active travel was associated with lower odds of metabolic syndrome (OR 0.72; 95%CI 0.61–0.86), triglycerides (OR 0.77; 95% CI 0.64–0.92) and abdominal obesity (OR 0.82; 95% CI 0.69–0.97) after controlling for socio-demographics and other types of physical activity. Furthermore, Steell et al. (2017) also used data from the CNHS with a larger sample size (n=5155) to investigate the associations with time spent in active commuting with metabolic markers. time spent in active commuting was categorised as 0 min, >30 minutes per day, 30-60 minutes per day, and >60 minutes per day. The authors found that those who actively commuted for up to 30 minutes per day had lower BMI and waist circumference (-0.56 kg/m^2 and -1.12 cm) compared to non-active commuters. Much larger differences were observed in those accumulating 30-60 minutes per day, and >60 minutes per day for waist circumference (-1.90 cm and -2.23 cm), fasting glucose concentration (-0.12m/mol and -0.22 m/mol), and systolic blood pressure (-2.72mmHg and -3.80 mmHg) compared to non-active commuters. Increasing time spent in active commuting from 30 minutes to ≥60 minutes per day was associated with lower odds of obesity (0.90; 95% CI: 0.84–0.96, p<0.001), type 2 diabetes (odds ratio, OR: 0.81; 95% CI: 0.75-0.88, p <0.001), and metabolic syndrome (OR: 0.86; 95% CI: 0.80-0.92, p <0.001) compared to those who reported not commuting actively, independent of potential confounders – smoking, leisure-time physical activity, diet, BMI (when fasting glucose was the outcome), sedentary behaviour, and sociodemographic characteristics (Steell et al., 2017). There were no significant differences between the time spent in active commuting and triglycerides, HDL-cholesterol, total cholesterol, and diastolic blood pressure. Although both studies used a representative adult sample, there were some limitations, including a lack of an objective measure of physical activity, which can result in over-estimation of the amount of time spent in each domain (Scheers et al., 2012), no differentiation of modes of travel, and the cross-sectional study design that will not allow for causality to be inferred (Lucas & McMichael, 2005). In addition, there was a misclassification error in both studies with respect to how travel was classified using the GPAQ, as travel to and from places were included as commuting, while commuting alone (i.e., to and from work) was not included as a travel option in the GPAQ (Sadarangani et al., 2018; Steel et al., 2017).

Byambasukh et al. (2020) explored the association between all domains of physical activity, including commuting and blood pressure using a population-based, prospective cohort of over 167,000 people living in the Netherlands – Lifelines cohort. The sample population was a total of 125, 402, excluding participants with a history of cardiovascular diseases, missing blood pressure data, and pregnant women. The domains of physical activity were measured using the Short Questionnaire to assess Health enhancing physical activity (SQUASH) and blood pressure was measured by trained personnel using three out of 10 measurements: the use of hypertensive medications was also reported, and hypertension was defined as ≥140/90 mmHg. Physical activity intensity level was defined based on METs as light (<4 MET). moderate (4 to <6.5 MET), and vigorous (≥6.5 MET) intensity. Byambasukh and colleagues reported that combining commuting and leisure time in MVPA was associated with lower systolic blood pressure in a dose-response manner (low: −1.64 (−2.03 to −1.24); middle: −2.29 (−2.68 to −1.90), and high: −2.90 (−3.29 to −2.50) mm Hg) and diastolic blood pressure compared to no MVPA after adjusting for age, sex, education, smoking, and alcohol use. The use of a representative data set for the people living in the North of the Netherlands limits the risk of selection bias and the results can be generalised to the resident of the North of the Netherlands. However, the use of a self-reported questionnaire may result in over-reporting of physical activities and under-reporting of sedentary behaviour (Bailey, 2005; Bowling, 2014; Setia, 2016).

Contrary to findings from Steel et al. (2017) and Sadarangani et al. (2017), a cross-sectional study among Colombian university students examined the relationship between walking and metabolic risk factors and found significant associations in men only (Garcia-Hermoso et al., 2018). Anthropometric and metabolic measures were measured objectively by trained researchers. The mode of commuting was assessed using a questionnaire validated in a Spanish population (http://profith.ugr.es/paco) (Herrador-Colmenero et al., 2014). Active commuting was classified as frequent walkers to campus and non-active commuting was classed as an infrequent walker to campus, that is, using other modes of commute. Only 3% of the 784 university students frequently walked to the university and the highest distance travelled was less than 2km. There were significant differences between the active and non-active commuters in waist circumference (p=0.004) and triglyceride levels (p=0.003). Further analysis showed that the only male active commuters had lower odds of having obesity (OR:

0.45, 95% CI 0.25-0.93, p=0.031), hypertension (OR: 0.26, 95% CI 0.13-0.55, p<0.001), and low HDL-cholesterol (OR: 0.29, 95% CI 0.14-0.59, p=0.001), after adjusting for age, BMI, physical activity, alcohol, tobacco, diet, and distance. Although a significant relationship was found with some metabolic risk factors, the cross-sectional design of the study cannot allow for causal relationships to be drawn (Bailey, 2005; Bowling, 2014). Also, the use of a self-reported method could have introduced reporting bias, resulting in over-and under-estimation of physical activity (Bowling, 2014; Setia, 2016). The study was limited to exploring walking alone in university students; hence, this could be a reason for the disparity in results found by Garcia-Hermoso and colleagues to the other two studies (Steell et al., 2017 and Sadarangani et al., 2017). In addition, the study did not capture other modes of commuting or mixed-mode journeys; therefore, the results are not comparable with other studies that may have measured other modes of commute.

In another cross-sectional study, using data from a longitudinal, randomised controlled trial conducted in Houston and Austin, Texas between 2006 to 2008, 327 women of ethnic minority groups were sampled to explore the associations between active transportation and metabolic risk factors (Lorenzo, Szeszulski, Todd, Mama, & Lee, 2020). Active transport included all journeys, including commuting, and it was measured using the IPAQ, while physical activity was measured using the ActiGraph GT1M device. Metabolic risk factors were objectively measured as part of baseline assessments in the survey. The authors reported that active transport was not significantly associated with any metabolic risk factors, apart from systolic blood pressure for all participants: the time spent in MVPA was negatively associated with diastolic blood pressure, and BMI in African American women, and body fat in Hispanic and Latina women. These results point out the variation in ethnicity in the associations of active transportation and metabolic risk factors. This study did not look primarily at active commuting but into active transportation in general; and although the sample population was from a larger survey, the study design was cross-sectional, therefore, temporal associations cannot be inferred. In addition, only time spent in MVPA was associated with lower diastolic blood pressure, BMI, and body fat as the authors did not report the intensity of the activity reported during active transportation, which may have led to the non-significant associations with metabolic risk factors. This shows that the intensity of physical activity undertaken is important when measuring active commuting (Lorenzo et al., 2020). The authors recommended that future studies should examine the associations between the dose-response relation between active transport with respect to MVPA and metabolic risk factors.

2.8.2.2.1 Summary of metabolic risk factors

There have been studies that have investigated the association between active commuting, in terms of modes of commute, with obesity, body fat percentage, BMI and cardiovascular risk factors (Flint & Cummins, 2016; Flint et al., 2014; Lerssrimongkol et al., 2016; Mytton et al., 2016); however, there are limited numbers of studies that have reported the metabolic benefits of active commuting. In addition, there is no consistency in the results from previous studies on the association between active commuting and metabolic risk factors (Steell et al., 2017). These differences among studies may be due to measurement error as many studies have employed the use of self-reported questionnaires to quantify commuting MVPA (Strath et al., 2013). Few studies have employed the use of objective measures, such as accelerometers to measure physical activity; however, the output from the accelerometers varies depending on the device used and proprietary algorithm in translating the raw data into meaningful outcomes (Iveson et al., 2021). Therefore, the gaps identified from these previous studies are:

- Self-reported measures of reporting commuting physical activity
- The definition of MVPA vary from study to study depending on the measuring instrument
- Limited studies exploring the time spent in commuting (dose-response) and health-related outcomes
- Limited studies exploring the use of more than one mode of commute, mixed-mode.

2.8.3 Summary on the role of commuting on health outcomes

There have been significant effects of commuting on health outcomes such as body fat, cardiovascular risk, obesity, and all-cause mortality; however, the results are not consistent and comparable between studies due to differences in the methods used. There is limited evidence on the role of active commuting and metabolic syndrome: Kassi et al. (2011) suggested that pending the development of a unified criterion for metabolic syndrome, the focus should be on established risk factors of metabolic syndrome in the diagnosis and prevention.

These health benefits demonstrate the potential importance of commuting and therefore strengthen the need for further investigation. However, most studies have relied on self-reported methods of measuring physical activity and commuting, with the focus of these studies on walking, cycling, and public transport or car, and the health outcomes. This has resulted in not capturing mixed-mode journeys, which is a major limitation in active commuting and health studies. Studies that have captured mixed-mode journeys, such as, Celis-Morales et al. (2017) have found beneficial associations with cardiovascular risk. Mixed-mode journeys are heterogeneous in context and will involve elements of walking or cycling and public transport or driving (Shannon et al., 2006). There is a need to understand the contribution of these individual modes of commute and their impact on health to inform and develop evidence-based interventions and policies.

2.9 Chapter Summary

Commuting has been associated with several health benefits including a reduction in BMI, and a reduced risk of cardiovascular risk factors. Even though some factors such as the mode of commute and other modifiable lifestyle factors can mediate this association, all these health benefits are independent of other forms of physical activity.

2.9.1 Why examine commuting physical activity?

Different methods have been employed in measuring physical activity such as subjective measures; however, there are limitations associated with this method of collection: these include recall bias, overestimation of physical activities, and underestimation of sedentary activities (Bailey, 2005; Bowling, 2014). Objective measures have been used in measuring physical activities as well; however, the estimation of MVPA has been defined based on the output from objective devices, which varies from device to device. Cadence has been suggested as a practical measure of estimating the intensity of activities; however, only one commuting study has reported MVPA in terms of cadence (Rafferty et al., 2016). Also, many studies have focused on the volume of the activity accumulated and failed to consider the length of bouts in which these activities occurred as recommended by the physical activity guidelines (DHSC, 2011).

Active commuting has been recognised as a feasible way of incorporating physical activity into a daily routine (NICE, 2012), and some studies have found associations between commuting actively and an increase in overall physical activity achieved (Audrey et al., 2014; Sahlqvist et al., 2014; Yang et al., 2014). Studies have shown that depending on the mode of commute, there are health benefits to commuting; however, many studies have focused on measuring commuting by self-reported methods (Audrey et al., 2014). The mode of commuting has been classified majorly as active and passive; furthermore, some studies have shown that commuting can be much more complex and can comprise more than one mode. Most commuting studies have focused on classifying active commuting as walking and cycling, and there is limited evidence indicating the role of mixed-mode commuting.

Commuting is a non-discretionary activity that is resistant to change because it is an everyday activity that is performed regularly and repetitively, at specific times (Jones & Ogilvie, 2012). In addition, commuting is measured in terms of duration and modes; therefore, it is important to investigate the importance of time spent in commuting at MVPA intensity and how it is associated with health-related outcomes. Another reason why time in MVPA during commuting was chosen as the exposure variable was to include the time spent cycling since it is an activity that is categorised as moderate-to-vigorous intensity (DHSC, 2019) and contributes to the total time spent in MVPA. The focus of the thesis was to investigate the contribution of the time spent in MVPA during commuting to total daily physical activity and whether there is an association with individual risk factors of metabolic syndrome. In terms of compliance with physical activity guidelines, the impact of the removal of bout lengths for continuous walking from the physical activity guidelines was explored.

2.9.2 Why measure metabolic markers?

There is a fast-emerging literature base that has found a relationship between active commuting and some health-related outcomes, such as BMI, percentage body fat. However, there is limited evidence investigating the link between commuting physical activity and metabolic risk factors, such as blood glucose, HDL-cholesterol, total cholesterol, and triglycerides; these risk factors are important pre-cursors to cardiovascular diseases and when clustered, can cause metabolic syndrome. Metabolic syndrome is a subject area of great importance to public health since metabolic syndrome is a cluster of seriously recognised risk factors associated with increased risk of stroke and cardiovascular diseases (Alberti et al., 2009). Previous studies have shown that total physical activity has beneficial effects on metabolic risk factors (Scheers et al., 2013; Glazer et al., 2013; Knaeps et al., 2016); however, the precise relationship between commute MVPA and the individual risk factors of metabolic syndrome is unknown. Although there have been previous studies that have investigated the association between commute MVPA and metabolic risk factors, these studies have mixed findings, with some reporting positive associations (Steell et al., 2017), negative associations (Garcia-Hermoso et al., 2018), and no significant findings (Lorenzo et al., 2020).

Previous commuting studies have either reported walking and cycling only or measured either walking or cycling, leaving out the remaining modes of commuting. Some studies have measured MVPA using self-report methods only or used objective instruments; however, the type and model of the accelerometer-based device differs from study to study. There is a need to investigate if there is an association between time in MVPA accumulated during commute and metabolic risk factors because metabolic syndrome affects one in four adults in the UK. Although some of these risk factors can be hereditary (non-modifiable factors), they can also be present because of modifiable risk factors such as lifestyle factors. Further work is needed to explore commuting MVPA to help inform public health policies and messages, and it is hoped that the work in this thesis can contribute to future recommendations of increasing active commuting in reducing the risk of detrimental health in the working population.

Furthermore, the exposure variable that has been frequently measured in previous commuting studies has been the effect of the modes of commute on various health-related outcomes: the time spent commuting at MVPA has not been extensively investigated. Steell et al. (2017) reported on the dose-response relationship of commuting and metabolic risk factors; however, the time in MVPA was based on self-reported measures. The health-enhancing benefits associated with moderate to vigorous intensity has been extensively evidenced in literature (Section 1.2) (Strath et al., 2013, Warburton et al., 2006).

2.10 Aim of thesis

The overarching aim of this thesis was to explore the contribution of objectively measured MVPA during commuting towards total MVPA and its association to metabolic markers.

There are three studies included in this thesis: Study One and Study Two have the same methods and study population but different aims and objectives. Study One focused on determining the contribution of time spent in MVPA during commuting to total daily MVPA. In addition, the question of how to define continuous walking and interruptions between continuous walking arose: this was because of the low compliance with physical activity guidelines observed among participants when the minimum bout lengths were considered. Therefore, Study Two sought to address the question of defining continuous walking events using an event-based approach. Study Three combined both the methods from Study One and Two to investigate the association between commuting time in MVPA before and after grouping with metabolic markers.

The aims and objectives of these studies are:

2.10.1 Study One: (Commuting and MVPA study)[15]

AIM: To objectively determine the contribution of MVPA during commuting to total MVPA, using cadence to define MVPA, and to explore how minimum walking bout length affects adherence to physical activity guidelines.

The objectives are:

1. To objectively quantify MVPA during commuting using the definition of MVPA as a cadence of 100 steps/minute.
2. To determine the difference between the different modes of commute and time spent in MVPA during commuting.
3. To determine the level of compliance to physical activity guidelines by examining the volume of MVPA and length of walking bouts accumulated.

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[15] Study One and Two's data were collected before the UK physical guidelines were updated; however, the study still looks at the impact of no restriction on bout length on compliance to physical activity (2019 update). The data was collected between February and March of 2017.

2.10.2 Study Two (Gap analysis study)

AIM: To use an event-based approach to define continuous walking events, by combining walking events with short interruptions between them based on an average cadence threshold.

The objectives are:

4. To combine walking events short interruptions between to form a new continuous walking event called a "grouped event."
5. To examine how grouping walking events changes total time walking and total time in MVPA
6. To ascertain whether combining walking events with short interruptions between them impacts compliance to physical activity guidelines.

2.10.3 Study Three (The association between commuting moderate-to-vigorous physical activity and metabolic markers)[16]

AIM: To investigate the association between MVPA during commuting physical activity and metabolic markers.

The objectives are:

7. To determine the difference between the different modes of commute and time spent in MVPA during commuting and non-commuting periods.
8. To objectively quantify MVPA, using different cadence thresholds for MVPA, for both commuting and non-commuting stepping.
9. To explore the patterns of commuting and non-commuting stepping at different lengths of walking bouts, before and after grouping walking events.
10. To determine the compliance to the 2011 and 2019 UK physical activity guidelines for all participants before and after grouping walking events.
11. To investigate associations between commuting time in MVPA (before and after grouping walking events) and metabolic markers.

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[16] Study Three's data were collected (July to November 2019) during the 2019 update for the UK physical activity guidelines: therefore, the analysis features both the 2011 and the 2019 UK physical activity guidelines.

Chapter 3: Methodology I – Methods for Study One and Two

Chapter	Summary of each chapter
1- Introduction	A background to physical activity, the role of commuting to contributing to physical activity, an overview of methods used in measuring commuting physical activity, and its association with health outcomes.
2- Literature review	A critical review and discussion of the literature surrounding measuring commuting MVPA, and its association to various health outcomes, especially metabolic risk factors
3- Methodology I – Methods for Study One and Two	Describes the methods for Study One:(*Commuting and MVPA)*; and Study Two: (*Gap analysis*) **Aim of Commuting and MVPA study**: To objectively determine the contribution of MVPA during commuting to total MVPA, using cadence to define MVPA, and explore how minimum walking bout length affects adherence to physical activity guidelines. **Aim of Gap analysis study**: To use an event-based approach to define continuous walking events, by combining walking events with short interruptions based on an average cadence threshold.
4- Results I – Results for Study One and Two	Presents the results for objectives one to six: 1. To objectively quantify MVPA during commuting using the definition of cadence. 2. To determine the difference between modes of commute and time spent in MVPA during commuting. 3. To determine the level of compliance to physical activity guidelines by examining the volume of MVPA and length of walking bouts accumulated. 4. To combine short interruptions between walking events to form a new continuous walking event called "grouped event" 5. To examine how grouping walking events changes total time walking and total time in MVPA 6. To ascertain whether combining walking events with short interruptions between them impacts compliance to physical activity guidelines.
5- Methodology II – Methods for Study Three	Describes the methods used in Study Three to address objectives seven to eleven **Aim**: To investigate the association between MVPA during commuting physical activity and metabolic markers.
6- Results II – Results for Study Three	Presents the results for objectives seven to eleven: 7. To determine the difference between the different modes of commute and time spent in MVPA during commuting and non-commuting periods. 8. To objectively quantify MVPA, using different cadence thresholds for MVPA, for both commute and non-commute stepping. 9. To explore the patterns of commute and non-commute stepping at different lengths of walking bouts, before and after grouping walking events. 10. To determine the compliance to the 2011 and 2019 UK physical activity guidelines for all participants before and after grouping walking events. 11. To investigate associations between commute time in MVPA (before and after grouping walking events) and metabolic markers.
7- Discussion	This chapter summarises the findings from Study One to Three, highlights their strengths and limitations within this thesis; Reflection on the impact of COVID-19 on commuting physical activity.
8- Conclusion	This chapter gives a concluding summary of the thesis and implications for policy and future research.

3.0 Chapter Overview

This chapter describes the study design, the data collection process, and the data analysis methods for Study One and Study Two as both studies had the same recruitment and study population. Study One aimed to investigate the contribution of MVPA during commuting to total daily MVPA using walking cadence. Objectives one to three were used to achieve this aim:

1. To objectively quantify MVPA during commuting using the definition of MVPA as a cadence of 100 steps/minute.
2. To determine the difference between the different modes of commute and time spent in MVPA during commuting.
3. To determine the level of compliance to physical activity guidelines by examining the volume of MVPA and length of walking bouts accumulated.

Study Two focused on defining and combining short interruptions between walking events using a novel approach based on the average cadence threshold. Objectives four to six were used to achieve this aim:

4. To combine walking events short interruptions between to form a new continuous walking event called a "grouped event."
5. To examine how grouping walking events changes total time walking and total time in MVPA
6. To ascertain whether combining walking events with short interruptions between them impacts compliance to physical activity guidelines.

In this thesis, Study One will be referred to as 'Commuting and MVPA study' and Study Two will be referred to as 'Gap analysis study'. The first section (Section 3.1) of this chapter describes the rationale for Study One. The second section (Section 3.2) describes the general study design, recruitment of participants and data collection process for Study One. The third section (Section 3.3) will focus on the data processing methods, including the data cleaning and reduction process for Study One – Commuting and MVPA study. Results from the Commuting and MVPA study have been published in the Journal of Physical Behaviour Measurement (JMPB) and is reproduced in this thesis with permission from the journal (Appendix 3); however, the methods used in this study are described in more detail in Sections 3.2 and 3.3. The rationale for Study Two is described in Section 3.4. The final section in this chapter (Section 3.5) will describe the data processing methods, with respect to the cleaning, reduction, and variables measured for Study Two – Gap analysis study.

3.1 Rationale for Study One: Commuting and MVPA study

3.1.1 Role of commuting on physical activity and health

The prevalence of physical inactivity has substantially increased globally, with physical inactivity being one of the leading risk factors responsible for non-communicable diseases and deaths worldwide (WHO, 2020). Increasing technological advancement, labour-saving devices at work and home, and increased use of cars are some of the factors responsible for the physical inactivity pandemic. Active commuting has been recognised as a feasible way of increasing levels of physical activity in daily life (NICE, 2012). Active commuting has been associated with a number of health-related outcomes (Section 2.8). Travelling by public transport might not involve the same degree or intensity of physical activity as commuting by walking and cycling only; however, there is evidence showing that travelling by public transport contributes to obesity reduction (Flint et al., 2014; King & Jacobson, 2017). There is limited evidence to show the impact of mixed-mode journeys and the role of using public transport as an active mode of commuting (Flint et al., 2014).

3.1.2 Measuring commuting physical activity

The variables that have been used to measure commuting using an objective device have differed from study to study, including, the duration of time spent in commuting, the mode of commute, and some have considered the intensity of the physical activity during commuting. However, due to differences in the objective device, reproducibility can be difficult. To quantify MVPA accurately, cadence – which has been identified as a preferred method of estimating intensity – was chosen as the preferred method in Study One. Only one previous study on commuting has used cadence to quantify MVPA in commuting (Rafferty et al., 2016); however, this study did not consider the modes of commute and the length of stepping bouts. Previous studies on commuting have not captured all the elements listed in the 2011 UK physical activity guidelines, particularly with regards to the length of the walking bouts in estimating MVPA. In the 2003-2004 NHANES study, Troiano et al. (2008) used the ActiGraph accelerometer cut-point thresholds for physical activity intensities, and compared total accumulated MVPA, irrespective of bout length, to MVPA calculated using modified 10-minute bouts (where interruptions of two minutes below the threshold was allowed). Although this study looked at total MVPA and did not consider commuting time, the authors found that when bout length was taken into consideration, adherence to physical activity recommendations in adults was less than 5%. In addition, Chastin et al. (2009), showed that the compliance to physical activity guidelines in a group of 78 postal workers decreased from eight participants to one participant when a minimum stepping bout length of 10 minutes was used. With the update to the physical activity guidelines in 2019, it is important to understand the consequence of removing the bout length requirement in terms of compliance and in relation to health-related outcomes (Lyden, 2019). This study aimed to objectively determine the contribution of MVPA during commuting to total MVPA, using cadence to define MVPA. A secondary aim was to explore how the length of walking bouts affected adherence to physical activity guidelines.

3.2 Overall methods for Study One and Study Two

3.2.1 Study design

The research design was a cross-sectional study, which is observational in design (Mann, 2003; Setia, 2016). Cross-sectional studies are useful in investigating the associations between exposure to risk factors and the outcome of interest (Bailey, 2005; Bowling, 2014). This information (exposure and outcome) is collected simultaneously from the study participants. Cross-sectional studies can be carried out over a short period, can be easy to conduct, and are usually collected by conducting surveys. Cross-sectional studies can be used to study the prevalence of a disease in a selected population, which is called a descriptive study; or can be used to investigate associations between risk factors and diseases, which is called an analytical study (Bailey, 2005).

Some of the limitations of cross-sectional studies include recall bias[17], selection bias[18], and the suitability of not being able to measure acute and episodic health outcomes, occurring for a short duration (Bailey, 2005; Tripepi et al., 2010; Setia, 2016). One main limitation of this study design is the measurement of the exposure and the outcome of interest at the same time, which means that the investigator is not able to determine if the exposure precedes the outcome or vice versa; therefore, it is not possible to show causality (Bowling, 2014). The studies presented in this thesis are cross-sectional studies because the data were collected at a single point in time and as a result, causality cannot be established between the exposure (commuting time in MVPA and the outcome (metabolic risk factors). Despite this limitation, this study design is suitable for generating research hypotheses and in the surveillance of health outcomes that can be applied to more rigorous studies (cohort or longitudinal studies) that can establish causality (Bailey, 2005; Setia, 2016). Therefore, as a result of the study design, the results from the studies presented in this thesis can be used to inform studies with robust designs in establishing causality between commuting MVPA and metabolic markers: this is because this thesis considers other aspects of commuting previous cross-sectional studies and longitudinal studies have not been previously explored.

3.2.2 Study Population and Recruitment Strategy

A convenience sample was used: this sampling method is formed by selecting individuals that are easy to recruit, easy to monitor and follow up, and ensures that individuals have similar characteristics (Offredy & Vickers, 2009). Participants were office-based workers at the University of Salford, aged 18 years and above, with no mobility problems, and travelled to work on at least three days a week. Participants were recruited as part of the research-informed teaching developed by lecturers in the Exercise, Physical Activity and Health programme at the University of Salford.

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[17]Recall Bias is an error in recalling past events. It occurs when survey questions involve recalling past events that may result in difference in response between those with and without the outcome of interest. For example, a person who is aware of exposure to a risk factor and is ill as a result will most likely recall events differently to a person that may have been exposed but will not remember due to them not having the illness.

[18] Selection bias occurs when participants may take part in a study based on their own health interest or comes from any error in selecting the study participants. It can be a non-response bias (where non-participation is related to the exposure and outcome being investigated), the incidence-prevalence bias, the loss-to-follow-up bias, and the confounding by indication bias, the volunteer bias

The research-informed teaching was developed based on the intention of collecting primary data to capture the movement patterns and physical activity behaviour of university workers in free-living and work-based environments. This curriculum involved the participation of all the second-year undergraduate students taking the Level 5 module – ***Exercise training contexts*** on the Exercise, Physical Activity, and Health undergraduate programme. The students monitored their physical activity behaviour to allow for familiarisation with the data collection instruments and gain an understanding of the processes involved before recruiting participants[19]. After the students understood the activity monitoring procedure, they were allocated into groups for the data collection process that involved recruiting and collecting physical activity data on University of Salford staff members. My role in the research-informed teaching included overall study design, designing the activity diary used in the data collection process, analysing the data obtained that the students had collected from staff, and presenting in an easy-to-understand format for the second-year lectures. Data collection took place between February and March 2017, recruiting a total of 27 participants (University of Salford staff).

3.2.3 Ethical Considerations

Ethical approval for the data collected was obtained in February 2017 from the University of Salford Ethical Approval Panel (reference number, HST1617-202– Appendix 4). All participants were given a minimum of 24 hours to read the participant information sheet (Appendix 5) and were allowed to ask questions. Prior to data collection, informed consent was obtained by signing the consent form (Appendix 6). All data collected were treated as confidential. The information collected was used for research purposes only according to the 1988 Data Protection Act.

3.2.4 Measurements and Data Collection

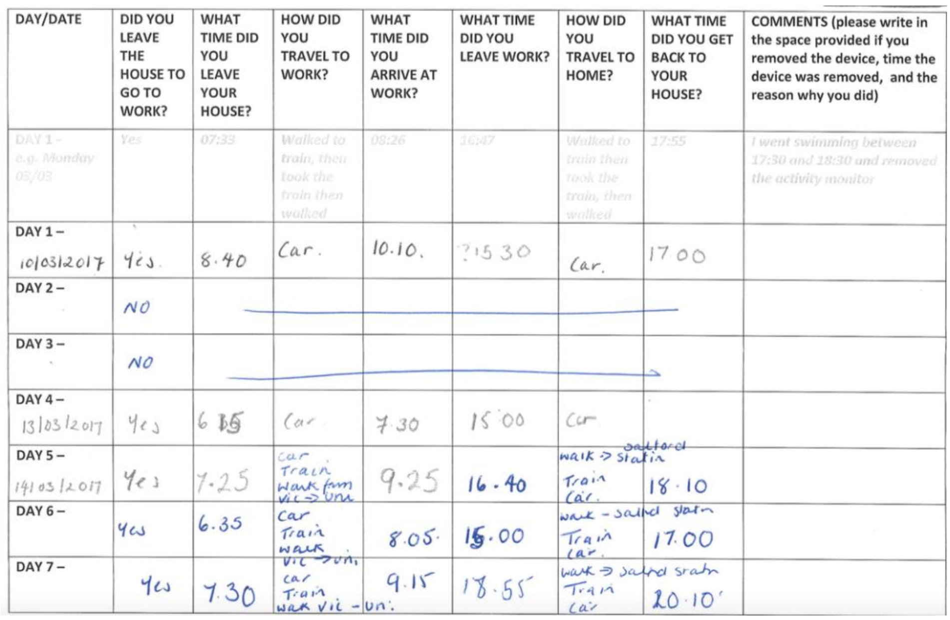
3.2.4.1 Measurements

The data collection instruments included: the activPAL™ accelerometer and an activity diary (Figure 3.1). The activPAL™ (PAL Technologies Ltd, Glasgow, Scotland, UK) classifies posture

[19] In this study, the student data was not used

as time spent sitting/lying, standing, and stepping, on a second-by-second basis and has been previously described in Section 2.3.5.3. The monitor has been validated for posture, step count and cadence in a range of populations (Grant et al., 2006; Ryan et al., 2006; Grant et al., 2008; Busse et al., 2009; Maddocks et al., 2010; Harrington et al., 2011): the validation studies have been discussed in detail in section 2.3.5.3. The model of the activPAL™ used in the studies included in this thesis was the activPAL3™.

The activity diary was designed to collect information on travel times to and from work, modes of commute, hours spent outside of commute, distance travelled to and from work, and removal periods of the accelerometer, if any (Figure 3.1, Appendix 7). The activity diary is an established additional assessment alongside an accelerometer for accurate data collection (Wen et al., 2010; Hamer et al., 2014). The activity diary was originally designed for a Level 7 Masters level dissertation on sedentary behaviour (The association between sedentary behaviour at work and mental wellbeing; 2016) by the researcher and was adapted for Study One in this thesis. The activity diary used in Study One included new information to capture commute times as the previous design only collected information on work arrival and departure times. In addition, the activity diary was based upon the design of the based on the information from the Commuting and Health in Cambridge study (Ogilvie et al., 2010).



DAY/DATE	DID YOU LEAVE THE HOUSE TO GO TO WORK?	WHAT TIME DID YOU LEAVE YOUR HOUSE?	HOW DID YOU TRAVEL TO WORK?	WHAT TIME DID YOU ARRIVE AT WORK?	WHAT TIME DID YOU LEAVE WORK?	HOW DID YOU TRAVEL TO HOME?	WHAT TIME DID YOU GET BACK TO YOUR HOUSE?	COMMENTS (please write in the space provided if you removed the device, time the device was removed, and the reason why you did)
DAY 1 – e.g. Monday 03/03	Yes	07:33	Walked to train, then took the train then walked	08:26	16:47	Walked to train then took the train, then walked	17:55	I went swimming between 17:30 and 18:30 and removed the activity monitor
DAY 1 – 10/03/2017	Yes.	8.40	Car.	10.10.	?15 30	Car.	17 00	
DAY 2 –	NO							
DAY 3 –	NO							
DAY 4 – 13/03/2017	Yes	6 15	Car	7.30	15 00	Car		
DAY 5 – 14/03/2017	Yes	7.25	car Train walk from vic → uni	9.25	16.40	walk → Salford Statin Train Car.	18.10	
DAY 6 –	Yes	6.35	Car Train walk vic → uni,	8.05.	15.00	walk – Salford Statn Train Car.	17.00	
DAY 7 –	Yes	7.30	car Train walk vic – uni.	9.15	18.55	walk → Salford Statn Train Car	20.10	

Figure 3.1: Image of a completed activity diary showing the mode of commute used and commute times to and from work (replicated with permission)

3.2.4.2 Procedure

Participants were asked to pick a suitable date that was convenient for data collection. Before the data collection session, the activPAL3™ accelerometers were fully charged and set up for recording using the manufacturer's software. The devices were waterproofed with a nitrile sleeve and Tegaderm transparent dressing (figure 3.2B). The participants were shown by the researcher how to attach the device (weighing 15g) to the front of the mid-line of the thigh using an adhesive medical waterproof dressing called Tegaderm and given an information leaflet on re-attachment of the accelerometer; participants were asked to wear an activPAL3™ accelerometer (figure 3.2A) continuously for a seven-day period. Each participant was asked to fill in the activity diary at the start and end of each day for the seven-day data collection period.

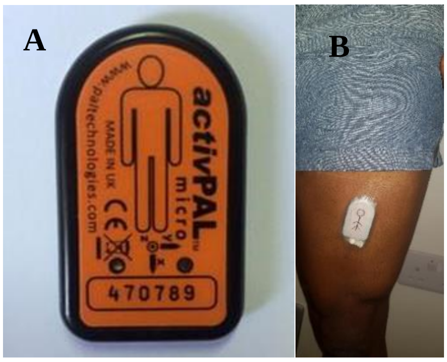


Figure 3.2: Figure showing correct orientation of attachment of the device (A), and the waterproofed activPAL™ with a diagram of the correct orientation for attachment (B) (Author's collection)

On return of the activPAL3™ accelerometers, the devices were checked that they contained data for the seven-day data collection period. If they did not contain any data, the participant was asked to re-wear the device for another seven-day period; however, the participant was excluded from the analysis if they did not consent.

Using the proprietary algorithms (activPAL™ software), the events files (these files contain the event-by-event classification of all activities) were downloaded for each participant and saved in Excel file format (.xlsx). Each event can be described as a continuous period in which an individual spends in a single activity, that is., sitting, standing, or stepping (Granat, 2012).

Therefore, these event-by-event classifications of all activities gave in-depth information of the participant's activities and provided the duration spent in each activity (the start and end time) for the period the device was worn. Figure 3.3 shows an excerpt from the analysis carried out showing the time stamp[20] of the event, the activity code[21], the duration spent in the event (seconds), the activity score. This file is transferred to MATLAB for further processing detailed in Section 3.3.

	A	B	C	D	E	F	G
1	Time	DataCount (samples)	Interval (s)	ActivityCode (0=sedentary, 1= standing, 2=stepping)	CumulativeStepCount	Activity Score (MET.h)	Abs(sumDiff)
2	42803.11	386112	1.3	1	2201	5.06E-04	213
3	42803.11	386125	1.3	2	2202	1.23E-03	292
4	42803.11	386138	1.2	2	2203	1.19E-03	214
5	42803.11	386150	1.2	2	2204	1.19E-03	266
6	42803.11	386162	1.1	2	2205	0.00115	332
7	42803.11	386173	1.1	2	2206	0.00115	200
8	42803.11	386184	1	2	2207	1.11E-03	197
9	42803.11	386194	1	2	2208	1.11E-03	162
10	42803.11	386204	4.1	1	2208	1.59E-03	334
11	42803.11	386245	45.8	0	2208	1.59E-02	316
12	42803.11	386703	1.4	1	2208	5.44E-04	245
13	42803.11	386717	3.6	2	2209	2.12E-03	883
14	42803.11	386753	1.1	2	2210	0.00115	165
15	42803.11	386764	1.2	2	2211	1.19E-03	225
16	42803.11	386776	0.8	2	2212	1.03E-03	133
17	42803.11	386784	2.7	1	2212	0.00105	400
18	42803.11	386811	15089.1	0	2212	5.239271	4224
19	42803.29	537702	1.1	1	2212	4.28E-04	147
20	42803.29	537713	1.2	2	2213	1.19E-03	323
21	42803.29	537725	2.5	2	2214	1.69E-03	435
22	42803.29	537750	1	2	2215	1.11E-03	427
23	42803.29	537760	1.4	2	2216	1.27E-03	230
24	42803.29	537774	2.3	2	2217	1.62E-03	300
25	42803.29	537797	2.1	2	2218	1.54E-03	475
26	42803.29	537818	3.8	2	2219	0.0022	507
27	42803.29	537856	1.2	2	2220	1.19E-03	234

Figure 3.3: Excerpt from Participant's event file showing the time stamp, the number of events, the activity code, and activity score used in further analysis

3.3 Data Processing for Study One: Commuting and MVPA study

3.3.1 Data cleaning and reduction

Event files containing activities over the seven-day period were obtained from the activPAL™ (PAL Technologies software) and were visually examined to ensure that there were at least three working days of complete data (sleep, waking, and working hours) for each participant. Incomplete days (fewer than 24 hours a day), at the start and end of the recording period,

[20] After download to Excel from the activPAL™ proprietary software, the time column contains date serial numbers that can be converted to actual date and time.
[21] The activity code includes 0 for sedentary, 1 for standing, and 2 for stepping.

were manually removed. The devices began recording at 3 pm on the first day of data collection, and they were set to end recording on the 8th day. Therefore, the data for the data collection day was day 0 and was deleted as well as the data for day 8 because they were both incomplete days. Non-wear times, such as swimming, were identified and removed from the analysis: this was done using the information provided in the diaries alongside data from the activPAL™ by manually screening the times reported in the diaries and making sure it coincides with the non-wear time on the data from the activPAL™. Analyses were carried out only on stepping events that occurred during waking hours and on workdays using information from the diaries.

A MATLAB (MathWorks Inc. MA, USA) script, which was previously written and adopted in previous studies, was used to extract all stepping events from the event file. The MATLAB script collected the single stepping events from the events file that are outputs from the activPAL™ to become a walking event, which consists of consecutive single stepping events with a duration which equates to the total sum of durations for the original steps. These stepping events were loaded into an Excel file for further analysis. For each stepping event, the duration, number of steps, and cadence of each stepping event were calculated (Figure 3.4).

	A	B	C	D	E	F	G
1	Participant ID	No	Event No	Time and Date	Duration (secs)	No of Steps	Cadence (steps/min)
2	P04.xlsx	1	2	10/03/2017 07:56:02	8.30	10	72.29
3	P04.xlsx	1	8	10/03/2017 07:56:54	1.20	2	100.00
4	P04.xlsx	1	10	10/03/2017 07:57:04	13.10	18	82.44
5	P04.xlsx	1	22	10/03/2017 08:05:26	9.90	14	84.85
6	P04.xlsx	1	32	10/03/2017 08:14:10	34.50	28	48.70
7	P04.xlsx	1	47	10/03/2017 08:14:56	1.20	2	100.00
8	P04.xlsx	1	49	10/03/2017 08:15:15	13.40	8	35.82
9	P04.xlsx	1	54	10/03/2017 08:15:38	11.10	12	64.86
10	P04.xlsx	1	61	10/03/2017 08:15:57	42.60	40	56.34
11	P04.xlsx	1	82	10/03/2017 08:16:47	5.90	8	81.36
12	P04.xlsx	1	87	10/03/2017 08:17:04	4.60	8	104.35
13	P04.xlsx	1	92	10/03/2017 08:17:15	36.60	36	59.02
14	P04.xlsx	1	113	10/03/2017 08:20:02	37.90	42	66.49
15	P04.xlsx	1	135	10/03/2017 08:20:53	9.20	6	39.13
16	P04.xlsx	1	141	10/03/2017 08:33:51	6.70	6	53.73
17	P04.xlsx	1	145	10/03/2017 08:35:30	2.80	2	42.86

Figure 3.4: Extract showing the date, time, duration, number of steps, the cadence of a stepping each event, and the coding of commuting and non-commuting periods

After exporting the data from MATLAB to Microsoft Excel, the activity diaries were used in the coding of commuting periods and to classify the mode of commute. Commute time was defined as travel time to and from the place of employment, and non-commute time was defined as all the time outside of commute. The mode of commute was categorised into walking, car, and mixed-mode (for those who travelled to or from work using more than one mode of commute)[22]. The commute times reported by the participants in the activity diary were verified using the activPAL™ data by manually and visually checking that the commute times and modes reported were in synchronisation with the activPAL™ data. For example, if a participant commuted by train and walk between 7 am to 8:15 am, the activPAL™ data was checked to confirm that the train activity (coded as standing or sitting on the events file) and the walking activity actually took place between the reported times.

3.3.2 Measurements

The main variable of interest in Study One was the time spent in MVPA during commuting. MVPA was defined as a period of walking with a cadence of at least 100 steps/minute (Tudor-Locke et al., 2018). The total time spent in MVPA was the sum of the duration spent at a cadence threshold of 100 steps/minute for all the participants. Commute time spent in MVPA was the sum of the duration spent during commuting at 100 steps/minute. Non-commute time spent in MVPA, and total time spent in MVPA were calculated as all walking bouts, irrespective of their lengths of the walking bouts.

The total number of steps taken per day were grouped by the modes of commute based on Tudor-Locke's classification of physical activity level: the categories are sedentary or inactive (<5000 steps/day), low active (5000-7499 steps/day), somewhat active (7500-9999 steps/day), active (10,000-12,500 steps/day), and highly active (>12,500 steps/day) (Tudor-Locke & Bassett, 2004).

To explore the cadence and walking bout distribution of commute and non-commute steps, the steps were classified into cadence bands based on Granat et al. (2015) that quantified the walking cadence of walking using an event-based approach in free-living conditions: 0-10, 10-

[22] Out of the 27 participants, none of the participants solely cycled.

20, 20-30, 30-40, 40-50, 50-60, 60-70, 70-80, 80-90, 90-100, 100-110, 110-120, 120-130, 130-140, ≥140 steps/minute and lengths of walking bouts were classified into: 0-30, 30-60, 60-90, 90-120, 120-150, 150-180, 180-210, 210-240, 240-270, 270-300, ≥300 seconds.

To determine compliance to physical activity guidelines, 2019 and 2011 UK guidelines were tested. For 2019 guidelines, the sum of all walking that lasted at least 30 minutes per day over five days at 100 steps/minute was deemed compliant. While for 2011 UK guidelines, the sum of all walking that lasted at least 30 minutes per day at 100 steps/minutes, in walking bouts of 10 minutes and more were deemed compliant.

To determine the effect of varying walking bout lengths, analyses were carried out using a minimum bout length of one, two, five and, 10 minutes. In addition, other definitions of MVPA for a healthy population, 76 steps/minute (Dall et al., 2013) and 109 steps/minute (Chastin et al., 2009), were also tested.

3.3.3 Statistical Analysis

Data analyses were carried out using SPSS Statistics (version 25.0; IBM, Armonk, NY, USA). Analysis, using the Shapiro-Wilk test, showed the data to be non-normally distributed; therefore, non-parametric tests were used in the analysis and results are presented as medians and interquartile ranges (IQR: 25^{th} – 75^{th}). Differences in time spent in MVPA during commuting between different modes of commute (car, walk, and mixed-mode) were analysed using the Kruskal-Wallis's test. Mann-Whitney-U tests were conducted to determine the difference between each pair of the commute modes (Car and walk/walk and mixed-mode/car and mixed-mode). Differences in the number of commute steps and non-commute steps between cadence ≥100 steps/minute and <100 steps/minute were analysed using the Mann-Whitney-U test. The Spearman's rank of correlation coefficient was calculated to compare the total number of steps and commute time and non-commute in MVPA. For all analyses, a probability value (p-value) of 0.05 was used to indicate statistical significance.

3.4 Rationale for Study Two: Gap analysis study

Sedentary behaviour and physical activity are often reported as total daily time spent at a specific intensity, typically minutes or hours per day. While the volume of these behaviours is important for health (Maddison et al., 2015; Powell et al., 2020), some recent evidence also suggests that the way these variables are accumulated, such as the length and duration of bouts, may be of public health importance (Bailey & Locke, 2015; Judice et al., 2015; Stephens et al., 2011).

Continuous walking can be interrupted by a pedestrian stopping for moving traffic, waiting for the pedestrian lights, or simply stopping to catch one's breath (Barry, Galna, Lord, Rochester, & Godfrey, 2015; Chastin et al., 2009). Interruptions during free-living walking is typical and it is an important consideration in research measuring walking using accelerometers because they can detect gaps in walking (Harvey et al., 2017). There have been limited studies that have looked at interruptions in continuous walking; however, these studies have assumed what the maximum interruption duration should be, ranging from 6 to 50 seconds (Ayabe et al., 2014; Barry et al., 2015; Harvey et al., 2017), including no consideration for the intensity of the walking activity. The intensity of an activity is important since the physical activity guidelines recommend that activity should be either moderate or vigorous intensity (DHSC, 2019), and cadence has been suggested as a practical way of estimating physical activity intensities (Tudor-Locke & Rowe, 2012).

Furthermore, physical activity intensity can help in understanding the dose-response relationships to health outcomes that can be used as a component of a physical activity prescription. For instance, Robson and Janssen (2015) found that MVPA embedded within bouts of light-intensity physical activities are negatively associated with cardiometabolic risk factors and metabolic syndrome: this association was found to be similar in MVPA accumulated in bouts of 10 minutes or more. Besides, some studies have shown that MVPA bouts of activity accumulated in fewer than 10 minutes are associated with cardiometabolic risk factors (Glazer et al., 2013). Robson and Janssen (2015) suggested that combining bouts of MVPA less than 10 minutes with light-intensity physical activity (non-sedentary bouts) are as beneficial as continuous activity of MVPA in 10 minutes or more.

Previous studies have also shown that light-intensity physical activities play an important role in improving cardiometabolic health (Chastin et al., 2019; McGregor et al., 2018). In addition, in sedentary behaviour studies, extensive research has been carried out to examine how breaking up bouts with short standing breaks through the day can improve postprandial plasma glucose levels and glycemic control (Chastin et al; 2019; Bailey & Locke, 2015). Therefore, the importance of MVPA has been well-established in reducing the risk of a number of health outcomes, and light-intensity physical activity has also been evidenced to improve metabolic health. Hence, combining walking bouts with short interruptions (standing) between them based on an average cadence threshold may provide a stronger protective effect with cardiometabolic health outcomes.

As there is currently no standardised method of defining continuous walking for research measuring walking using accelerometers (Chastin et al., 2009), a definition of continuous walking is needed for comparison between similar studies in physical activity research. In this study, a new approach was developed and tested with no assumption on the maximum length of the interruptions (duration): we considered both the duration and cadence of the walking events on either side of the interruption. The event-based approach adopted in this study was described by Granat (2012) in redefining continuous walking bouts from walking events by allowing defined gaps between them to be combined based on a user-defined rule. The only decision made was based on the intensity (MVPA), with cadence as an alternative method of estimating intensity. MVPA was defined based on cadence thresholds: 76, 100, & 109 steps/minute. When a break in walking occurs, the walking cadence of that individual reduces drastically below moderate intensity and as a result that walking is no longer considered continuous. However, as a result of combining individual walking bouts and the interruptions between them to form a newly grouped walking event based on an average MVPA cadence, the newly grouped walking event remains continuous if the calculated average cadence is above the specified cadence threshold. The use of an average cadence can be likened to the physiological response like oxygen uptake or heart rate and if the average cadence is above the defined cadence threshold, then walking is considered continuous and at moderate intensity.

Therefore, this study aimed to use an event-based approach to define continuous walking bouts and how to combine walking bouts with short interruptions between them based on an average cadence threshold. A secondary aim was to explore combining walking events with short interruptions between them with compliance to physical activity guidelines, in terms of continuous walking for 10 minutes or more.

3.5 Data processing for Study Two: Gap analysis

3.5.1 Data cleaning and reduction

Figure 3.5 and 3.6 shows the data processing as conducted in this study. A MATLAB® (MathWorks Inc. MA, USA) script analysed the event files and all walking events were extracted to give details of the start time, duration, number of steps, and cadence. Before processing, the walking events were referred to as ungrouped events: the walking events after processing were referred to as grouped events.

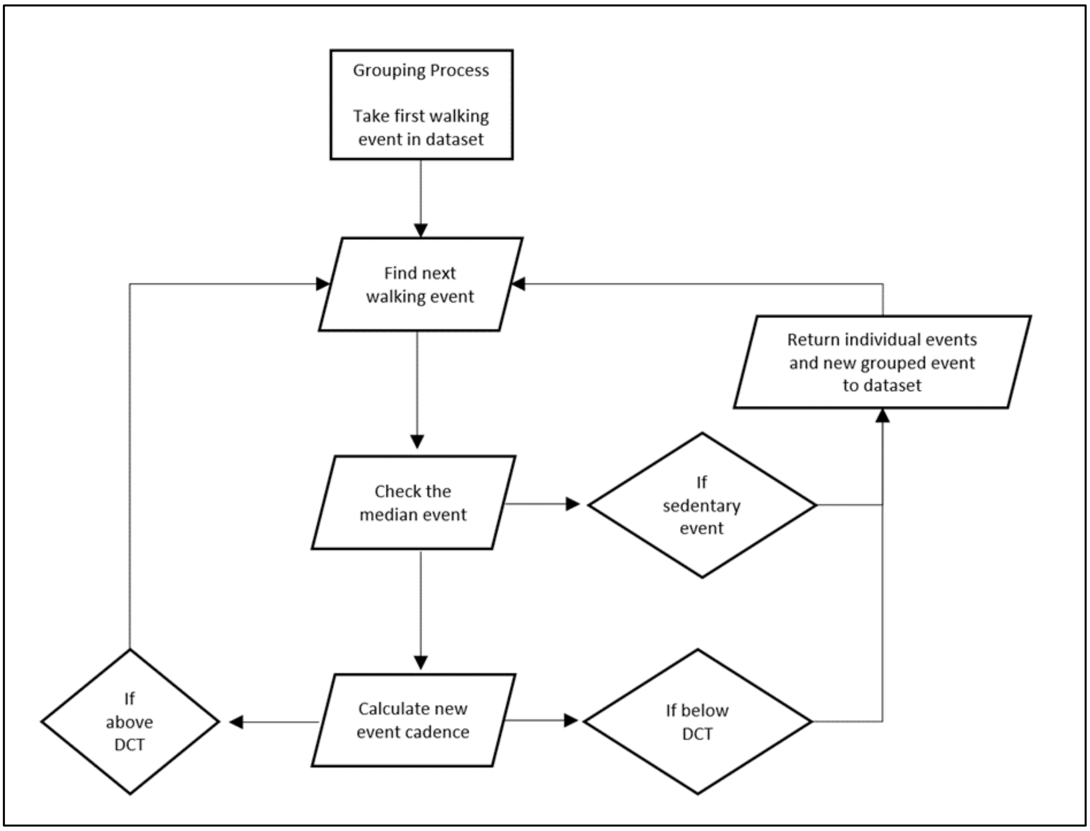


Figure 3.5: Flow diagram of the data cleaning and reduction process (DCT: defined cadence threshold)

To re-define a continuous bout of walking, two consecutive walking events interspersed with a standing event were combined to create a new grouped event. Using the duration and step count for this new event, the average cadence was calculated and compared to the cadence threshold (76, 100 or 109 steps/minute). If the new events average cadence was higher than the cadence threshold, the event would be accepted as a new continuous walking event and the processing would continue. However, if the new events average cadence fell below the cadence threshold (76, 100 or 109 steps/minute), or if the processing encountered a sedentary event, the processing would cease and the newly formed grouped events up to this point (before the sedentary events) would be added to the dataset. After each processing round, the events are added one at a time to the grouped event until the process reached an endpoint.

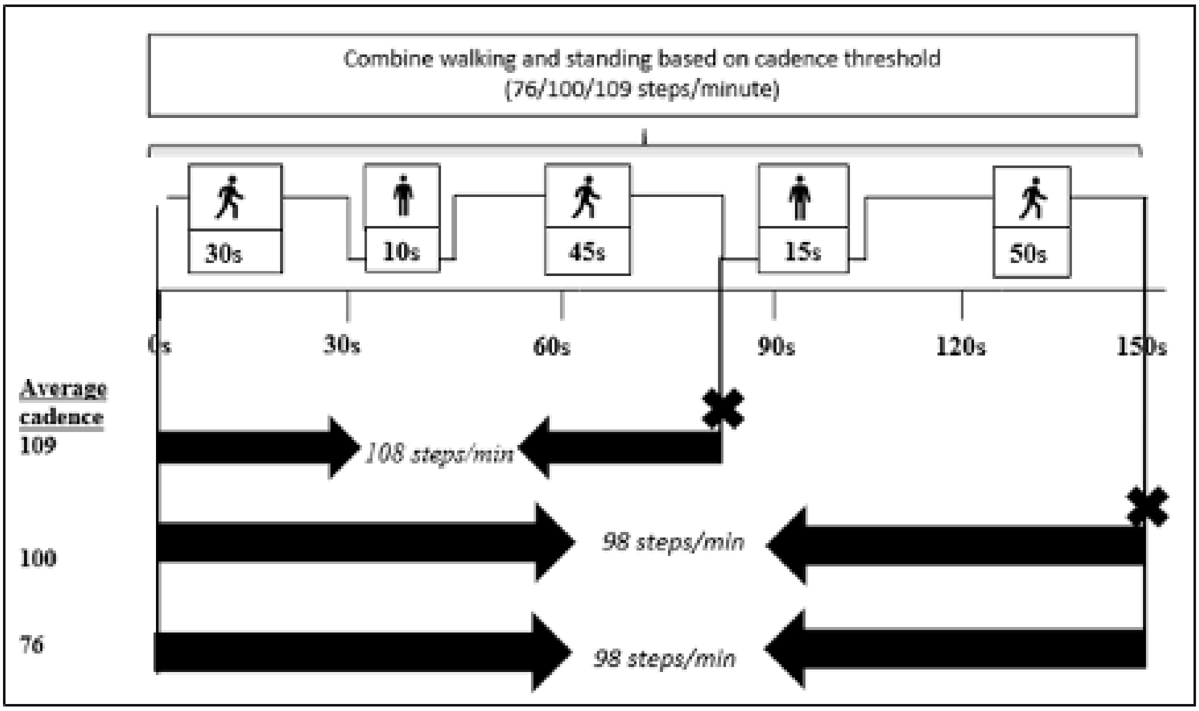


Figure 3.6: Illustration of activities over 150 seconds showing standing, walking, and sitting activities (combining the walking bouts with the short standing events to calculate a new average cadence; and if the new average cadence falls within the specified cadence threshold, the combined activities are grouped as one continuous bout). The **'X'** represents the point where the grouping process terminates because the average cadence is lower than the threshold as in the case of 100 and 109 steps/minute threshold). However, the grouping process based on the 76 steps/minute threshold continues because the average cadence is greater than the threshold. The grouping process continues until the average cadence is lower than the threshold or the processing encounters a sedentary event.

3.5.2 Measurements

The outcome measures were:

1) Total time per day of grouped events versus ungrouped events,

2) The composition of the grouped events (walking and standing events).

All analyses were carried out using the defined cadence (MVPA) threshold of 100 steps/minute, 76 steps/minute (Dall et al., 2013), and 109 steps/minute (Chastin et al., 2009).

The total time for ungrouped events is the sum of the duration of all the walking bouts before any processing took place, and the total time for grouped events is the sum of the duration of all the walking bouts (grouped and individual events) after the grouping process. The composition of the grouped event dataset was analysed by first distributing the grouped events into lengths of walking bouts based on their total duration, each length of walking bout represented event lengths typical of free-living physical behaviours: 0-1, 1-10, 10-30, 30-60, ≥60 minutes. Next, each grouped event was averaged per day per participant to understand the average composition of individual events that make up the grouped events. The analysis was conducted for individual walking events and individual standing events

To determine compliance to 2011 physical activity guidelines, the sum of all walking at a particular cadence threshold for MVPA (76, 100, or 109 steps/minute), with a minimum bout length of 10 minutes and those that lasted at least 30 minutes per day, in walking bouts of 10 minutes and more were deemed compliant. While for 2019 UK guidelines, the sum of all walking that lasted at least 30 minutes per day at either 76, 100, or 109 steps/minute was deemed compliant. Compliance was calculated for each participant.

3.5.3 Statistical Analysis

Data analyses were carried out using SPSS Statistics (version 26.0; IBM, Armonk, NY, USA). The data were checked for normality using the Shapiro-Wilk test and the variables were normally distributed. The average daily walking duration for the ungrouped and three walking event datasets (76, 100, and 109 steps/minute) was compared using a repeated measure one-way ANOVA. An analysis of MVPA was conducted for each of the three MVPA values. The average daily time spent in MVPA was calculated using the three thresholds before and after grouping, with the grouping cadence threshold set as the relevant MVPA threshold. These data were analysed using a repeated measures two-way ANOVA to understand the effects of grouping and MVPA threshold on time spent in MVPA. Means, standard deviations and percentage increases are presented along with significance level, with significance taken as $p < 0.05$.

Chapter 4: Results for Study One and Two

Chapter	Summary of each chapter
1- Introduction	A background to physical activity, the role of commuting to contributing to physical activity, an overview of methods used in measuring commuting physical activity, and its association with health outcomes.
2- Literature review	A critical review and discussion of the literature surrounding measuring commuting MVPA, and its association to various health outcomes, especially metabolic risk factors
3- Methodology I – Methods for Study One and Two	Describes the methods for Study One:(*Commuting and MVPA)*; and Study Two: (*Gap analysis*) **Aim of Commuting and MVPA study**: To objectively determine the contribution of MVPA during commuting to total MVPA, using cadence to define MVPA, and explore how minimum walking bout length affects adherence to physical activity guidelines. **Aim of Gap analysis study**: To use an event-based approach to define continuous walking events, by combining walking events with short interruptions based on an average cadence threshold.
4- Results I – Results for Study One and Two	Presents the results for objectives one to six: 1. To objectively quantify MVPA during commuting using the definition of cadence. 2. To determine the difference between modes of commute and time spent in MVPA during commuting. 3. To determine the level of compliance to physical activity guidelines by examining the volume of MVPA and length of walking bouts accumulated. 4. To combine short interruptions between walking events to form a new continuous walking event called "grouped event" 5. To examine how grouping walking events changes total time walking and total time in MVPA 6. To ascertain whether combining walking events with short interruptions between them impacts compliance to physical activity guidelines.
5- Methodology II – Methods for Study Three	Describes the methods used in Study Three to address objectives seven to eleven **Aim**: To investigate the association between MVPA during commuting physical activity and metabolic markers.
6- Results II – Results for Study Three	Presents the results for objectives seven to eleven: 7. To determine the difference between the different modes of commute and time spent in MVPA during commuting and non-commuting periods. 8. To objectively quantify MVPA, using different cadence thresholds for MVPA, for both commute and non-commute stepping. 9. To explore the patterns of commute and non-commute stepping at different lengths of walking bouts, before and after grouping walking events. 10. To determine the compliance to the 2011 and 2019 UK physical activity guidelines for all participants before and after grouping walking events. 11. To investigate associations between commute time in MVPA (before and after grouping walking events) and metabolic markers.
7- Discussion	This chapter summarises the findings from Study One to Three, highlights their strengths and limitations within this thesis; Reflection on the impact of COVID-19 on commuting physical activity.
8- Conclusion	This chapter gives a concluding summary of the thesis and implications for policy and future research.

4.0 Overview

This results chapter is divided into two main sections: The first section (Section 4.1 to 4.4) presents the results from Study One and the second section (Section 4.5) presents results for Study Two. Study One aimed to investigate the contribution of MVPA during commuting to total daily MVPA using walking cadence. Objectives one to three were used to achieve this aim:

1. To objectively quantify MVPA during commuting using the definition of MVPA as a cadence of 100 steps/minute.
2. To determine the difference between the different modes of commute and time spent in MVPA during commuting.
3. To determine the level of compliance to physical activity guidelines by examining the volume of MVPA and length of walking bouts accumulated.

This chapter presents the results from Study One to address the first aim, to objectively determine the contribution of MVPA during commuting to total MVPA, using cadence to define MVPA. The first section of this chapter describes descriptive analyses of commute steps and time spent in MVPA. The second section presents the distribution of steps accumulated based on cadence and lengths of walking bouts.

4.1 Study One's results: Commuting and MVPA study

4.1.1 Descriptive Analyses

Twenty-seven participants were recruited; however, four participants did not have complete activPAL™ data. Of the 23 participants included in the analysis, 13 (57%) commuted by car, three (13%) by walking and seven (31%) commuted using more than one mode (mixed-mode journeys). All participants maintained the same mode of commute throughout the data collection period.

The median total daily time spent in MVPA was 49.6 (27.4 -75.8) minutes with all commutes contributing 31% of that time (15.2 minutes). The median commute time spent at any physical activity intensity was 23.7 (14.2-43.2) minutes per day. The median contribution of commute time in MVPA to total MVPA was 14% for car commuters, 36% for mixed-mode commuters and 61% for walking commuters. The walking commuters had a median of 37.6 (29.9-38.7) minutes per day of MVPA, mixed-mode commuters had 26.9 (14.2-40.8) minutes, and car commuters had 5.8 (2.8 –15.2) minutes.

The median total daily step count was 10,639 (IQR: 7,884-13,556) steps and the number of steps taken at MVPA at 100 steps/minute (irrespective of bout length) was 5,731 (3,020-9,020) steps; with 33% of steps taken at MVPA accumulated during commuting for all participants. The total number of steps were categorised to help understand physical activity levels in participants for those in the inactive category, the major mode of commute was by car (Table 4.1). The category with more than 7,500 steps per day was populated with both mixed-mode and car commuters.

Table 4.1: Participants' physical activity levels

Activity level (Steps per day)	Number of participants	Mode of commute
Inactive (<5000)	3	car
Low active (5000-7499)	3	car
Somewhat active (7500-9999)	5	1 walking, 1 car, 3 mixed-mode commuters
Active (10000-12500)	6	2 walking, 3 car, 1 mixed-mode commuters
Highly active (>12500)	6	3 car and 3 mixed-mode commuters

4.2 Cadence and Stepping events distribution of steps

4.2.1 Cadence distribution of commute and non-commute steps

Commute and non-commute steps were classified into different cadence bands, which were in increments of 10 steps/minute from 10 steps/minute to 140 steps/minute (Figure 4.1). Non-commute steps were greater than commute steps between cadences of 20-100 steps/min. At a cadence of over 110 steps/min, there was a far greater proportion of stepping during commuting compared to other cadence bands. However, using a difference test, the Mann-Whitney U test showed that there was no statistically significant difference in the distribution of commute steps between cadence ≥100 steps/min and <100 steps/min ($p=0.075$).

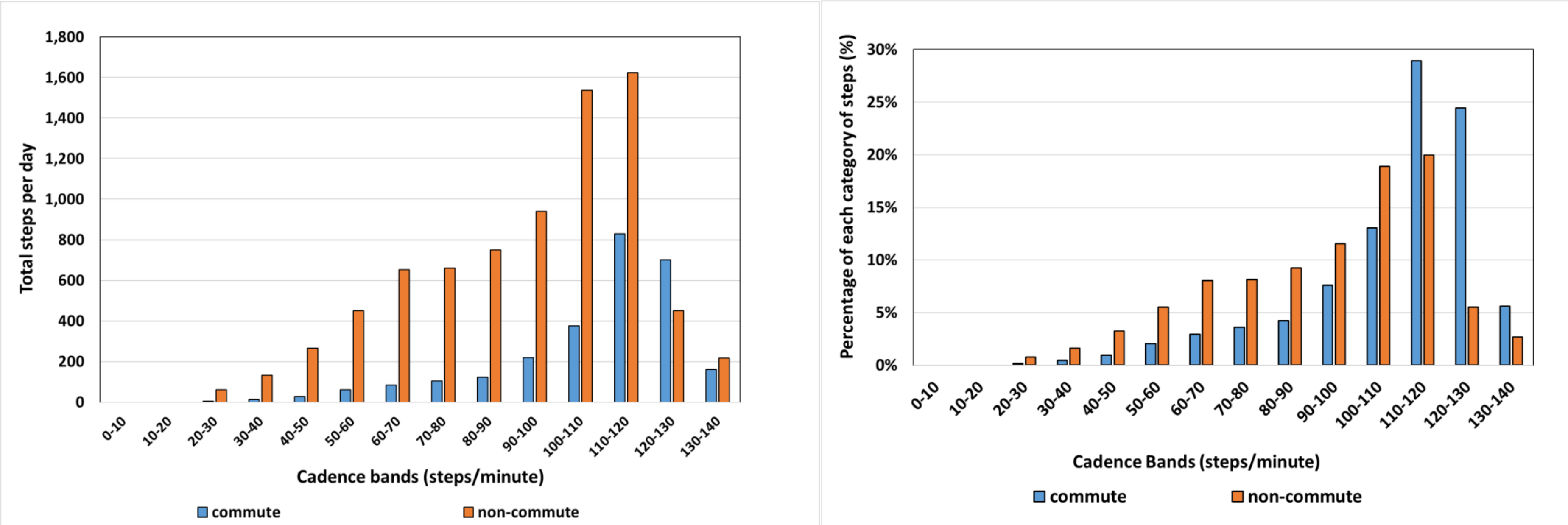


Figure 4.1: Cadence distribution of commute and non-commute steps

4.2.2 Walking bouts distribution of commute and non-commute steps

Stepping during commuting and non-commuting periods varied according to lengths of stepping bout (Figure 4.2). Non-commute stepping was predominantly accumulated in shorter bout lengths. Stepping bouts of greater than 210 seconds were only undertaken whilst commuting, with a higher number of steps accumulated in bouts over 300 seconds.

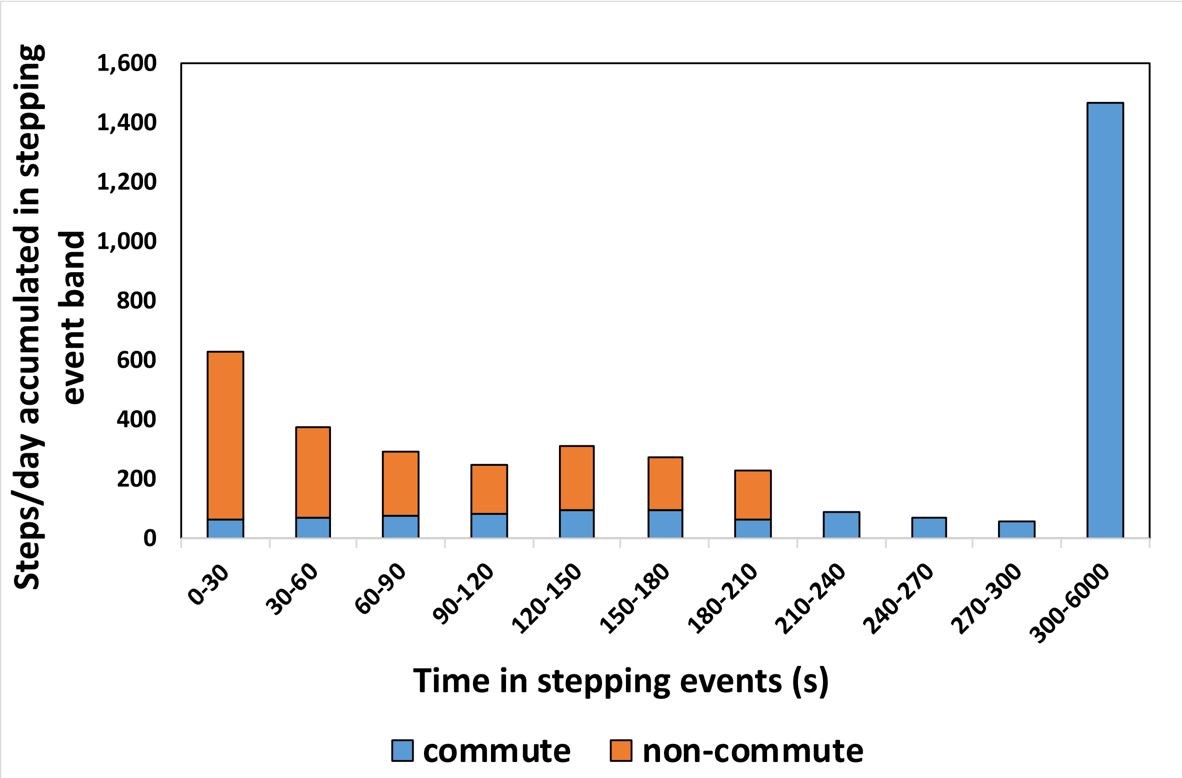


Figure 4.2: Stepping bout distribution of commute and non-commute steps

4.3 Compliance with physical activity guidelines

Both the 2011 and the 2019 UK physical activity guidelines were used to examine compliance with physical activity guidelines for all the participants. The definition of MVPA used in the literature as the cadence of ≥100 steps/minute was considered and the main components of the physical activity recommendations (amount of time spent in MVPA and bout length requirement). The commute time versus non-commute time in MVPA and the percentages of commute time to the total time spent in MVPA for all participants are shown in Figure 4.3. For the 2019 UK guidelines, 17 out of the 23 participants achieved a minimum of 30 minutes of MVPA per day and five, all mixed-mode or walking commuters, achieved at least 30 minutes of MVPA during their commute alone.

The percentage of commute to total time in MVPA was higher in participants in the mixed-mode and walking commuters than the car commuters. Some mixed-mode and car commuters had high percentages (that is, accumulated more MVPA in commute) in MVPA during commute towards total MVPA; however, they did not meet the minimum recommendation of at least 30 minutes per day.

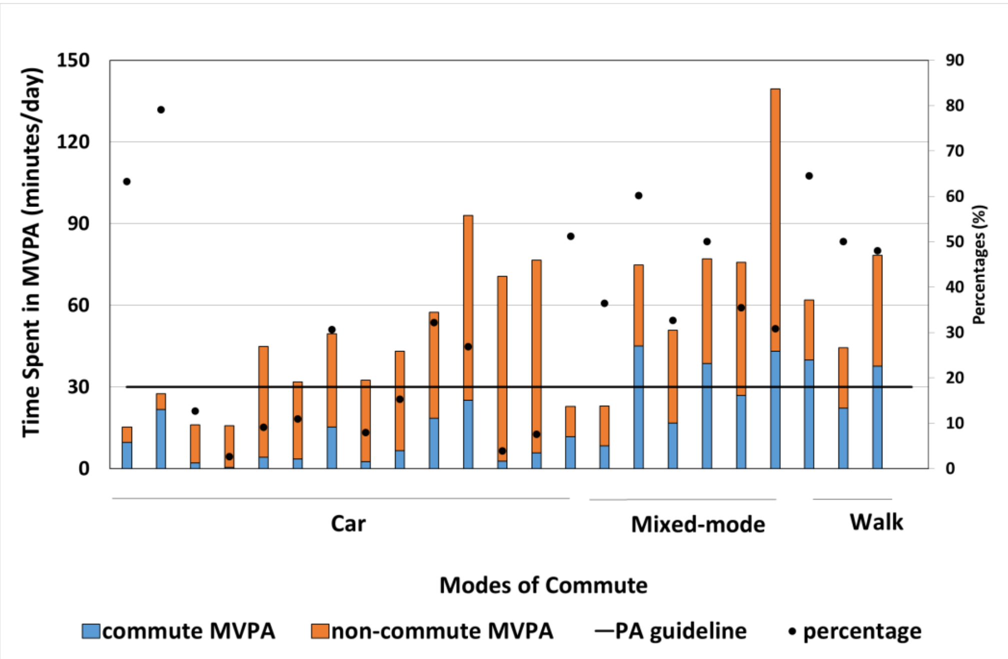


Figure 4.3: Commute time and non-commute time in MVPA at ≥100 steps/min for all walking bouts for all subjects grouped by commute mode (The dots represent percentage of commute time in MVPA to total time spent in MVPA)

Using the 2011 physical activity recommendations of accumulating at least 30 minutes of MVPA per day in bouts of greater than 10 minutes (DH, 2011), seven participants met these guidelines: one participant, a walking commuter, met this guideline from their commute alone (Figure 4.4). The participants with continuous bouts of greater than 10 minutes were primarily mixed-mode and walking commuters.

Due to the inclusion of the minimum bout length, the percentage of commute time in MVPA to total MVPA was reduced to zero for some of the participants. Thirteen out of 24 participants had no continuous walking bout of ≥10 minutes and most of the remaining participants who had continuous bout length of ≥10 minutes were in the mixed and walking categories.

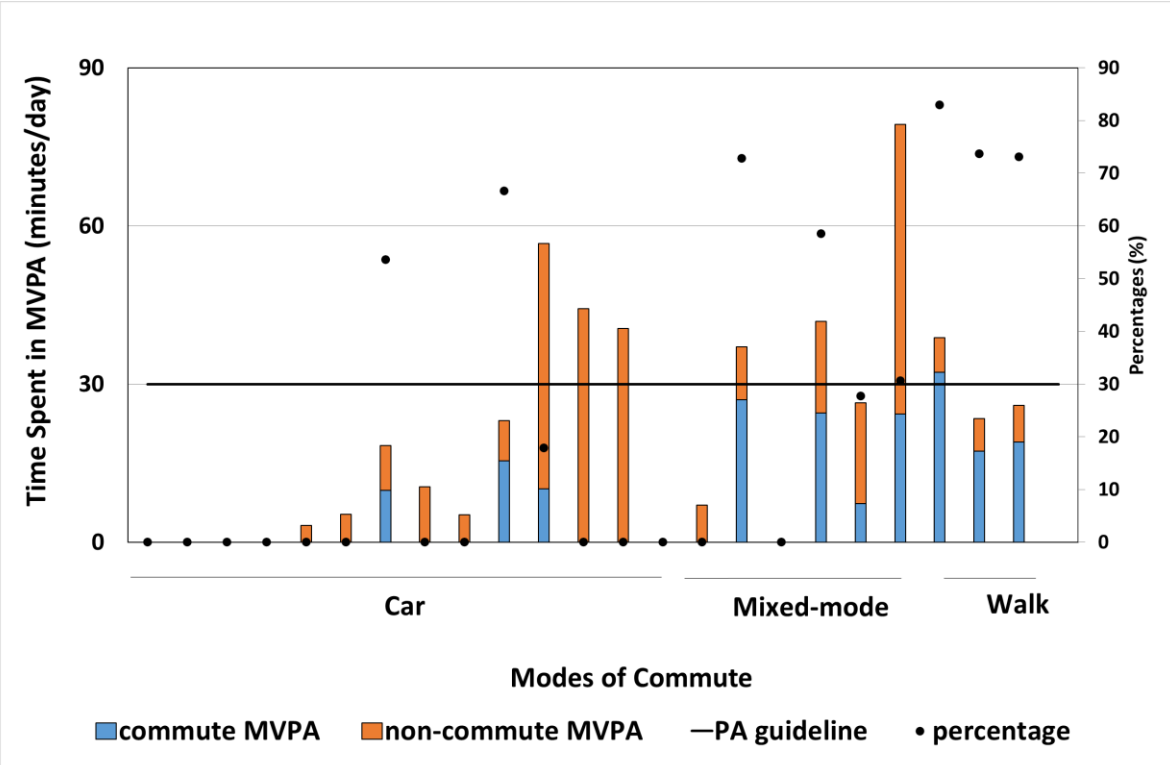


Figure 4.4: Commute time and non-commute time in MVPA at ≥100 steps/min and walking bouts greater than 10 minutes

The requirements to meet the physical activity guidelines were altered by changing the cadence threshold definition for MVPA and the minimum walking bout length, and the median time spent in MVPA were reported (Table 4.2). The number of participants compliant as the bout length increases reduces at all cadence thresholds. The bout length between one and five minutes had similar effects on 76 steps/minute and 100 steps/minute threshold. The total time spent in MVPA decreased as the length of walking bouts increased for all cadences; however, commute time in MVPA at all cadence thresholds was similar.

Table 4.2: Compliance with physical activity guidelines using different criteria for MVPA and different minimum stepping bouts

Cadence / Length of stepping bouts (minutes)	No of the participants that met the PA guidelines	Participants that met PA guidelines in commute alone	Total time contributing to PA guidelines (minutes)	Commute time contributing to PA guidelines (minutes)
76 steps/minute				
0	22	6	72.3	20.0
1	18	5	47.9	15.2
2	17	5	39.9	11.8
5	9	3	18.7	6.9
10	7	1	7.0	0.0
100 steps/minute				
0	17	5	49.6	15.2
1	15	5	40.0	13.6
2	14	5	34.7	11.2
5	9	3	18.0	6.9
10	7	1	7.0	0.0
109 steps/minute				
0	12	4	31.2	12.3
1	12	4	27.2	11.9
2	11	4	25.1	11.1
5	9	2	13.7	4.5
10	7	1	5.5	0.0

4.4 Statistical Results

The Kruskal-Wallis non-parametric test was used to test the null hypothesis that there is no difference in commute time in MVPA across the modes of commute. There was a significant difference in commute MVPA for all modes of commute (p= 0.005). Further analysis using the Mann-Whitney-U tests to determine the difference on each pair of the groups showed that there was a significant difference between the car and walking commuters (p=0.013) and the car and mixed-mode commuters (p=0.008); however, there was no significant difference between walking and mixed-mode commuters (p=0.732).

The correlation test using Spearman's rank correlation coefficient showed that there was a significant moderate positive relationship (r=0.65; p<0.001) between commute time in MVPA, and total steps per day (Table 4.3). Also, there was a positive relationship between non-commute time in MVPA (r=0.88; p<0.001) and total steps per day.

Table 4.3: Correlation of total number of steps with time in MVPA

	Steps per day	**Time in MVPA (mins)**	r^2	***P*-value**
Total	10,639	49.6	0.84	<0.001
Commute	2,820	15.2	0.65	<0.001
Non-commute	7,314	23.7	0.88	<0.001

4.5 Study Two- Gap analysis study

This section presents the results for Study two aimed at defining and combining short interruptions between walking events using a novel approach based on the average cadence threshold. Objectives four to six were used to achieve this aim:

4. To combine walking events short interruptions between to form a new continuous walking event called a "grouped event."
5. To examine how grouping walking events changes total time walking and total time in MVPA
6. To ascertain whether combining walking events with short interruptions between them impacts compliance to physical activity guidelines.

4.5.1 Descriptive analysis

The average total time spent walking before grouping (123.1 ±36.9 minutes) was significantly different to the average total time spent walking after grouping at all MVPA cadence thresholds (t=4.849, p<0.001). The average total time at 76 steps/minute (132.7.1 ±39.1 minutes) was greater than the greater the total time spent walking at 100 steps/minute (126.3 ±38.0 minutes) and 109 steps/minute (124.7 ±37.4 minutes) (Figure 4.5). Similarly, after grouping, the total time spent walking increased by 8% at the 76 steps/minute threshold, 3% at the 100 steps/minute threshold, and 1% at 109 steps/minute threshold. (Figure 4.5).

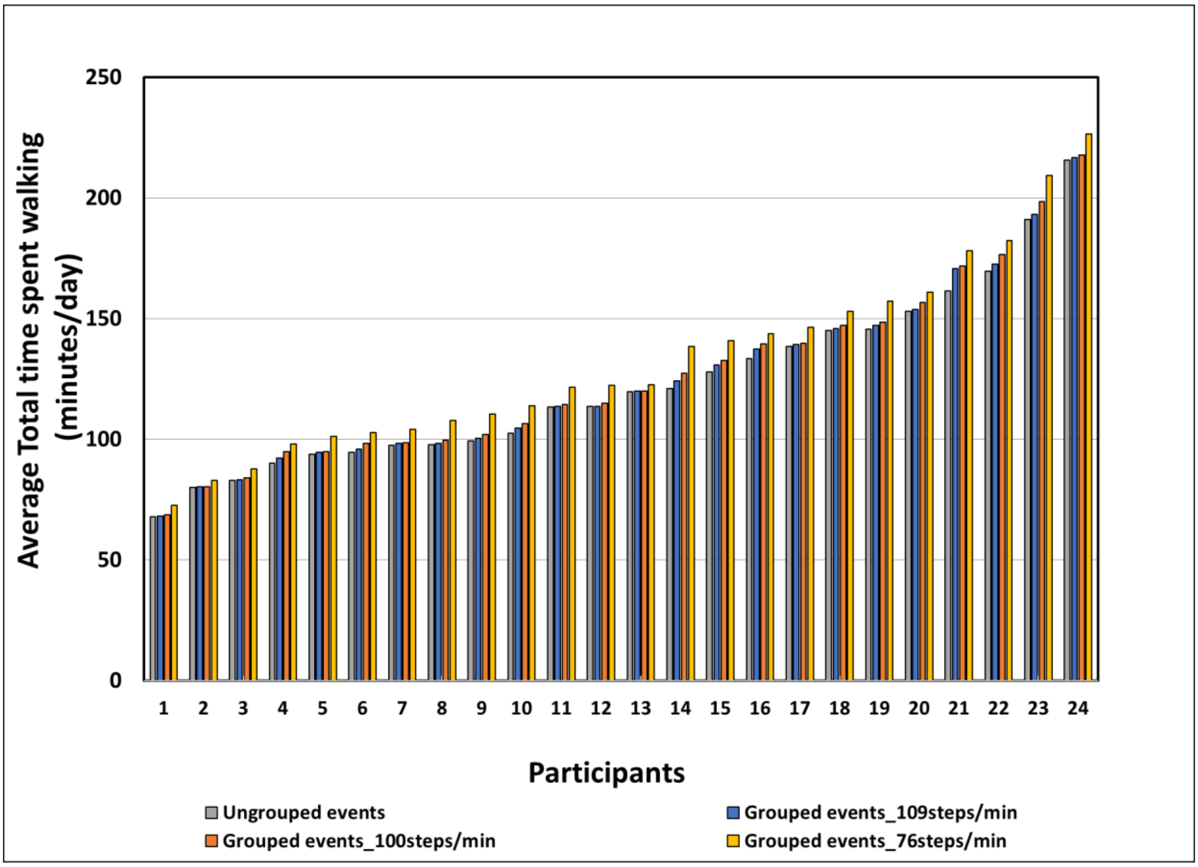


Figure 4.5: Average total duration of walking per day between grouped and ungrouped events

4.5.2 Time in MVPA

Figures 4.6, 4.7, and 4.8 show the total time spent in MVPA at 76, 100, and 109 steps/minute before and after grouping. As a result of grouping, the total time spent in MVPA increased by 15% at 76 steps/minute, 10% at 100 steps/minute, and 9% at 10 steps/minute. Figure 4.7 shows the average total time per day spent at MVPA (defined as 100 steps/minute) differed between ungrouped and grouped events. At 100 steps/minute, grouping increased the total time spent in MVPA between 2% to 17% (0.3 minutes to 11.2 minutes) among the participants. The average daily time spent in MVPA increased by from 75.2 ±32.6-minutes to 86.5 ±37.4-minutes using the 76 steps/minute, 48.3 ±29.5-minutes to 53 ±33.3-minutes using the 100 steps/minute threshold, and 31.4 ±20.5-minutes to 33.9 ±22.6-minutes using the 109 steps/minute threshold. The results of the two-way repeated-measures ANOVA revealed that there was a significant main effect of the threshold on time spent in MVPA [F (1.352,31.109) =175.817, $p < .05$, $\eta p\ 2 = .884$]. Similarly, there was a significant main effect of the grouping process on time spent in MVPA [F (1,23) =61.152, p < .05, ηp 2 = .727] and a significant interaction between the threshold and the grouping process (F (1.6,36.801) = 83.351, p < .05, ηp 2 = .784), such that the increase in time spent in MVPA through grouping was related to the choice of MVPA threshold. Again, post-hoc pairwise comparison using the Tukey test showed there were significant differences between all the cadence thresholds for MVPA (p < 0.05).

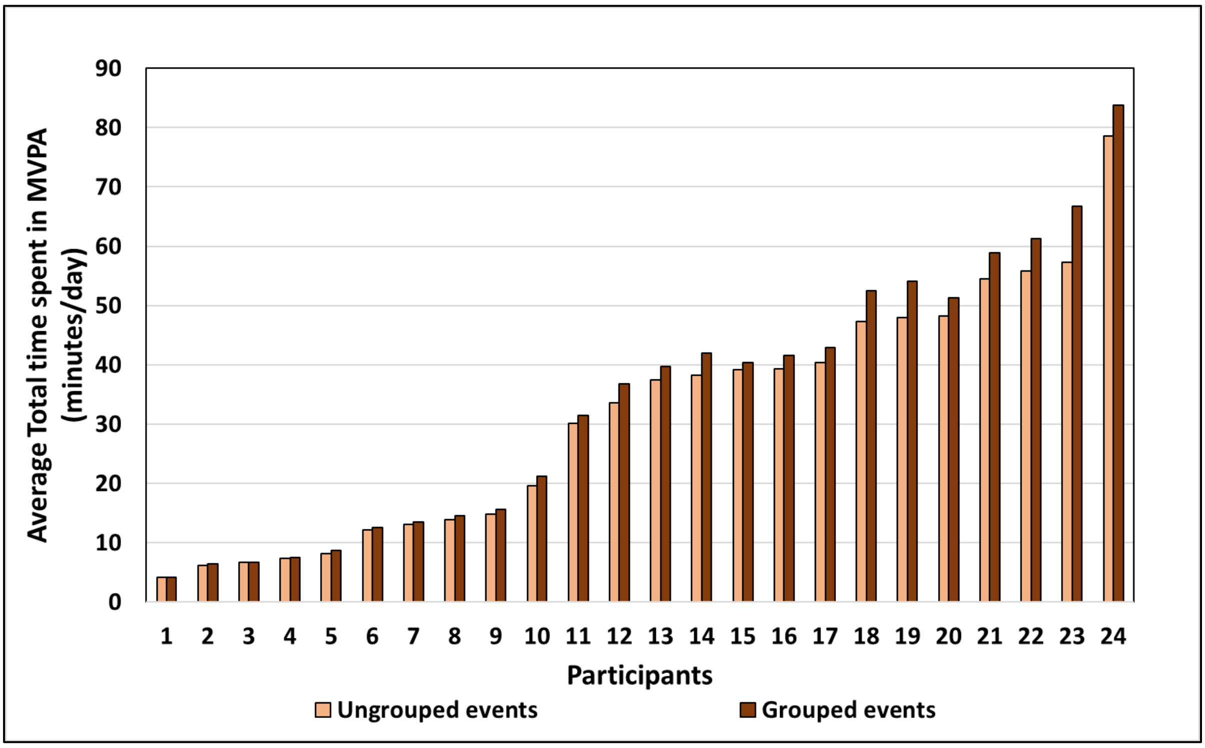


Figure 4.6: Average Total Time in MVPA at 76 steps/minute per day showing grouped and ungrouped events

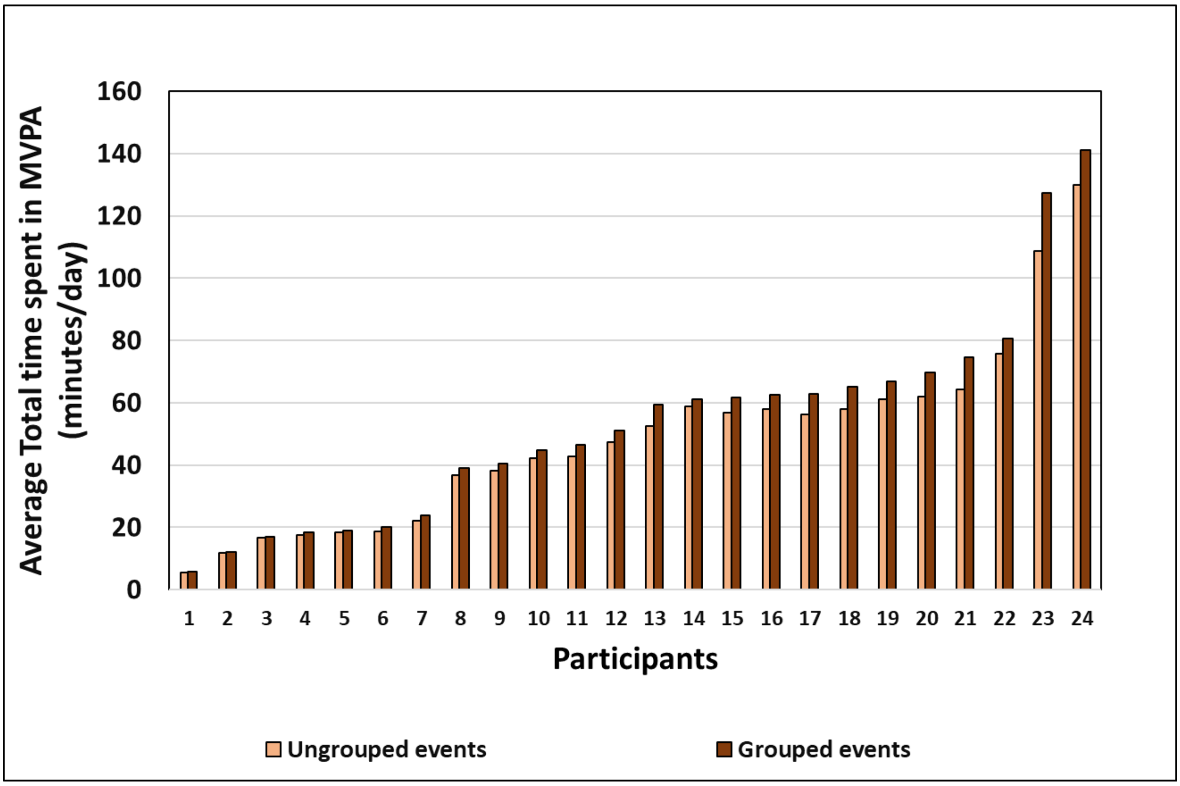


Figure 4.7: Average Total Time in MVPA at 100 steps/minute per day showing grouped and ungrouped events

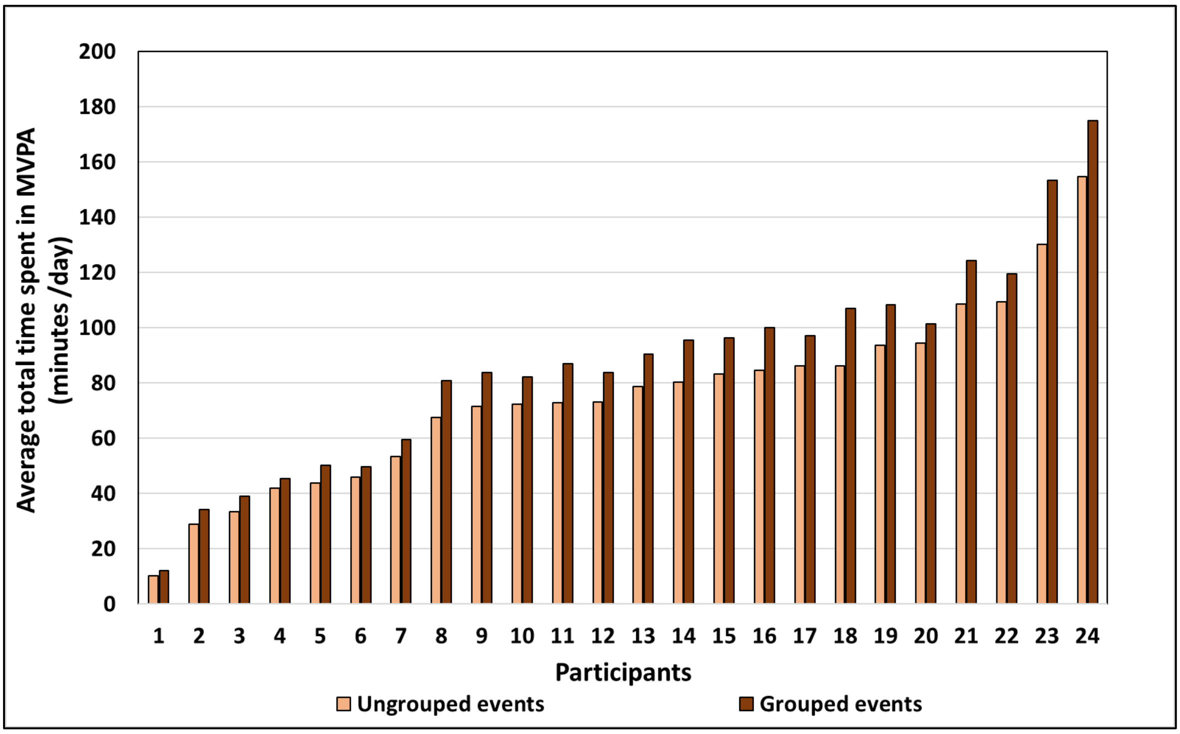


Figure 4.8: Average Total Time in MVPA at 109 steps/minute per day showing grouped and ungrouped events

4.5.3 Lengths of walking events

Figure 4.9 shows the distribution of the lengths of walking events, at the different cadence thresholds, after grouping. Grouping resulted in the redistribution of short walking events to longer walking duration, with this being more pronounced for walking bouts longer than 10 minutes. For walking events that lasted between 0-1 minute, there was an average duration of 65.5 minutes across all participants per day before grouping, compared to 63.9 minutes for the 100 steps/minute threshold, showing that these events were being incorporated in longer events as part of the grouping process. For walking bouts of >60 minutes long, there was an average duration of 2.2 minutes across all participants per day in the ungrouped data and 10.8 minutes for the 100 steps/minute threshold, showing that the grouping process increased the amount of long continuous walking. This shift from short duration walking events (0 -1 minutes) to longer duration walking events (>60 minutes) is also prominent in the 76 steps/minute (59.4 minutes, 0-1 minutes and 14.8 minutes, >60 minutes) and 109 steps/minute threshold (64.8 minutes, 0-1 minutes and 7.2 minutes, >60 minutes).

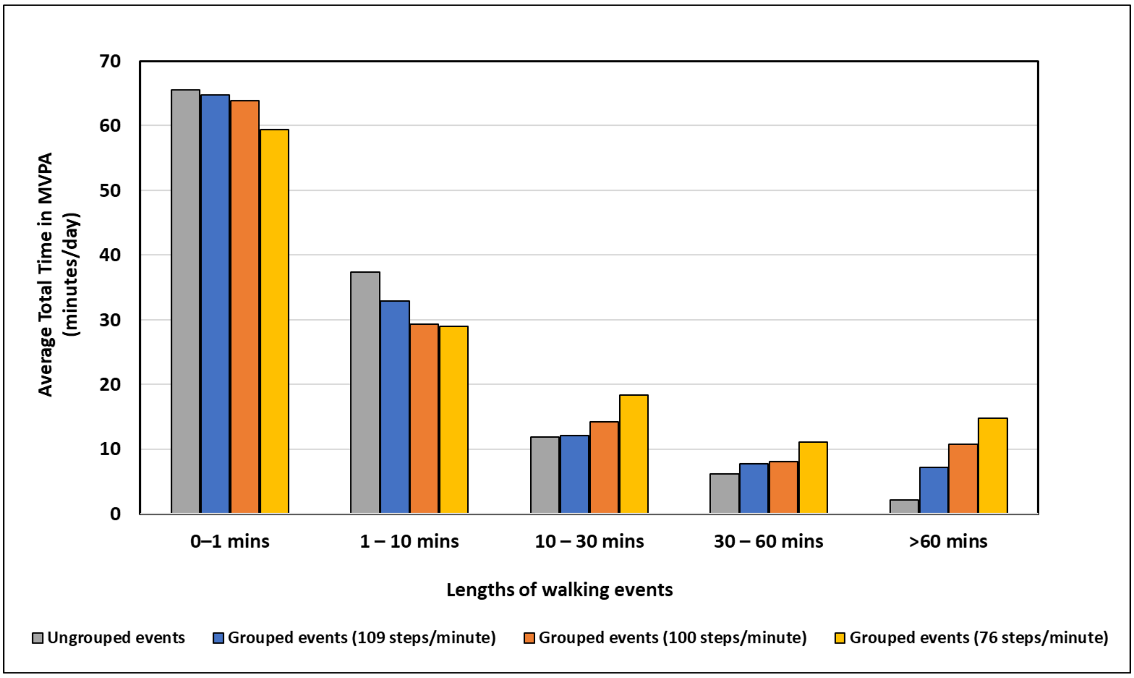


Figure 4.9: Walking events lengths of ungrouped and grouped events in terms of duration per day

4.5.4 Composition of the events included in the grouping analysis

The composition of grouped events was expressed as the average total duration per participant per day: to show the individual make-up of the grouped events in terms of the lengths of walking and standing events. At a cadence threshold of 100 steps/minute, the standing events that were included in the processing of the grouped events ranged from 0.9 to 2.5 minutes long. The standing events included varied depending on the cadence threshold used: at 76 steps/minute, the average duration of standing events ranged from 1.9 to 5.1 minutes long, at 100 steps/minute, the average duration of standing events ranged from 0.9 to 2.5 minutes long and at 109 steps/minute, the average duration of standing events ranged from 0.5 to 1.8 minutes. Figure 4.10 shows the composition of the grouped walking bouts using the 100 steps/minute threshold for four different bout length ranges. The shorter walking bouts of 0-10 minutes, were exclusively made up of walking events equal to this duration and short standing events, no events shorter than this duration were included as this was the smallest possible duration range. As the walking bout size is increased, the distribution of events that make up the event bout shifts from predominantly events of the same duration to events shorter than the duration. This shows that the longer bout lengths are predominantly made up of shorter events and highlights the influence of the grouping process on these bout lengths that would be considered continuous walking (>10 minutes).

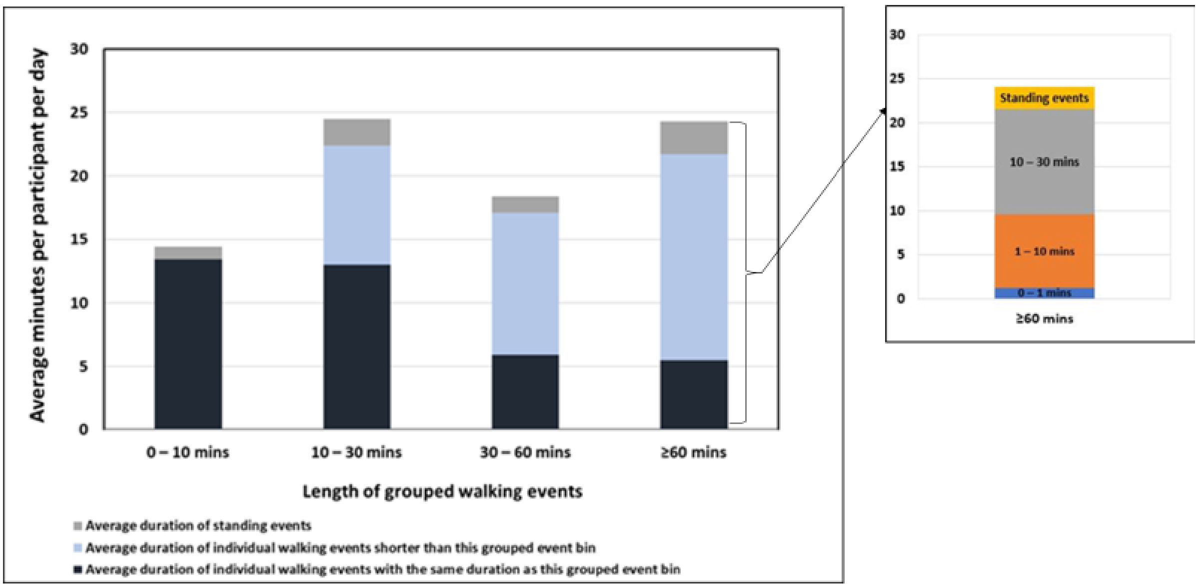


Figure 4.10: Composition of grouped events, showing walking and standing events included (showing a breakdown of the composition of the ≥60 minutes event length)

4.5.5 Compliance with physical activity guidelines

In terms of compliance to 2019 physical activity guidelines (to achieve a minimum of 150 minutes of MVPA per week, or on at least 30 minutes of MVPA per day on five days a week) (DHSC, 2019), the number of compliant participants varied based on the definition of MVPA used (Table 4.4). At 100 steps/minute for the 2019 guidelines, there were 17 compliant participants before grouping, and an additional five participants after grouping, making a total of 22 participants meeting recommended guidelines. Regarding the 2011 physical activity guidelines (the inclusion of a minimum bout length of 10 minutes), only seven participants were compliant with the guidelines before grouping; however, after grouping, seven additional participants met the guidelines, making a total of 14 participants. The effect of grouping was more evident in compliance to the 2011 participants, where a 100% increase in compliance was observed among the participants at a cadence threshold of 100 steps/minute from seven to 14 participants, and an 83% increase at 109 steps/minute threshold from six to 11 participants being compliant.

Table 4.4: Compliance to 2011 and 2019 UK physical activity guidelines among the participants

Cadence threshold for MVPA (steps/minute)	Number of compliant participants	
	2011 UK physical activity guidelines [a]	2019 UK physical activity guidelines [b]
76		
• **Ungrouped**	7	22
• **Grouped**	17	23
100		
• **Ungrouped**	7	17
• **Grouped**	14	22
109		
• **Ungrouped**	6	13
• **Grouped**	11	13

[a] 2011 physical activity guidelines was defined as a minimum of 30 minutes of MVPA per day on five days a week, with a minimum bout length of 10 minutes [b] 2019 physical activity guidelines was defined as a minimum of 30 minutes of MVPA per day on five days a week.

Chapter 5: Methodology II –Methods for Study Three

Chapter	Summary of each chapter
1- Introduction	A background to physical activity, the role of commuting to contributing to physical activity, an overview of methods used in measuring commuting physical activity, and its association with health outcomes.
2- Literature review	A critical review and discussion of the literature surrounding measuring commuting MVPA, and its association to various health outcomes, especially metabolic risk factors
3- Methodology I – Methods for Study One and Two	Describes the methods for Study One:(*Commuting and MVPA)*; and Study Two: (*Gap analysis*) **Aim of Commuting and MVPA study**: To objectively determine the contribution of MVPA during commuting to total MVPA, using cadence to define MVPA, and explore how minimum walking bout length affects adherence to physical activity guidelines. **Aim of Gap analysis study**: To use an event-based approach to define continuous walking events, by combining walking events with short interruptions based on an average cadence threshold.
4- Results I – Results for Study One and Two	Presents the results for objectives one to six: 1. To objectively quantify MVPA during commuting using the definition of cadence. 2. To determine the difference between modes of commute and time spent in MVPA during commuting. 3. To determine the level of compliance to physical activity guidelines by examining the volume of MVPA and length of walking bouts accumulated. 4. To combine short interruptions between walking events to form a new continuous walking event called "grouped event" 5. To examine how grouping walking events changes total time walking and total time in MVPA 6. To ascertain whether combining walking events with short interruptions between them impacts compliance to physical activity guidelines.
5- Methodology II – Methods for Study Three	Describes the methods used in Study Three to address objectives seven to eleven **Aim**: To investigate the association between MVPA during commuting physical activity and metabolic markers.
6- Results II – Results for Study Three	Presents the results for objectives seven to eleven: 7. To determine the difference between the different modes of commute and time spent in MVPA during commuting and non-commuting periods. 8. To objectively quantify MVPA, using different cadence thresholds for MVPA, for both commute and non-commute stepping. 9. To explore the patterns of commute and non-commute stepping at different lengths of walking bouts, before and after grouping walking events. 10. To determine the compliance to the 2011 and 2019 UK physical activity guidelines for all participants before and after grouping walking events. 11. To investigate associations between commute time in MVPA (before and after grouping walking events) and metabolic markers.
7- Discussion	This chapter summarises the findings from Study One to Three, highlights their strengths and limitations within this thesis; Reflection on the impact of COVID-19 on commuting physical activity.
8- Conclusion	This chapter gives a concluding summary of the thesis and implications for policy and future research.

5.0 Chapter Overview

This chapter describes the data collection procedures and analysis used to answer Study Three's aim: *To investigate the associations between MVPA during commuting and metabolic markers.* This chapter presents the methods used to answer objectives seven to eleven:

7. To determine the difference between the different modes of commute and time spent in MVPA during commuting and non-commuting periods.
8. To objectively quantify MVPA, using different cadence thresholds for MVPA, for both commute and non-commute stepping.
9. To explore the patterns of commute and non-commute stepping at different lengths of walking bouts, before and after grouping walking events.
10. To determine the compliance to the 2011 and 2019 UK physical activity guidelines for all participants before and after grouping walking events.
11. To investigate associations between commute time in MVPA (before and after grouping walking events) and metabolic markers.

This study used the previously described methods for quantifying MVPA using cadence in Study One and Study Two (Section 3.3 and 3.5) during commuting and non-commuting periods. These techniques and novel outcomes (that is, ungrouped vs. grouped time in MVPA at the three cadence thresholds for MVPA) are applied to Study Three to determine if there are any associations with these new commuting MVPA outcomes and metabolic markers.

5.1 Study Design

A cross-sectional, observational design was used to address the aim of this study. The study design was the same as that of Study One and has been fully discussed in Section 3.2.1; However, Study Three used a different study population and included finger-prick blood tests for testing the metabolic markers. The full description of the sample population and recruitment process is detailed in Section 5.2.

5.2 Study sample

5.2.1 Recruitment of participants and Inclusion/exclusion criteria

The original aim was to recruit a convenience sample of 50-80 staff and postgraduate research students at the University of Salford. The minimum number of participants was estimated based on previous research that has used the convenience sampling method, the range of participants in those previous studies was between 26 to 117 participants (Chastin et al., 2009; Dall et al., 2013; Rafferty et al., 2016). The average of these studies was used to determine the lower limit of the study sample (50). In addition, according to Green (1991), a rule of thumb for regression analysis is that per predictor variable, a minimum of 10 participants should be appropriate: a total of eight confounding variables were initially selected, with five of them being high priority based on confounding variables controlled for in previous studies (age, sex, other forms of physical activity, mode of commute, and diet). Therefore, the lower limit of the study sample was 50 based on the five confounding variables that were of high priority, and the maximum number of 80 participants were chosen to allow for a larger number of confounding variables to be controlled for in the regression analysis. However, the final sample population recruited for Study Three was 40 in total due to the onset of Covid, thereby restricting the total number of participants recruited.

The study was advertised via email distribution lists and snowballing technique where the supervisory team/recruited staff/postgraduate research students let other staff members and postgraduate research students know of the study's recruitment. Participants were aged 18 years and above, in full or part-time employment or postgraduate research students at the university and travelled to work at least three days a week by car, public transport (bus, tram, and train), walk, or cycle (Panter et al., 2018). Participants were excluded if they were pregnant, diagnosed with diabetes, or previous history of heart disease or medications known to affect lipid or glucose metabolism, or sensitive skin to medical dressings because of the attachment of the activPAL™ to the skin.

Staff and postgraduate students who were interested in the study were sent the participant information sheet (Appendix 8) and if they agreed to take part, they were asked to sign a consent form (Appendix 9) before data collection. Participants were asked to wear an activPAL™ for seven days, fill in an activity diary, and partake in health checks that involved a finger prick blood test. The fasting finger-prick blood samples were tested to measure fasting blood glucose, HDL-cholesterol, and triglycerides, following an 8-hour overnight fast; blood pressure measurements were also taken.

Before commencement of data collection, ethical approval was first granted by the Research, Enterprise, and Engagement Ethical Approval Panel, the University of Salford on 29/11/2018; (application number: HSR1819-019- Appendix 10). An amendment was made to the study to include additional questions to the activity diary on fruit and vegetable intake because the diet may confound or mediate the relationship between commute time and metabolic markers (Mytton et al., 2016; Suyigama et al., 2016). Ethical approval was granted on 20/05/2019 (Appendix 11).

5.3 Data collection procedure

Data collection was carried out between June and November 2019 at the physiological laboratory was located at the School of Health and Society at the University of Salford. Data collection was staggered and based on the physiological laboratory's availability: participants were asked to book on to the most convenient date available and the week that is a better representation of their regular working week. The data collection session involved handing out the activPAL™ accelerometer and activity diary to the participants and taking the finger-prick test.

5.3.1 ActivPAL™

The activPAL™ accelerometers were fully charged and set up for recording using the manufacturer's software and set up a day before the data collection session. The devices were waterproofed with a nitrile sleeve and Hypafix transparent dressing. The accelerometers were set to start recording at 3 pm on the day of the data collection and they were handed out to the participants at the beginning of the data collection session.

At the start of the data collection session, the procedure for attaching the accelerometer and taking the finger-prick test was explained to the participant before commencing; and each participant signed the consent form. Each participant was shown how to attach the activPAL3™ accelerometer and fill in the activity diary –containing questions on commute times and an information leaflet on re-attachment of the accelerometer. The activPAL3™ accelerometer was attached to the front of the thigh using an adhesive medical waterproof dressing called Hypafix. Participants were asked to wear the activPAL3™ accelerometer continuously for seven days and take it off the morning of the eighth day. On return of the activPAL3™ accelerometers, the devices were checked that they contained data for the period the device had been worn. Any participant with incomplete data after initial checks was asked to re-wear the device for another seven days; however, if they did not consent, the participant was excluded from the analysis. For this study, the participant (n=1) with an initial incomplete accelerometer data accepted to re-wear the accelerometer for another seven-day period.

5.3.1.1 ActivPAL™ accuracy testing

As previously evidenced in the literature review section (Section 2.3.5.3), the activPAL™ has been validated for measuring stepping (that is, walking and running) in different populations (Grant et al., 2006); however, the specific activPAL™ devices to be used in this study were tested for accuracy. This testing was conducted to ensure that the devices recorded the intended variables needed to be measured, i.e., standing, stepping (walking or running), and cycling. The five activPAL™ devices were checked for validity in terms of postural classification of activities by placing the devices flat in a vertical position and upright in a horizontal for one hour each as per the manufacturer's instruction. All the devices showed 100% accuracy in detecting both postural positions (vertical and horizontal) for the specified times.

Further testing was conducted in one of the sports laboratories at the University of Salford; a postgraduate student at the university agreed to take part in the testing procedures. The five activPAL™ devices were attached to the front mid-line of both thighs using a hypoallergenic medical dressing. The student was asked to perform two and half minutes of walking, running, sitting, standing, and cycling[23] (Dahlgren et al., 2010): these activities were repeated three times. The activity was video recorded using a smartphone to allow for a comparison between

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[23] An exercise bike (Monark Ergomedic 828E) was used to assess cycling

direct observation and the output from the devices, and the start and finish times of each activity were noted.

The devices recorded accurately within the two and half minute window of each activity; however, it was observed that there were small differences (not statistically significant) in terms of when the device began recording. This could have been as a result of the time stamp differences of one to 30 seconds between the devices, resulting in small differences in the total number of steps accumulated. With the most recent update to the activPAL™ software, time spent cycling has been differentiated from walking and all five devices had 100% accuracy in classifying this activity in the correct time window.

5.3.2 **Activity diary**

An activity diary was used to record information on commute times to and from work, mode of commute used, the times spent outside of commute, distance travelled to and from work, and any removal periods of the accelerometer (Figure 5.1, Appendix 12). The activity diary was developed for Study One (Section 3.2.4); however, the diary used in Study One could not capture the amount of time spent in each mode for people that travelled with more than one mode. Therefore, the activity diary was modified for Study Three to capture the duration spent in each mode of commute and particularly commutes involving more than one mode, (mixed-mode journeys) (Figure 5.1). Additional questions on demographic, lifestyle factors, and fruit and vegetable intake were collected from all participants (Section 5.5.2).

DAY/DATE:

Did you travel to work today? ______________________

What time did you leave the house? ______________________

What time did you arrive at work? ______________________

What time did you leave work? ______________________

What time did you get back into the house? ______________________

How much time in total did you spend travelling **to and from work** by:

TO WORK		FROM WORK	
Walking	HOURS MINUTES	Walking	HOURS MINUTES
Cycle		Cycle	
Car and Taxi		Car and Taxi	
Train		Train	
Bus		Bus	

COMMENTS (Please fill in the blank spaces below if you removed the device, the time the device was put back on, and the reason why you did)

Time removed: ______________________ Time put back on: ______________________

Reason: ____

Figure 5.1: Activity diary designed for Study Three

5.3.2.1 Commute modes classification

Participants were asked to fill in the activity diary for the mode used in commuting to and from work. They were assigned to one of four groups: car, cycle, walk or mixed-mode. The car commuters were those who drove primarily to and from work; walking commuters were those who walked primarily to and from work; while cycle commuters were those who cycled to and from work throughout the sample week. The mixed-mode commuters were those who walked or cycled as a part of their journey in combination with a car or a train ride.

5.3.3 Metabolic markers measurements

The finger-prick test required all the participants to fast overnight for eight hours before their data collection session. The metabolic markers included the anthropometric measures (height, weight, and waist circumference), blood pressure measures, fasting blood glucose, and lipid measures (HDL-cholesterol, LDL-cholesterol, and triglycerides)

5.3.3.1 *Anthropometric measures*

- Height was measured using a portable stadiometer: each participant was asked to stand barefoot and with the back of their head and heels against the stadiometer. Measurements were recorded to the nearest 0.1cm. Weight was measured without shoes on a weighing scale (Seca 769, Birmingham, UK). Measurements were recorded to the nearest 0.01kg.
- Waist circumference was measured using a tape measure at the midpoint between the lower rib margin and the iliac crest of the participant. The waist circumference was recorded to the nearest 0.1cm. Waist circumference does not distinguish between fat and fat-free mass; neither does BMI (Bozeman et al., 2012), but waist circumference is one of the risk factors used to define the presence of metabolic syndrome (Kassi et al., 2014)

5.3.3.2 *Metabolic markers*

- Blood pressure was measured using an automated sphygmomanometer, Omron blood pressure monitor (Omron Healthcare Limited, Milton Keynes, UK). The participants were asked to sit down for five minutes before the first reading was taken. Three measurements were taken with a 60 second rest period interval between each measurement. The average of the last two measurements was used.

- Finger-prick blood samples on the index finger on the non-dominant hand were collected in a fasting state for fasting blood glucose, HDL-cholesterol, and triglycerides tests, using the CardioChek professional analyser (PTS Diagnostics, Indiana, USA). The CardioChek professional analyser is a portable analyser and a test strip system capable of running several biochemical analyses. The tests strips are for the quantitative analysis of glucose, HDL cholesterol, and triglycerides in capillary whole blood from the fingertip. The analyser is a component of a test system that included PTS Panels glucose test strips and PTS Panels lipid test strips. The portability of the test device makes it ideal for the testing of blood in all kinds of locations. Relevant training in finger-prick blood testing and the use of the CardioChek analyser was received as part of data collection assistant work on the SMART Work & Life study (Edwardson et al., 2018) (Appendix 13).
- The CardioChek analyser was calibrated using the corresponding code chip to match the test strip lot number. The lipids and the glucose test strips were then inserted into the CardioChek analyser. Gloves were used to avoid cross infection and contamination: the participant's finger was wiped clean using an antibacterial wipe and dried. A single-use sterile lancet was used to prick the finger and discarded in a recognised sharps bin after use. Capillary pipettes were used to transfer the blood (15-40ml of blood) from the pricked finger to the test strips. Used test strips and capillary pipettes were discarded in a clinical waste bag. Both fasting blood glucose and lipid tests were performed simultaneously using the CardioChek analyser. The results were recorded using a test result sheet, and the participant received a copy of their results at the end of the data collection session (Appendix 14).

5.4 Data cleaning and reduction

The data were cleaned as per the process detailed in Sections 3.3.1 and 3.5.1). For cycling commuters, the updated proprietary algorithm software for the activPAL™ gave the time spent cycling as an output from the accelerometer. Therefore, all the cycling time was included as time spent in MVPA as previously described by Johansson et al., (2019). The total time spent while cycling can be used as a proxy for the time spent in MVPA because cycling is a high-intensity interval activity and usually requires more energy expenditure per unit of time (Ainsworth et al., 2011; Johansson et al., 2019). However, the time spent cycling did not involve accumulating actual steps as the activPAL™ accelerometer did not record any step count for the time spent cycling. In this study, cycling commuters were excluded from any stepping analysis.

In summary, the data was processed using a pre-written MATLAB script to extract all stepping/walking events containing the duration, the number of steps, and the cadence of each stepping/walking event. As per the grouping process, two walking events were combined with a standing/non-sedentary event between them to create a new grouped event: and an average cadence for this new grouped event and compared to the cadence threshold for MVPA (76, 100, or 109 steps/minute). After the data were cleaned and reduced, the data were then transferred to SPSS software for further statistical analysis.

5.5 Measurements

5.5.1 Exposure (Independent variables)

The main exposure was the commute time in MVPA, based on cadence before and after grouping (defined as combining walking events and short interruptions between them). MVPA was defined as a period of walking with a cadence of 100 steps/minute as suggested by previous research (Marshall et al., 2009; Rowe et al., 2011; Tudor-Locke et al., 2005). Other cadence thresholds of MVPA for a healthy population, 76 steps/min (Dall et al., 2013) and 109 steps/min (Chastin et al., 2009) were also included in the analysis. In this study, MVPA was quantified in terms of cadence and the data processing for extracting information from the activPAL™ has been described in detail in Section 3.3.1. The total number of steps taken per day were grouped by the modes of commute based on Tudor-Locke's classification of physical activity level: the categories are sedentary or inactive (<5000 steps/day), low active (5000-7499 steps/day), somewhat active (7500-9999 steps/day), active (10,000-12,500 steps/day), and highly active (>12,500 steps/day) (Tudor-Locke & Bassett, 2004).

The main outcome measures from the activPAL™ were steps and time spent in MVPA during commuting and non-commuting periods. To achieve objectives six to nine, the duration and steps taken during commuting and non-commuting periods were classified based on:

- Cadence: 76, 100, & 109 steps/minute.
- Lengths of walking bouts: short, <5 minutes; medium, 5-9.99 minutes; and long, ≥10 minutes (Mark & Janssen, 2009).
- Mode of commute: car, walk, cycle, and mixed-mode.

Compliance with physical activity guidelines was calculated by summing the time spent in MVPA for each cadence threshold of 76, 100, and 109 steps/minute. As a result of changes to the 2019 physical activity guidelines – the length of walking bouts was removed as an important component to determine compliance with physical activity guidelines; therefore, the compliance to the 2011 and 2019 guidelines was tested in all participants. A minimum duration of 30 minutes per day in MVPA was considered compliant with the 2019 guidelines; and in addition to the 2019 guidelines, a minimum walking bout length of 10 minutes was compliant with the 2011 guidelines. Furthermore, the grouping of walking events was analysed and compliance to the 2011 and 2019 guidelines was explored to determine the effect of grouping on compliance to physical activity guidelines.

5.5.2 Demographic and lifestyle factors

The following demographic and lifestyle factors were collected from all participants: age, sex, level of education, employment status, and fruit and vegetable intake.

- Age was treated as a continuous variable
- Sex was categorised as male and female
- Level of education was categorised as GCSE and below, A-Levels, First degree, and Higher degree
- Average fruit and vegetable per day was categorised as fewer than five a day and greater than or equal to five a day

The variables were adjusted for in the regression models as potential confounding factors including non-commute in MVPA and sedentary time per day. This is based on whether time spent in MVPA is co-dependent or independent of time spent in other domains of physical activity across the day, due to the composition of behaviours across the day, i.e., if one behaviour increases, then inherently, the other decreases (Chastin et al., 2015).

5.5.3 Outcome measures (Dependent variables)

Metabolic markers were measured and entered into the linear regression model using the following variables:

- BMI was calculated as weight (in kilograms) divided by the square of height (in metres) and BMI was treated as a continuous variable.
- The waist circumference was recorded to the nearest 0.1cm and was treated as a continuous variable.
- Blood pressure: The systolic and diastolic blood pressure measures were entered into the regression model separately and treated as continuous variables.
- Fasting blood glucose was treated as a continuous variable.
- HDL-cholesterol was treated as a continuous variable
- Triglycerides was treated as continuous variables.

For the logistic regression models, dichotomous responses were used based on the cut-off points of the metabolic markers measured: triglycerides <1.70 mmol/l; HDL-cholesterol: >1.03 mmol/l in men, >1.29 mmol/l in women; blood pressure: <130/85 mmHg, and fasting blood glucose: <5.6 mmol/l; however, waist circumference was defined according to IDF'S criteria population-specific cut-offs (for Europeans, <102 cm in men and <88 cm in women; and for South Asians, Chinese, and Japanese, <90 cm in men and <80 cm in women). The NCEP ATP III definition was used in this study because it is the most used definition in commuting studies (Expert Panel on Detection, 2001). Metabolic syndrome was determined by using the definition by NCEP ATP III as the presence of three or more of the following (Table 5.1). According to IDF'S definition, abdominal obesity can be assumed if BMI is greater than $30kg/m^2$ using population-specific cut-offs. Therefore, BMI was included as an anthropometric measure in the case where waist circumference data was not available.

The abdominal obesity population-specific cut-offs were considered in this study because the black minority ethnic group are more at risk of some diseases than the white ethnic group (Alberti et al., 2009). The participants included in the analysis for Study Three were predominantly white British, with two participants being classed as Black African and Arab.

Therefore, the European cut-off points for waist circumference was used for the sample population included in this study.

Table 5.1: Metabolic markers and their specific cut-offs

Metabolic markers	**Ranges**	**Categorical classification**
Fasting blood glucose (FBG)	<5.6mmol/L >5.6mmol/L	No (low FBG) Yes (high FBG)
HDL-cholesterol (HDL-Chol)	>1mmol/l(men); >1.2mmol/l (women	No (High HDL) Yes (Low HDL)
Triglycerides (TRIG)	<1.7mmol/l >1.7mmol/l	No (Low Trig) Yes (High Trig)
Blood Pressure (BP)	<130/85mmHg	No (Normotensive) Yes (Hypertensive)
Waist circumference	<102cm in men, <88cm in women	No (Low WC) Yes (High WC)
Body mass index (BMI)	>30kg/m^2 <30kg/m^2	Obese Healthy weight

5.6 Statistical Analysis

Data analyses were carried out using SPSS Statistics (version 25.0; IBM, Armonk, NY, USA). Variables were tested for normality using Shapiro-Wilk test: the data were skewed, that is, non-normally distributed. The mean steps and time per day in MVPA were calculated for each participant; however, because of the non-normal distribution of the data, the median of the means of the time and steps per day in MVPA are presented within the results section for Study Three (Chapter 6). Therefore, the medians of the means are presented throughout this thesis.

Descriptive analysis of participants' characteristics was expressed as means with standard deviations for normally distributed variables, medians, and interquartile ranges for non-normally distributed variables, and numbers with percentages for categorical variables in the car, cycle, walk, and mixed-mode commuters. The differences between the modes of commute and time spent in MVPA during commuting were compared using the Kruskal Wallis test. To determine the differences between walking events before and after grouping at all three cadence thresholds, Wilcoxon signed-rank test was carried out.

5.6.1 The rationale for the regression analyses

Quantile regression is an alternative to ordinary least squares (OLS) regression or linear regression when the conditions of normality, homoscedasticity, and independence have not been met (Koenker & Hallock, 2001; Le Cook & Manning, 2013). It is an appropriate analysis for modelling non-normally distributed data as it estimates using the median of the target variable (Le Cook & Manning, 2013). To carry out a quantile regression analysis for the non-normally distributed dependent variables, it was important to perform a heteroscedasticity test. A heteroscedasticity test tests that the variance of the errors does not depend on the values of the independent variables. This test proves that the coefficients of the quantile regression are significantly different from the linear regression: therefore, the use of a quantile regression rather than a linear regression is justified. Two major tests were carried out to justify the use of quantile regression for non-normally distributed dependent variables (BMI, waist circumference, and triglycerides):

1. Visual examination of the residual plots: squared residuals plotted against predicted y-values.
2. Breusch-Pagan tests for heteroscedasticity: this tests that the variance of the errors does not depend on the values of the independent variables (Koenker & Bassett, 1978). A significant value of $p<0.05$ indicates that the data are heteroscedastic and therefore, the quantile regression is applicable.

After visually examining the plots, there was no observable pattern in the residuals indicating homoscedasticity. To further establish the result obtained from the visual inspection, the Breusch-Pagan test for heteroscedasticity was conducted and the result was not significant (BMI: $p=0.81$; waist circumference: $p=0.86$; triglyceride: $p=0.39$). The test indicates that the linear regression model is better suited for non-normally distributed dependent variables as the quantile regression model is not significantly different from the linear regression model.

Therefore, the linear regression model was used in this thesis in predicting the effect of MVPA during commuting on metabolic risk factors.

5.6.2 Regression Analyses between Commute time in MVPA and metabolic outcomes

Linear regression was performed to investigate the association of MVPA during commuting with metabolic outcomes. For the linear regression, commute time in MVPA before and after grouping was treated as a continuous variable and all three thresholds (76, 100, & 109 steps/minute) were analysed.

The outcome measures (dependent variables) were included one by one as the dependent variable, and each confounder was included together with commute time in MVPA as an independent variable. To identify potential confounders, univariate models were used for each of the outcome variables. To select the relevant confounders, a forward selection procedure was performed, using a univariate analysis for the first step. In this case, the confounders were added to the model one by one. The strongest confounder in the model was first chosen and other important confounders were added to the model until no confounder had a relevant effect ($p>0.1$) (Bursac et al., 2008; VanderWeele, 2019). The linear regression models were adjusted for potential confounders: age, fruit and vegetable intake, non-commute time in MVPA, and sedentary time per day. The models with BMI as an outcome were additionally adjusted for WC, and the model with waist circumference as an outcome was additionally adjusted for BMI. A probability, p-value of 0.05 was set to determine the level of significance of the results obtained.

The collinearity of covariates was checked for each model with variance inflation factors (Coombs & Stamatakis, 2015; Stamatakis, Hamer, et al., 2012); variance inflation factors quantify the severity of multicollinearity in regression models (Mansfield & Helms, 1982). Generally, variance inflation factors greater than 10 suggest the presence of collinearity between the models' covariates (Mansfield & Helms, 1982). For all the covariates in the regression model in this study (for each health-related outcome), variance inflation factors were all less than one, which indicated that collinearity warranted no further investigation in these analyses.

The logistic regression was used to investigate the association between hypertension, obesity, dyslipidaemia, and metabolic syndrome. This model is best suited for categorical dependent variables. For the logistic regression, the independent variable – commute time in MVPA –was expressed as a continuous variable. The cut-offs for defining metabolic syndrome and the individual risk factors have been previously defined in Section 5.3.3 (Table 5.1). Metabolic syndrome was defined as the presence of three or more of the following: high waist circumference, high triglycerides, low HDL-cholesterol, high systolic or diastolic blood pressure, high blood glucose (NHS, 2018). Logistic regression was used to assess the odds ratio and 95% confidence interval associated with commute time in MVPA for metabolic outcomes.

Chapter 6: Results II – Study Three: Association between Commute time in MVPA and metabolic outcomes

Chapter	Summary of each chapter
1- Introduction	A background to physical activity, the role of commuting to contributing to physical activity, an overview of methods used in measuring commuting physical activity, and its association with health outcomes.
2- Literature review	A critical review and discussion of the literature surrounding measuring commuting MVPA, and its association to various health outcomes, especially metabolic risk factors
3- Methodology I – Methods for Study One and Two	Describes the methods for Study One:(*Commuting and MVPA)*; and Study Two: (*Gap analysis*) **Aim of Commuting and MVPA study**: To objectively determine the contribution of MVPA during commuting to total MVPA, using cadence to define MVPA, and explore how minimum walking bout length affects adherence to physical activity guidelines. **Aim of Gap analysis study**: To use an event-based approach to define continuous walking events, by combining walking events with short interruptions based on an average cadence threshold.
4- Results I – Results for Study One and Two	Presents the results for objectives one to six: 1. To objectively quantify MVPA during commuting using the definition of cadence. 2. To determine the difference between modes of commute and time spent in MVPA during commuting. 3. To determine the level of compliance to physical activity guidelines by examining the volume of MVPA and length of walking bouts accumulated. 4. To combine short interruptions between walking events to form a new continuous walking event called “grouped event” 5. To examine how grouping walking events changes total time walking and total time in MVPA 6. To ascertain whether combining walking events with short interruptions between them impacts compliance to physical activity guidelines.
5- Methodology II – Methods for Study Three	Describes the methods used in Study Three to address objectives seven to eleven **Aim**: To investigate the association between MVPA during commuting physical activity and metabolic markers.
6- Results II – Results for Study Three	Presents the results for objectives seven to eleven: 7. To determine the difference between the different modes of commute and time spent in MVPA during commuting and non-commuting periods. 8. To objectively quantify MVPA, using different cadence thresholds for MVPA, for both commute and non-commute stepping. 9. To explore the patterns of commute and non-commute stepping at different lengths of walking bouts, before and after grouping walking events. 10. To determine the compliance to the 2011 and 2019 UK physical activity guidelines for all participants before and after grouping walking events. 11. To investigate associations between commute time in MVPA (before and after grouping walking events) and metabolic markers.
7- Discussion	This chapter summarises the findings from Study One to Three, highlights their strengths and limitations within this thesis; Reflection on the impact of COVID-19 on commuting physical activity.
8- Conclusion	This chapter gives a concluding summary of the thesis and implications for policy and future research.

6.0 Chapter Overview

This chapter presents the results from **Study Three** to address the following aim: to investigate the association between MVPA during commuting and metabolic syndrome and its risk factors. This chapter presents results that answer objectives seven to eleven:

7. To determine the difference between the different modes of commute and time spent in MVPA during commuting and non-commuting periods.
8. To objectively quantify MVPA, using different cadence thresholds for MVPA, for both commute and non-commute stepping.
9. To explore the patterns of commute and non-commute stepping at different lengths of walking bouts, before and after grouping walking events.
10. To determine the compliance to the 2011 and 2019 UK physical activity guidelines for all participants before and after grouping walking events.
11. To investigate associations between commute time in MVPA (before and after grouping walking events) and metabolic markers.

In this chapter, the first section describes the characteristics of all participants grouped by the modes of commute (Section 6.1). These characteristics are the demographic data, anthropometric measures, metabolic outcomes, accelerometer-derived variables, and self-reported responses (from the activity diary). The second section focuses on the distribution of total steps at different cadence bands and lengths of walking bouts: grouped by commuting and non-commuting periods for the different modes of commute (Section 6.2). The third section examines the compliance with UK physical activity guidelines for all the participants grouped by the modes of commute (Section 6.3).

The methods used in Study Two (Gap analysis study), described in Section 3.5, are also used in some of the analyses, in exploring the patterns of the lengths of walking bouts and compliance to UK physical activity guidelines (Section 6.4). The last section looks at the association between MVPA during commuting and metabolic syndrome and its risk factors (Section 6.5). Throughout this chapter, three cadence thresholds for MVPA, 76, 100, and 109 steps/minute were used and cycling commuters were excluded from any stepping analysis.

6.1 Descriptive Analyses

6.1.1 Participants

The total number of participants recruited and sampled was 40. Thirty-six participants had complete waking and commute data from the activPAL™ accelerometer and activity diary for seven days, and the remaining four participants had complete waking and commute data from the activPAL™ accelerometer and activity diary for six days. The participants were staff and postgraduate research students at the University of Salford: all the staff participants were in full-time employment, and all the postgraduate research students were in full-time education. Thirty out of 40 (70%) participants had at least three full days of commute data, that is, activPAL™ accelerometer and activity diary: with the remaining 10 participants having only two full days of commute data.

Many of the participants (n=27) maintained the same mode of commute throughout the data collection period. However, the remainder of the participants (n=13) had an alternative mode of commute (that is, did not use the same mode of commute throughout the data collection period) on only one day during the data collection period. Out of these 13 participants, four of them reported not commuting to their usual workplace (attended off-campus meetings) on the day the alternative mode of commute was used during the data collection period. Although having an alternative mode of commute represents commuting in free-living activities, the main and most frequent mode of commute is usually reported in the literature (Mytton et al., 2018; Vaara et al., 2020). Therefore, the most frequent mode of commute reported was used as the mode of commute for all participants in this study.

Of the 40 participants, 19 (48%) commuted by car only, 13 (32%) were mixed-mode commuters, six (15%) were walking commuters, and two (5%) were cycling commuters. The mixed-mode commuters consisted of participants that commuted with more than one mode involving a train, bus, walk, and car travel throughout the data collection period. All the mixed-mode commuters had a walking component included in their journey. Eight of the mixed-mode commuters commuted by train and walking; two mixed-mode commuters combined car, train, and walking, one mixed-mode commuter combined train, bus, and walking; another by tram, bus, and walking; and one combined bus and walking in a commuting journey. All the mixed-mode commuters maintained the same mixed-mode component throughout the data collection period.

The use of the modified diary for Study Three was designed in a way that allowed for participants to report the time spent in each mode of commute undertaken in a commuting journey. This helped in classifying participants into different commute modes based on their responses. The diary used in Study One may have resulted in some car users being classed as mixed-mode commuters: the activity diary in Study One allowed for participants to report all the modes used in each journey without reporting the time spent in each mode; therefore, allowing car commuters to report being mixed-mode commuters. In Study Three, four participants may have been misclassified as mixed-mode commuters if the diary from Study One had been used, as they reported car and walk as their mode of commute to and from work (Table 6.1).

Table 6.1: Classification of modes of commute using Study One and Study Three's activity diary

Participant ID	Classifications using Study One's diary	Classifications using Study Three's diary
3	Mixed-mode	Car
7	Mixed-mode	Car
27	Mixed-mode	Car
28	Mixed-mode	Car

6.1.2 Demographic and lifestyle factors

Table 6.2 shows the characteristics of all participants for the four modes of commute classifications: car, cycle, walk, and mixed-mode (including public transport). The mean age of all the participants was 39.0 (SD: ±11.8) years, with more females than male participants (70% vs. 30%). Regarding the level of education, 78% of the participants had a higher degree: this is not surprising as the data were collected among staff and postgraduate research students at the University of Salford. There were more staff participants than postgraduate research students (83% vs. 17%), and the car mode was the most common mode of commute. Across all the modes of commute, 57% of the participants consumed greater than the recommended portions of fruit and vegetables while 43% consumed fewer than the recommended guidelines of five a day (NHS, 2018).

The median time spent commuting to work was 72.3 (Interquartile range (IQR): 54.6-129.8) minutes per day, and this differed significantly among the modes of commute (p=0.016). The walking commuters spent the shortest time commuting to and from work (41.7 (25.6-62.4) minutes), followed by the car commuters (81.7 (54.0-113.3) minutes), then the cycling commuters (88.3 (25^{th} quartile: 56.5 minutes), and the mixed-mode commuters had the longest duration (120.0 (IQR: 65.0-183.4) minutes). Although mixed-mode commuters spent the longest time commuting to work (120.0 (65.0-183.4)) minutes, they did not travel the longest distance to work (5.3 (2.8-29.9) miles). The distance travelled to work differed across the modes of commute (p=0.004), with car commuters travelling the longest distance to work (9.9 (IQR: 5.8-28.0) miles), followed by the cycle commuters (6.1 (3.7) miles), then mixed-mode commuters (5.3 (2.8-29.9) miles), and then walking commuters (1.3 (0.6-0.9) miles).

Overall, 73% (n=29) of participants met the recommended 2019 physical activity guidelines (at least 30 minutes of MVPA per day for at least 5 days), with all mixed-mode, cycling, and walking commuters meeting these guidelines. Only 42% (n=8) of the car commuters met the recommended physical activity guidelines.

Table 6.2: Demographic and lifestyle factors for all participants

Characteristics	All (n=40)	Car (n=19)	Cycle (n=2)[f]	Walk (n=6)	Mixed mode (n=13)	p-value[d]
Age (years)[a]	39.0 (±11.8)	41.2 (±10.7)	45.5 (±3.5)	29.3 (±9.3)	39.4 (±13.4)	0.149
Sex (No, %)[c]						
• **Female**	28 (70)	15 (55)	2 (7)	3 (11)	8 (28)	0.367
• **Male**	12 (30)	4 (33)	-	3 (25)	5 (42)	
Level of Education, %[c]						
• **GCSE and below**	3 (8)	1 (5)	-	1 (17)	1 (8)	
• **College Degree**	2 (5)	1 (5)	-	1 (17)	-	0.765
• **First Degree**	4 (10)	2 (11)	-	-	2 (15)	
• **Higher Degree**	31 (78)	15 (79)	2 (100)	4 (66)	10 (77)	
Fruit and vegetable portions, %[c]						
• **Less than 5 a day**	17 (43)	9 (47)	0	4 (67)	4 (31)	0.281
• **≥ 5 a day**	23 (57)	10 (53)	2 (100)	2 (33)	9 (69)	
Self-reported commute time to work, mins/day[b]	72.3 (54.6-129.8)	81.7 (54.0-113.3)	88.3 (56.5)	41.7 (25.6-62.4)	120.0 (65.0-183.4)	**0.016[e]**

Characteristics	All (n=40)	Car (n=19)	Cycle (n=2)[f]	Walk (n=6)	Mixed mode (n=13)	p-value[d]
Distance travelled to work (one-way) (miles)	7.5 (2.4-21.0)	9.9 (5.8-28.0)	6.1 (3.7)	1.3 (0.6-1.8)	5.3 (2.8-29.9)	**0.004**[e]
Duration spent sedentary, mins/day[b]	501.6 (422.5-583.7)	480.6 (378.7-568.7)	535.8 (484.9)	509.2 (399.6-716.9)	545.3 (449.8-665.7)	0.447
Meet physical activity guidelines [g]**, n (%)**[c]						
• **Yes**	29 (73)	8 (42)	2 (100)	6 (100)	13 (100)	**<0.001**[e]
• **No**	11 (27)	58	0	0	0	

[a]Continuous variables, mean (SD); [b]Continuous variable, median (IQR: 25[th]-75[th]), [c]Categorical variable, no(%), [d]Differences between the modes of commute(Chi-square test for categorical variables; Kruskal-Wallis test for continuous variables), [e]Significant differences (p<0.05), [f]Only reported IQR(25[th]) for cycling commuters, [g] MVPA was defined as 100 steps/minute for compliance to physical activity guidelines.

6.1.2.1 Classification of physical activity levels using total steps

The total number of steps taken per day were grouped by the modes of commute based on Tudor-Locke's classification of physical activity level (Figure 6.1): the categories are sedentary or inactive (<5000 steps/day), low active (5000-7499 steps/day), somewhat active (7500-9999 steps/day), active (10,000-12,500 steps/day), and highly active (>12,500 steps/day) (Tudor-Locke & Bassett, 2004). On average, at least one commuter in each commuting category accumulated over 12,500 steps per day, with mixed-mode commuters being the most highly active group. Car commuters were in each of the activity levels; however, 14 out of 19 were in the low active or somewhat active category. The profile of walking commuters ranged from being less active to being highly active. Commute steps[24] and total steps[25] were significantly different across the three modes of commute ($p<0.001$); however, non-commute steps[26] did not differ across the modes of commute ($p=0.246$).

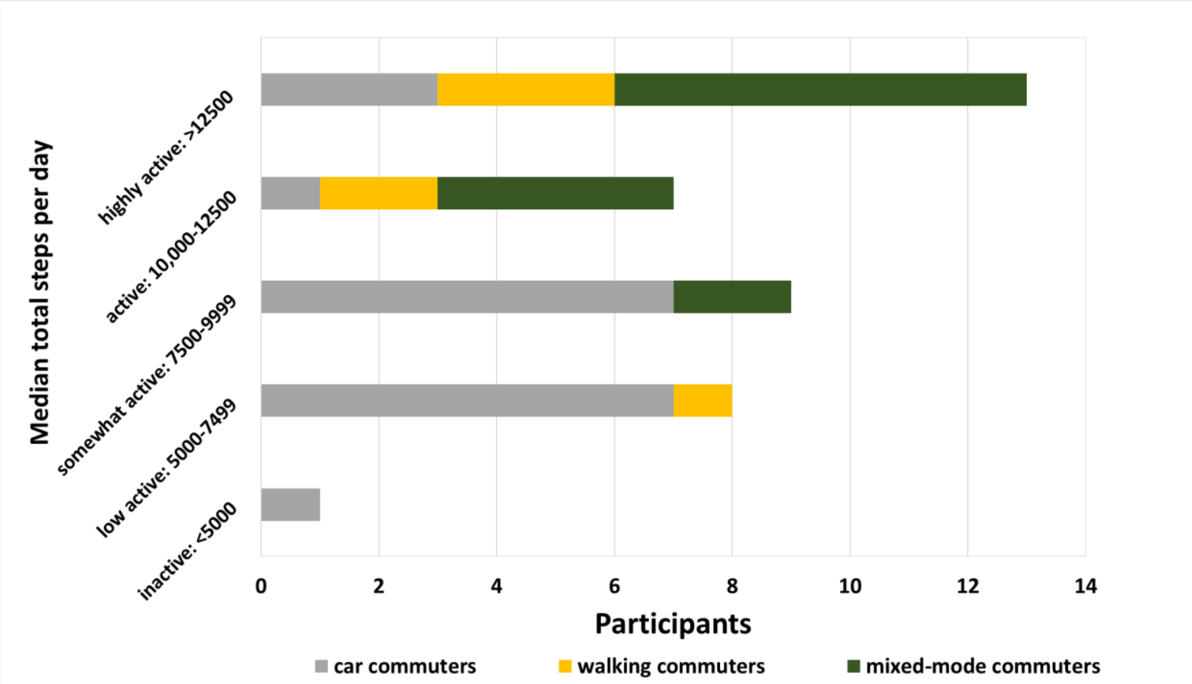

Figure 6.1: Activity level of all participants, grouped by commute mode

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[24] Kruskal-Wallis Test: H(3)=28.984
[25] Kruskal-Wallis Test: H(3)=18.447
[26] Kruskal-Wallis Test: H(3)=4.145

6.1.3 Adiposity and metabolic markers

Table 6.3 shows the adiposity and metabolic profile for all participants grouped by the modes of commute. Car (25.7 (23.7-27.4) kg/m^2) and walking commuters (25.2 (21.5-29.2) kg/m^2) were slightly overweight, compared to the mixed-mode commuters, who had an average BMI in the 'normal' range (23.8 (21.7-25.7) kg/m^2). Despite having a healthy BMI, mixed-mode commuters had the largest waist circumference (84.7 (77.5-86.8) cm), compared to the car commuters (77.7 (75.0-92.0) cm), cycling commuters (76.7 (74.5) cm), and walking commuters (76.4 (72.1-92.2) cm), who all had a lower waist circumference. Overall, the participants were in the normal/healthy ranges for fasting blood glucose, high HDL-cholesterol, low triglycerides, systolic blood pressure, and diastolic blood pressure as defined by National Cholesterol Education Program Adult Treatment Panel III (NCEP ATP III) criteria and International Diabetes Federation (IDF) criteria (Kassi et al., 2014). Furthermore, there were no statistically significant differences between all the metabolic markers across the different modes of commute.

Table 6.3: Adiposity and Metabolic markers for all participants

Characteristics	All (n=40)	Car (n=19)	Cycle (n=2)[f]	Walk (n=6)	Mixed mode (n=13)	p-value[d]
Weight (kg)[b]	68.0 (62.5-75.6)	68.4 (65.0-82.4)	62.5 (60.4)	68.3 (61.8-78.5)	73.8 (60.4-76.5)	0.570
Height (cm)[a]	168.1 (±8.6)	166.2 (±8.1)	163.6 (±5.8)	167.8 (±9.2)	171.0 (±9.2)	0.296
BMI (kg/m^2)[b]	24.5 (22.9-27.1)	25.7 (23.7-27.4)	23.4 (21.5)	25.2 (21.5-29.2)	23.8 (21.7-25.7)	0.669
Waist circumference, cm[b]	81.0 (74.6-90.3)	77.7 (75.0-92.0)	76.7 (74.5)	76.4 (72.1-92.2)	84.7 (77.5-86.8)	0.676
Fasting blood glucose (mmol/L)[a]	4.8 (±0.4)	4.9 (±0.5)	4.5 (±0.5)	4.8 (±0.5)	4.8 (±0.4)	0.695
Triglyceride (mmol/L)[b]	1.0 (0.7-1.9)	1.1 (0.9-1.8)	0.7 (0.6)	0.7 (0.6-1.4)	1.5 (0.7-2.5)	0.187
HDL-cholesterol (mmol/L)[a]	1.5 (±0.4)	1.5 (±0.5)	1.6 (±0.2)	1.4 (±0.4)	1.7 (±0.5)	0.687
Systolic BP (mmHg)[a]	119.2 (±12.1)	117.5 (±9.7)	113.5 (±12.0)	117.5 (±12.3)	123.2 (±15.3)	0.529
Diastolic BP (mmHg)[a]	79.3 (±8.6)	78.7 (±8.4)	75.0 (±2.8)	80.8 (±6.3)	80.0 (±10.6)	0.846

[a]Continuous variables, mean (SD); [b]Continuous variable, median (IQR: 25th-75th), [c]Categorical variable, no(%), [d]Differences between the modes of commute(Kruskal-Wallis test for continuous variables), [e]Significant differences ($p<0.05$), [f]Only reported IQR(25th) for cycling commuters. Abbreviations: BMI – Body mass index, WC- waist circumference, HDL-cholesterol- High-density lipoproteins cholesterol, BP- Blood pressure.

Using the criteria for defining metabolic syndrome as defined by NCEP ATP III criteria and IDF criteria (Table 6.4), only three participants (two-car commuters and one mixed-mode commuter) were at risk of developing metabolic syndrome, that is had the presence of three or more of the metabolic risk factors. High waist measurements and high triglyceride levels were common among mixed-mode and car commuters: 23% of mixed-mode commuters and 21% of car commuters had a high waist measurement, and 46% of mixed-mode commuters and 26% of car commuters had high triglyceride levels. All the mixed-mode commuters with a high waist measurement were females only (n=3). There was one walking commuter with a high waist circumference, one with high triglyceride levels, and another with low HDL-cholesterol levels. Despite this, none of the walking commuters were at risk of developing metabolic syndrome. Overall, a high waist circumference measurement (n=9) and high triglyceride levels (n=12) were more prevalent among the participants than high blood pressure (n=5), high BMI (n=4), and low HDL-cholesterol levels (n=2)

Table 6.4: Criteria for metabolic outcomes for all participants

Metabolic outcomes	Definition for metabolic syndrome criteria [a]	All (n=40)	Car (n=19)	Cycle (n=2)	Walk (n=6)	Mixed mode (n=13)	p-value[b]
High BMI, n (%)	≥30kg/m^2	4 (10)	3 (16)	0 (0)	0 (0)	1 (8)	0.643
High WC, n (%)	≥102 cm in men ≥88 cm in women	1 (3) 8 (20)	1 (5) 4 (21)	0 (0) 0 (0)	0 (0) 1 (17)	0 (0) 3 (23)	0.595
High Triglyceride, n (%)	≥1.7mmol/L	12 (30)	5 (26)	0 (0)	1 (17)	6 (46)	0.376
Low HDL-cholesterol, n (%)	<1.0 mmol/L in men <1.2 mmol/L in women	2 (5)	1 (5)	0 (0)	1 (17)	0 (0)	0.473
High BP, n (%)	≥130/85 mmHg	5 (12)	1 (5)	0 (0)	0 (0)	4 (31)	0.111
Metabolic Syndrome, n (%)[c]	The presence of three or more of the above individual risk factors	3 (8)	2 (11)	0 (0)	0 (0)	1 (8)	0.896

[a]The criteria for the metabolic syndrome definition by National Cholesterol Education Program Adult Treatment Panel III (NCEP:ATPIII) criteria and waist circumference was defined by International Diabetes Federation (IDF) criteria. ; [b]Differences between the modes of commute (Chi-square test and Fisher Exact test for categorical variables); [c] To estimate the number of participants with metabolic syndrome, one of the adiposity measures (BMI or WC) was used in terms of calculating the presence of the risk factors. Abbreviations: BMI – Body mass index, WC- waist circumference, HDL-cholesterol- High-density lipoproteins-cholesterol, BP- Blood pressure.

6.1.4 **Accelerometer-derived variables**

Objective 7: To determine the difference between the different modes of commute and time spent in MVPA during commuting and non-commuting periods.

Table 6.5 gives a summary of accelerometer-derived variables of the steps and time spent in MVPA during commuting and non-commuting periods, using the three different cadence thresholds for MVPA: 76, 100, and 109 steps/minute.

Total time

The median total time spent walking per day for all participants was 114.1 (95.0-160.4) minutes, with cycling commuters (153.3 (121.5) minutes) and walking commuters (132.2 (95.8-162.6) minutes) having the highest duration of walking per day compared to the car commuters (99.7 (88.2-114.8) minutes). There were significant differences in total time spent walking between the modes of commute (p=0.018).

Overall, non-commute walking time per day was 95.63 (76.56-121.83) minutes that contributed a greater proportion (84%) to the total time spent walking per day compared to commute walking time per day, which contributed only 15% (15.09 (6.94-36.01) minutes). The median commute walking time per day differed significantly between the modes of commute (p<0.001); however, there was no significant difference in the non-commute time spent walking per day between the modes of commute and (p=0.919).

Cycling commuters spent more time cycling per day during commuting (55.0 (47.1) minutes) compared to the remaining groups, contributing 48% of their total time walking per day. The car commuters spent the lowest time walking during commuting periods (6.9 (4.2-9.5) minutes), with only 6% of their total time walking spent during commuting periods. Mixed-mode and walking commuters spent at least 31% (34.8 (28.5-55.5) minutes) and 23% (26.2 (14.2-42.6) minutes) respectively, of their total walking time per day during commuting periods.

Total steps

The median total steps per day taken were 10,036 (7,488-13,796) steps, with the number of steps taken during non-commuting periods greater than those taken during commuting periods. There were significant differences in the total number of steps accumulated by all participants across the different modes of commute (p=0.003); with the mixed-mode commuters (13,203 (10,344-17,247) steps) and walking commuters (12,187 (9,218-15,045) steps) accumulating more steps per day compared to car commuters (8,174 (6,983-9,936) steps). The median commute steps per day differed significantly between the modes of commute (p<0.001); however, there was no significant difference between the modes of commute and non-commute steps per day (p=0.724).

Time in MVPA

The median total time spent walking in MVPA at 76 steps/minute was 77.6 (55.0-105.2) minutes, 46.8 (28.6-67.7) minutes at 100 steps/minute, and 32.0 (13.5-54.2) minutes threshold at 109 steps/minute threshold; and they differed significantly between the modes of commute (p=0.003, p<0.001, and p<0.001 respectively).

Similarly, the median commute time in MVPA at 76 steps/minute was 12.9 (4.7-32.8) minutes, 9.9 (2.9-30.1) minutes at 100 steps/minute, and 8.4 (1.6-26.2) minutes at 109 steps/minute threshold: this was significantly different between the modes of commute (p<0.001, p<0.001, and p<0.001 respectively). Conversely, the median non-commute time spent in MVPA at 76 steps/minute (55.0 (43.9-77.5) minutes), 30.6 (18.8-45.8) minutes at 100 steps/minute, and 18.3 (8.5-30.7) minutes at 109 steps/minute threshold were not significantly different across the modes of commute (p=0.645, p=0.289, and p=0.160 respectively).

The percentage contribution of time spent in MVPA to total time in MVPA varied between commute time and non-commute time. The percentage contribution of median commute time in MVPA towards total time spent in MVPA at 76 steps/minute was 17%, at 100 steps/minute was 21%, and at 109 steps/minute was 26%. Meanwhile, the percentage contribution of the median non-commute time in MVPA to total time in MVPA decreased from 71% to 57% as the MVPA threshold was changed from 76 steps/minute to 109 steps/minute. A similar pattern at the different cadence threshold for MVPA was observed in commute steps, non-commute steps, and total steps taken at MVPA (Table 6.5).

For all MVPA cadence thresholds, the cycling commuters, mixed-mode commuters, and walking commuters spent more time and accumulated more steps in MVPA than the car commuters during commuting and non-commuting periods. At the MVPA threshold of 100 steps/minute, cycling commuters spent more time in total at MVPA intensity (97.0 minutes), followed by mixed-mode commuters (66.7 minutes), then the walking commuters (59.1 minutes), and the car commuters (28.5 minutes). Similarly, during commuting at the 100 steps/minute threshold, cycling commuters and mixed-mode commuters spent a considerably higher percentage of time in MVPA than the remaining modes of commute (Table 6.5).

For non-commuting periods, mixed-more commuters were also active during non-commuting periods, with a median MVPA time of 36.9 minutes compared to car commuters (22.9 minutes) at 100 steps/minute threshold. Although the mixed-mode commuters accumulated more MVPA than the car commuters, they spent more time being sedentary per day (545.3 minutes) compared to the other modes of commute (Table 6.2).

Table 6.5: Accelerometer-derived variables for all participants

Characteristics	All (n=40)	Car (n=19)	Cycle (n=2)[f]	Walk (n=6)	Mixed mode (n=13)	p-value[d]
Total walking time per day	114.1 (95.0-160.4)	99.7 (88.2-114.8)	153.3 (121.5)	132.2 (95.8-162.6)	127.7 (116.0-182.9)	0.018[e]
Commute walking time per day	15.1 (6.9-36.0)	6.9 (4.2-9.5)	55.0 (47.1)	26.2 (14.16-42.6)	34.8 (28.5-55.5)	<0.001[e]
Non-commute walking time per day	95.6 (76.6-121.8)	95.5 (79.4-107.9)	98.3 (74.4)	91.9 (63.5-138.9)	95.8 (80.6-124.7)	0.919
Total time in MVPA per day	77.6 (55.0-105.2)	57.8 (47.7-71.1)	127.4 (82.7)	92.6 (71.4-116.1)	90.4 (80.1-134.8)	0.003[e]
• **76 steps/minute**	46.8 (28.6-67.7)	28.2 (19.0-36.7)	97.0 (56.3)	59.1 (49.5-90.1)	66.7 (46.8-109.0)	<0.001[e]
• **100 steps/minute**	32.0 (13.5-54.2)	14.0 (7.0-21.8)	82.4 (43.2)	48.2 (36.5-73.8)	40.1 (34.1-93.5)	<0.001[e]
• **109 steps/minute**						
Commute time in MVPA per day						
• **76 steps/minute**	12.9 (4.7-32.8)	4.6 (2.9-7.1)	64.4 (42.8)	21.6 (13.8-41.7)	28.7 (23.8-52.2)	<0.001[e]
• **100 steps/minute**	9.9 (2.9-30.1)	2.7 (1.7-5.1)	58.5 (37.3)	19.2 (13.5-40.3)	25.6 (18.3-47.6)	<0.001[e]
• **109 steps/minute**	8.4 (1.6-26.2)	1.3 (0.1-3.1)	56.2 (36.3)	18.0 (13.5-40.1)	20.7 (11.1-42.8)	<0.001[e]
Non-commute time in MVPA per day						
• **76 steps/minute**	55.0 (43.9-77.5)	49.2 (43.6-65.4)	63.0 (40.0)	59.3 (40.9-94.3)	65.0 (46.6-87.7)	0.645

Characteristics	All (n=40)	Car (n=19)	Cycle (n=2)[f]	Walk (n=6)	Mixed mode (n=13)	p-value[d]
• **100 steps/minute**	30.6 (18.8-45.8)	22.9 (17.0-34.6)	38.6 (18.9)	36.9 (25.1-52.5)	36.9 (17.4-64.4)	0.289
• **109 steps/minute**	18.3 (8.5-30.7)	12.4 (7.0-19.5)	26.3 (7.0)	18.9 (18.2-39.6)	21.6 (7.5-50.4)	0.160
Total steps per day	10,036 (7,488-13,796)	8,174 (6,983-9,936)	10,243 (6,695)	12,187 (9,218-15,045)	13,203 (10,344-17,247)	**0.003**[e]
Commute steps per day	1,345 (589-3,297)	578 (353-890)	1,778 (924)	2,729 (1,709-5,011)	3,367 (2,862-6,107)	**<0.001**[e]
Non-commute steps per day	7,956 (6,300-10,858)	7,419 (6,519-9,358)	8,465 (5,771)	7,821 (5,415-12,884)	8,544 (6,780-12,251)	0.724
Total Steps in MVPA per day						
• **76 steps/minute**	6,661 (5,051-10,114)	5,607 (4,734-7,415)	8,094 (4,623)	9,722 (7,579-13,102)	9,306 (8,045-15,079)	**<0.001**[e]
• **100 steps/minute**	4,137 (2,546-6,797)	3,184 (2,168-4,342)	5,418 (2,294)	6,745 (5,624-10,953)	7,405 (5,159-12,776)	**<0.001**[e]
• **109 steps/minute**	2,795 (1,379-5,266)	1,657 (793-2,569)	3,896 (939)	5,611 (4,279-9,011)	4,817 (4,049-11,152)	**<0.001**[e]
Commute Steps in MVPA per day						
• **76 steps/minute**	1,212 (471-3,004)	433 (300-775)	1,494 (708)	2,462 (1,687-4,966)	3,159 (2,584-5,930)	**<0.001**[e]
• **100 steps/minute**	1,041 (294-2,678)	310 (184-556)	970 (235)	2,260 (1,668-4,840)	2,849 (2,031-5,502)	**<0.001**[e]
• **109 steps/minute**	728 (135-2,340)	150 (12-361)	735 (130)	2,129 (1,666-4,814)	2,384 (1,327-5,033)	**<0.001**[e]
Non-commute Steps in MVPA per day						
• **76 steps/minute**	5,539 (4,212-8,389)	4,773 (4,087-6,982)	6,600 (3,915)	6,098 (4,211-9,773)	6,846 (4,397-9,810)	0.610

Characteristics	All (n=40)	Car (n=19)	Cycle (n=2)[f]	Walk (n=6)	Mixed mode (n=13)	p-value[d]
• **100 steps/minute**	3,501 (2,016-5,352)	2,539 (1931-4,104)	4,448 (2,060)	4,097 (2,805-6,068)	4,349 (1,864-7,539)	0.246
• **109 steps/minute**	2,169 (972-3,587)	1,447 (793-2,358)	3,161 (809)	2,225 (2,092-4,706)	2,615 (866-6,057)	0.174

[a] Continuous variables, mean (SD); [b] Continuous variable, median (IQR: 25th-75th), [c] Categorical variable, no(%), [d] Differences between the modes of commute(Kruskal-Wallis test for continuous variables), [e] Significant differences ($p<0.05$), [f] Only reported 25th quartiles for cycling commuters because of the small number of participants in the group

Steps in MVPA

In terms of the MVPA thresholds, the higher the cadence threshold definition of MVPA applied, the lower the number of steps accumulated at this threshold; with a greater number of steps (6,661 steps) being accumulated at a cadence of 76 steps/minute than at 109 steps/minute threshold (2,795 steps).

Figure 6.2 shows the three different definitions of MVPA applied to the distribution of the total number of steps per day during commuting and non-commuting periods. There were distinct differences in how the MVPA steps were accumulated during commuting and non-commuting periods as the definition of MVPA changed. Although there were more steps accumulated during non-commuting periods than during commuting periods, the change in cadence thresholds for MVPA from 76 to 109 steps/minute had a greater impact on the number of non-commute steps (5,539 steps to 2,169 steps) than on the number of commute steps (1,212 steps to 728 steps). The percentage decrease of the number of commute steps taken at MVPA when the definition of MVPA was changed from 76 steps/minute to 109 steps/minute was 40% (1,212 steps to 728 steps); however, the percentage decrease for the number of non-commute steps was greater at 61% (5,539 steps to 2,169 steps). Therefore, the change in the definition of MVPA had a greater effect on non-commute steps than commute steps.

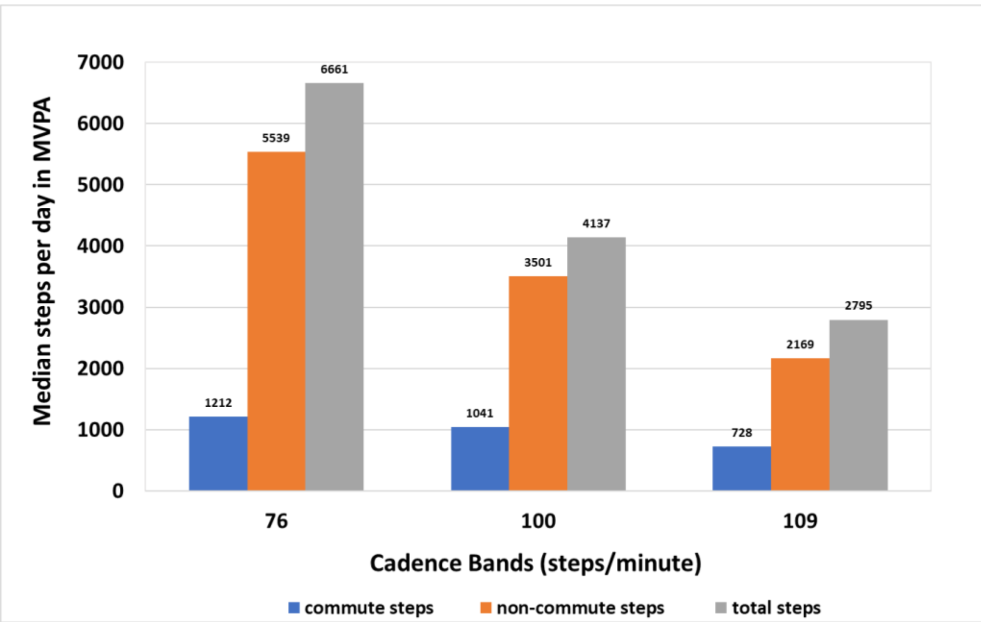

Figure 6.2: Distribution of total steps using different cadence thresholds of MVPA

6.1.5 Grouping of walking events

The methods used in Study Two (Section 3.5) were applied to this dataset to better understand the impact of combining short interruptions between walking bouts (grouping) on the total time spent walking at specified cadence thresholds of MVPA. The median time spent walking before and after grouping at all cadence thresholds for MVPA was statistically significantly different (p<0.001). Table 6.6 shows the increase in total time spent in MVPA based on the mode of commute. The increase in the time spent in MVPA after grouping decreased as the MVPA threshold increased.

<u>Time in MVPA</u>

The median total time spent walking in MVPA increased by 16% at 76 steps/minute from 77.6 minutes to 90.3 (63.2-126.9) minutes, by 6% at 100 steps/minute from 46.8 minutes to 49.5 (30.7-77.6) minutes, and by 8% at 109 steps/minute from 32.0 minutes to 34.7 (14.2-59.0) minutes. The total time spent in MVPA at 76, 100, and 109 steps/minute differed significantly between the modes of commute (p=0.003, p<0.001, and p<0.001 respectively). The same pattern of increase as total time in MVPA was observed with the commute and non-commute time in MVPA at the different thresholds after grouping. Commute time in MVPA increased by 40%, 23%, and 5% at 76, 100, and 109 steps/minute respectively; while non-commute time in MVPA increased by 11%, 3%, and 9% at 76, 100, and 109 steps/minute MVPA thresholds respectively. The percentage contribution of commute time towards total MVPA was 20% at 76 steps/minute, 25% at 100 steps/minute, and 26% at 109 steps/minute.

After grouping, the total time spent in MVPA at 76 steps/minute increased by 13% for car commuters, 12% for cycle commuters, 19% for walking commuters, and 20% for mixed-mode commuters. At the 100 steps/minute threshold, the total time spent in MVPA increased by 8% for car commuters, 4% for cycle commuters, 11% for walking commuters, and 9% for mixed-mode commuters. The impact of grouping on the total time spent in MVPA was greater among the mixed-mode commuters and walking commuters; for example, at 76 steps/minute, the total time spent in MVPA increased by 20% for mixed-mode commuters (90.4 to 108.6 minutes), 19% for walking commuters (115.0 to 92.6 minutes) compared to the 13% increase for car commuters (57.8 to 65.4 minutes). There were significant differences across the modes of commute for total time spent in MVPA (p<0.001) and commute time spent in MVPA (p<0.001).

Steps in MVPA

The median total steps per day increased by 20% from 6661 to 7984 steps at 76 steps/minute threshold, by 16% from 4,187 to 4,851 steps at 100 steps/minute threshold, and by 24% from 2,795 to 3,472 steps at 109 steps/minute threshold after grouping (Figure 6.3). For all of the three cadence thresholds for MVPA, mixed-mode and walking commuters accumulated more steps in MVPA compared to the car commuters. For example, at 100 steps/minute threshold, the mixed-mode (3,100 (2,100-7,002) steps) and walking commuters (2,915 (1,724-4,628) steps) accumulated a greater number of steps per day during commuting than the car commuters (313 (184-561) steps). Similar observations were made during non-commuting periods. There were significant differences in the total number of steps per day across the modes of commute after grouping at all three thresholds (p<0.001). Also, the number of grouped commute steps taken per day at all three cadence thresholds was significantly different across the modes of commute (p<0.001). However, there was no significant difference between grouped non-commute steps and the modes of commute at all three cadence thresholds (p=0.594, p=0.239, and p=0.087 respectively).

Table 6.6: Accelerometer-derived variables (grouped outcomes) for all participants

Characteristics	All (n=40)	Car (n=19)	Cycle (n=2)[f]	Walk (n=6)	Mixed mode (n=13)	p-value[d]
Grouped Total time in MVPA[b]						
• **76 steps/minute**	90.3 (62.3-126.9)	65.4 (55.1-83.5)	142.1 (97.0)	115.0 (85.3-141.4)	108.6 (93.6-166.4)	**<0.001[e]**
• **100 steps/minute**	49.5 (30.7-77.6)	30.5 (20.8-42.5)	101.3 (57.3)	65.4 (54.9-106.1)	72.4 (50.7-122.4)	**<0.001[e]**
• **109 steps/minute**	34.7 (14.2-59.0)	14.5 (7.1-22.6)	84.4 (43.7)	48.9 (37.8-79.8)	42.7 (37.1-99.9)	**<0.001[e]**
Grouped Commute time in MVPA per day[b]						
• **76 steps/minute**	18.1 (6.4-43.9)	6.2 (4.0-9.7)	68.4 (45.3)	32.8 (18.2-55.6)	37.9 (30.7-75.7)	**<0.001[e]**
• **100 steps/minute**	12.2 (3.0-35.7)	2.9 (1.7-5.3)	59.3 (37.9)	27.0 (16.1-43.6)	29.4 (19.8-65.5)	**<0.001[e]**
• **109 steps/minute**	8.8 (1.5-27.1)	1.3 (0.1-3.1)	56.6 (36.3)	21.1 (15.0-32.9)	24.5 (13.1-51.2)	**<0.001[e]**
Grouped Non-commute time in MVPA[b]						
• **76 steps/minute**	61.5 (49.4-92.5)	55.6 (47.0-77.7)	73.8 (45.8)	71.2 (49.0-109.4)	76.7 (50.6-102.8)	0.638
• **100 steps/minute**	31.5 (19.8-51.5)	24.4 (18.5-40.2)	42.1 (19.9)	40.0 (29.3-57.2)	40.6 (18.9-71.7)	0.239
• **109 steps/minute**	20.0 (8.7-33.6)	13.1 (7.1-20.8)	27.9 (7.3)	27.5 (20.7-42.2)	23.4 (7.7-59.7)	0.091
Grouped Total steps in MVPA[b]						
• **76 steps/minute**	7,984 (5631-11,418)	5,696 (4,818-7,605)	8,269 (4,803)	10,029 (7,771-13,442)	9,539 (8,366-15,399)	**<0.001[e]**

Characteristics	All (n=40)	Car (n=19)	Cycle (n=2)[f]	Walk (n=6)	Mixed mode (n=13)	p-value[d]
• **100 steps/minute**	4,851 (2,811-8,395)	3,245 (2,187-4,453)	5,517 (2,328)	6,841 (5,808-11,310)	7,489 (5,291-13,068)	**<0.001[e]**
• **109 steps/minute**	3,472 (1,562-6,665)	1,682 (793-2,610)	3,938 (954)	5,455 (4,232-8,964)	4,914 (4,162-11,324)	**0.001[e]**
Grouped Commute steps in MVPA[b]						
• **76 steps/minute**	1,511 (598-3,295)	592 (344-847)	1,588 (844)	3,130 (1,772-4,965)	3,309 (2,778-7,418)	0.594
• **100 steps/minute**	1,096 (302-3,056)	313 (184-561)	986 (235)	2,195 (1,724-4,628)	3,100 (2,100-7,002)	0.239
• **109 steps/minute**	699 (135-2,714)	194 (12-361)	751 (130)	2,354 (1,696-3,708)	2,743 (1,459-5,778)	0.087
Grouped Non-commute steps in MVPA[b]						
• **76 steps/minute**	5,611 (4,262-8,603)	4,849 (4,017-7,120)	6,681 (3,960)	6,203 (4,362-9,893)	6,967 (4,526-9,805)	0.594
• **100 steps/minute**	3,374 (2,060-5,434)	2,593 (1,939-4,215)	4,530 (2,094)	4,144 (3,067-6,063)	4,453 (1,952-7,774)	0.239
• **109 steps/minute**	2,322 (975-3,794)	1,488 (793-2,428)	3,187 (824)	3,070 (2,320-4,751)	2,624 (870-6,752)	0.087

[a] Continuous variables, mean (SD); [b] Continuous variable, median (IQR: 25th-75th), [c] Categorical variable, no(%), [d] Differences between the modes of commute (Kruskal-Wallis test for continuous variables), [e] Significant differences (p<0.05), [f] Only reported 25th quartiles for cycling commuters because of the small number of participants in the group

6.2 The cadence distribution of commute and non-commute steps

Objective 8: To objectively quantify MVPA using different cadence thresholds for MVPA to explore patterns of commute and non-commute stepping.

6.2.1 Cadence distribution of the total steps at MVPA and non-MVPA intensity

Figure 6.3 shows the distribution of total steps taken for commuting and non-commuting periods, using the three cadence thresholds for MVPA (76, 100, and 109 steps/minute). The distribution of the total number of steps per day was broken down into steps taken at less than the specified cadence threshold (non-MVPA steps) and steps taken at greater than or equal to the specified cadence threshold (MVPA steps).

The median total number of MVPA and non-MVPA steps accumulated per day were not equally distributed between commuting and non-commuting periods. For commute steps, the number of MVPA steps taken per day was much greater than the number of non-MVPA steps taken at all cadence thresholds for MVPA (76 steps/minute (1,212 vs. 141 steps: 90% vs. 10%), 100 steps/minute (1,014 vs. 329 steps: 76% vs. 24%), 109 steps/minute (728 vs. 481 steps: 60% vs. 40%). Furthermore, for non-commute steps, the number of non-MVPA steps taken per day was greater than the number of MVPA steps taken per day at all cadence thresholds for MVPA except at 76 steps/minute threshold, where the number of MVPA steps were greater than the number of non-MVPA steps (5,539 vs. 1,886 steps: 75% vs. 25%). At the 100 steps/minute threshold, the number of non-commute non-MVPA steps taken was greater than that of non-commute MVPA steps (4,146 vs. 3,501 steps; 54% vs. 46%). Similarly, at 109 steps/minute, the number of non-commute non-MVPA steps taken was greater when compared to the number of non-commute MVPA steps taken (5,712 vs. 2,169 steps; 72% vs. 28%).

For non-MVPA steps, the proportion of non-commute steps taken increased from 25% to 72% compared to the proportion of commute non-MVPA steps that increased from 10% to 40%, when the definition of MVPA was changed from 76 steps/minute to 109 steps/minute threshold. For MVPA steps, there was a greater percentage decrease in the number of non-commute steps taken (75% to 28%) compared to the percentage decrease in the number of commute steps taken (from 90% to 60%) when the definition of MVPA was changed from 76 steps/minute to 109 steps/minute.

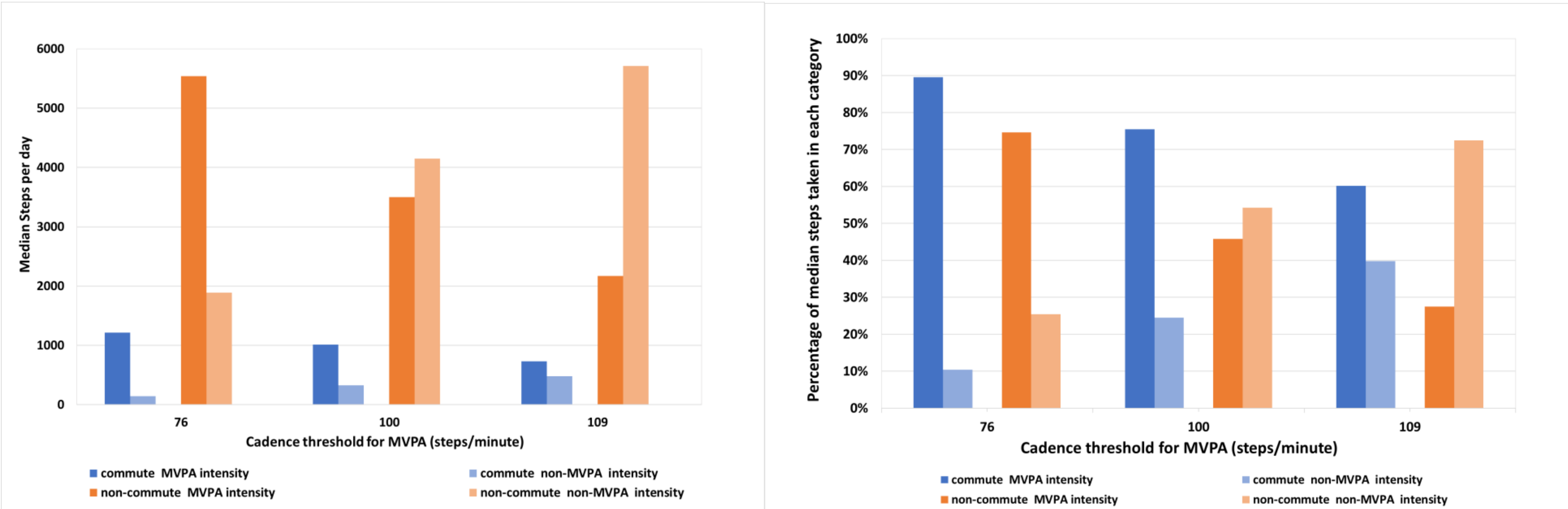

Figure 6.3: The distribution of average daily total steps taken at MVPA and non-MVPA intensities for the three cadence thresholds of MVPA for both commuting and non-commuting periods

Figure 6.4 shows the distribution of commute and non-commute steps at different cadence bands. For commute and non-commute steps, there was a steady increase in the number of steps from the cadence band of 20-30 steps/minute to 100-110 steps/minute and decreased at higher cadence bands of greater than 110 steps/minute threshold. Commute steps showed a peak in the 110-120 steps/minute cadence band whereas, for non-commute steps, the peak was between 100-110 steps/minute cadence band. For commute steps, there was an increase between the cadence bands of 100-120 steps/minute; however, the peak of non-commute steps was taken at a cadence threshold of less than 110 steps/minute, with a decline in the proportion of commute steps for higher cadence thresholds.

Figure 6.4 also shows the percentage breakdown of steps accumulated during commuting and non-commuting periods at different cadence bands. Commute steps were mostly accumulated at higher cadences compared to non-commute steps (110 steps/minute: 37% vs. 16%; 120 steps/minute: 13% vs. 4%). For non-commute steps, the proportion of the number of steps accumulated at lower cadence bands between 60 to 90 steps/minute was greater when compared to the number of commute steps accumulated at the same cadence bands (9% to 15% vs. 4% to 8%). There was a steady increase in the accumulation of non-commute steps taken until its peak at cadence band between 100-110 steps/minute, with no changes in the pattern of accumulation. Conversely, for commute steps, the accumulation of steps at lower cadence bands (20-90 steps/minute) occurred differently to steps accumulated at higher cadence bands (110-140 steps/minute): at a cadence band of 130-140 steps/minute, only a small proportion of 0.3% (25 steps) of total steps, 0.4% (24 steps) of non-commute steps, and 0.5% (7 steps) of commute steps were accumulated.

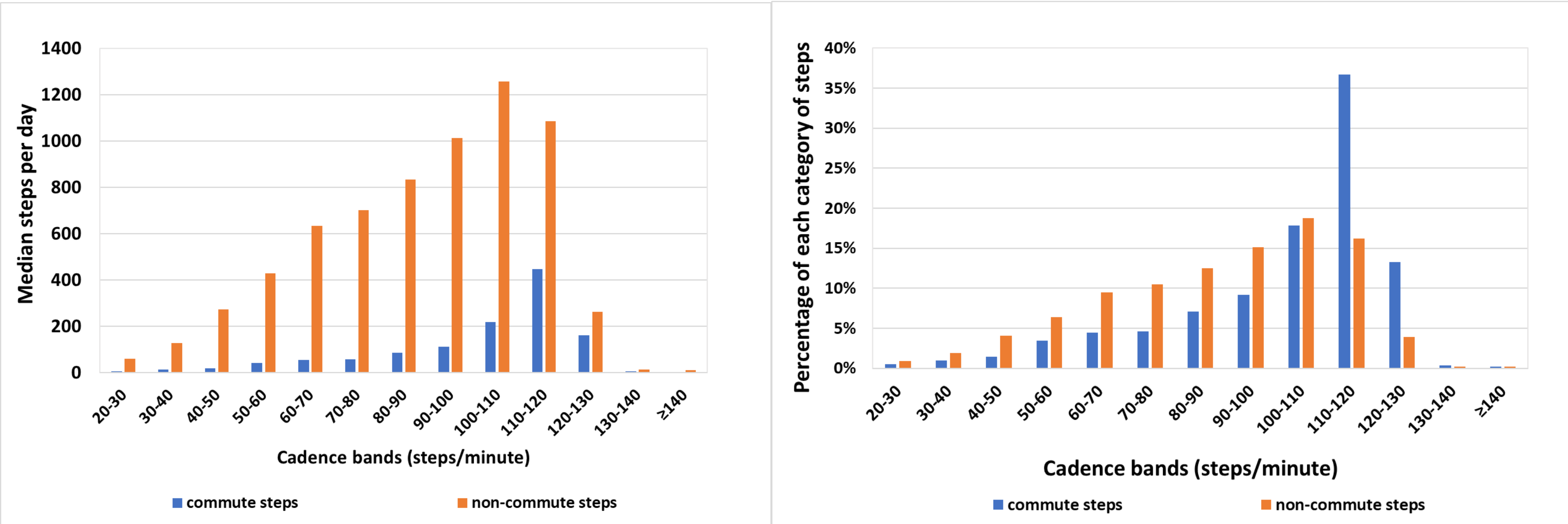

Figure 6.4: Cadence distribution of commute and non-commute steps, showing the percentage of each category of steps accumulated

6.2.2 Cadence distribution of commute and non-commute steps based on the mode of commute

The cadence distribution of total commute steps were categorised based on the mode of commute: car, walk, and mixed-mode (Figure 6.5). The commute steps accumulated by car commuters increased steadily as the cadence bands increased up to 110-120 steps/minute followed by a sharp decline above 120 steps/minute. The number of commute steps taken by mixed-mode and walking commuters between 20-100 steps/minute were 202 and 47 steps per day respectively; however, a far greater number of steps were accumulated between 110-130 steps/minute (1341 and 559 steps per day respectively) (Figure 6.5). At a cadence band of 130-140 steps/minute, only mixed-mode commuters accumulated a small number of steps per day (25 steps) in this category. The proportion of commute steps taken at cadence bands between 20-100 steps/minute were greater among the car commuters (52%) compared to mixed-mode commuters (13%) and walking commuters (8%). However, at higher cadence bands greater than 100 steps/minute, mixed-mode and walking commuters accumulated a greater proportion (87% and 92% respectively) of their steps at greater than 100 steps/minute cadence threshold compared to the car commuters.

During non-commuting periods, the distribution of non-commute steps was similar across all the modes of commute: there was a steady increase in the number of steps per day, from 20-110 steps/minute, and a sharp decline from 110-140 steps/minute (Figure 6.6). The total number of non-commute steps per day accumulated by car commuters was 3,837 steps, followed by the mixed-mode commuters (2,917 steps), and the walking commuters (1,271 steps). The car commuters accumulated 48% of their total commute steps between 20-100 steps/minute threshold and the remaining 52% at cadence bands greater than 100-140 steps/minute. Mixed-mode and walking commuters accumulated over 50% of their total non-commuting steps at a cadence greater than 100 steps/minute compared to car commuters. During both commuting and non-commuting periods, mixed-mode commuters and walking commuters accumulated most of their steps taken at a cadence band of 110-140 steps/minute.

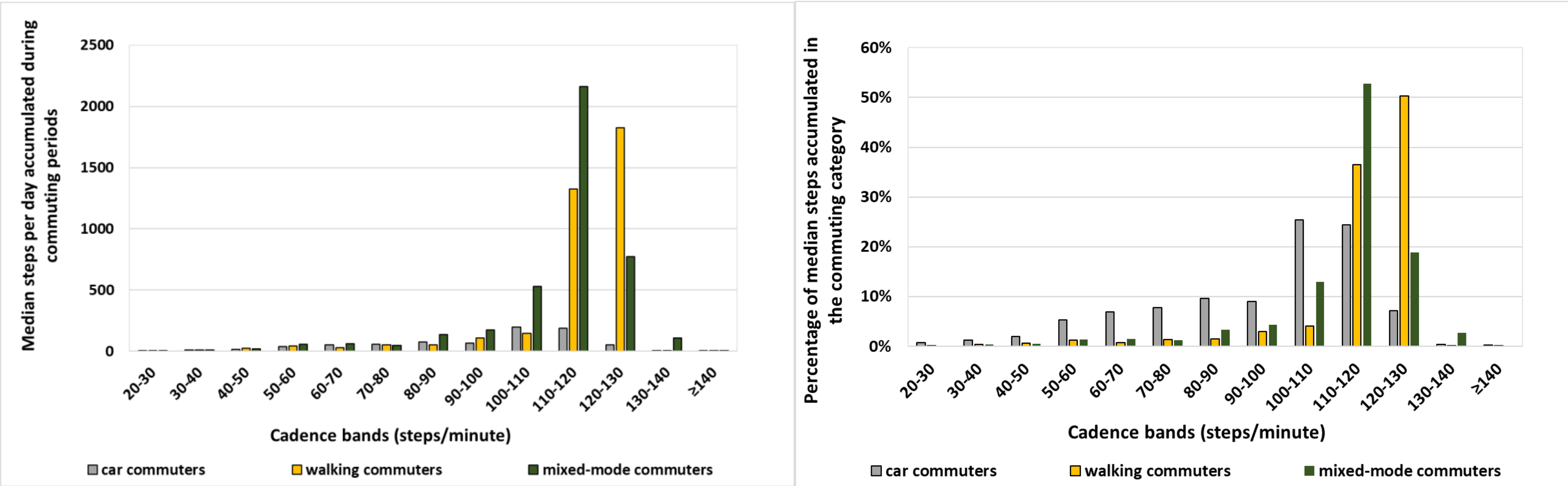

Figure 6.5: The cadence distribution of total commute steps grouped by mode of commute, showing percentage contribution of each mode

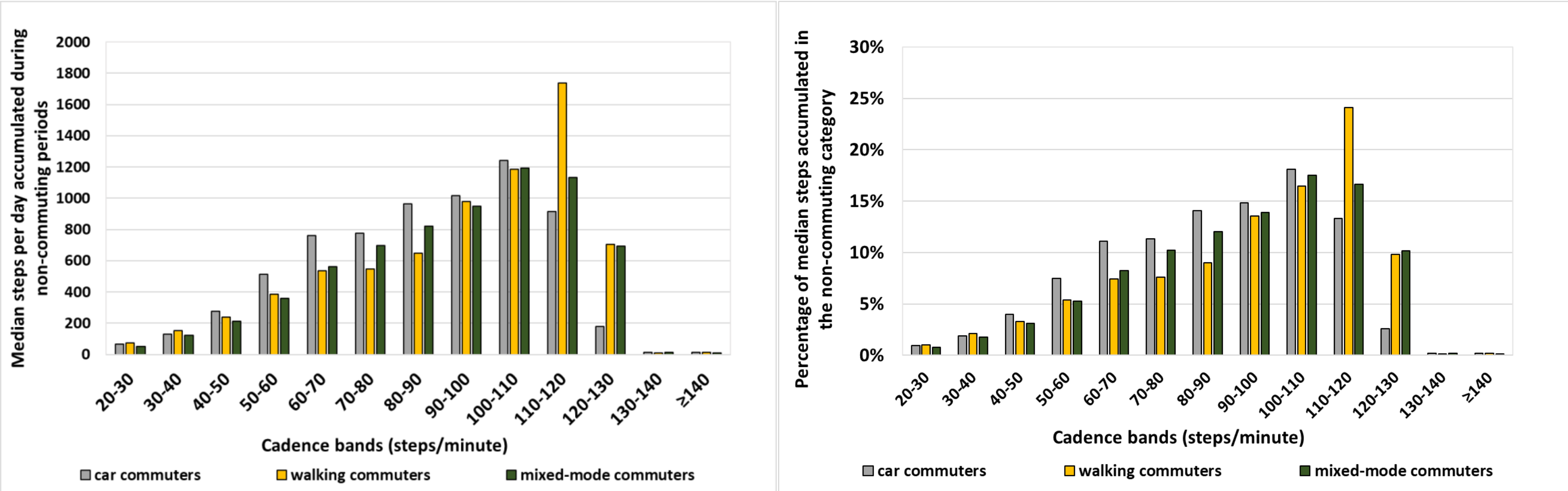

Figure 6.6: The cadence distribution of total non-commute steps grouped by mode of commute, showing percentage contribution of each mode

6.3 Distribution of total steps by the length of walking bouts

Objective 9: To explore the patterns of commuting and non-commuting stepping at different lengths of walking bouts, both before and after grouping.

6.3.1 Walking bout distribution of all steps taken

Figure 6.7 shows the distribution of all steps at different walking bouts lengths based on Mark & Janssen's classification of walking bouts (short, <5 minutes; medium, 5-9.99 minutes; and long, ≥10 minutes) (Mark & Janssen, 2009). Most steps were taken at short walking bouts (66% of total steps), while the remaining steps were accumulated at medium walking bouts (17%) or long duration, lasting for 10 minutes or more (19% of total steps). Overall, walking continuously for less than 10 minutes was most common as most steps are taken at short (66%) and medium (17%) walking bout lengths than at long (19%) walking bout lengths.

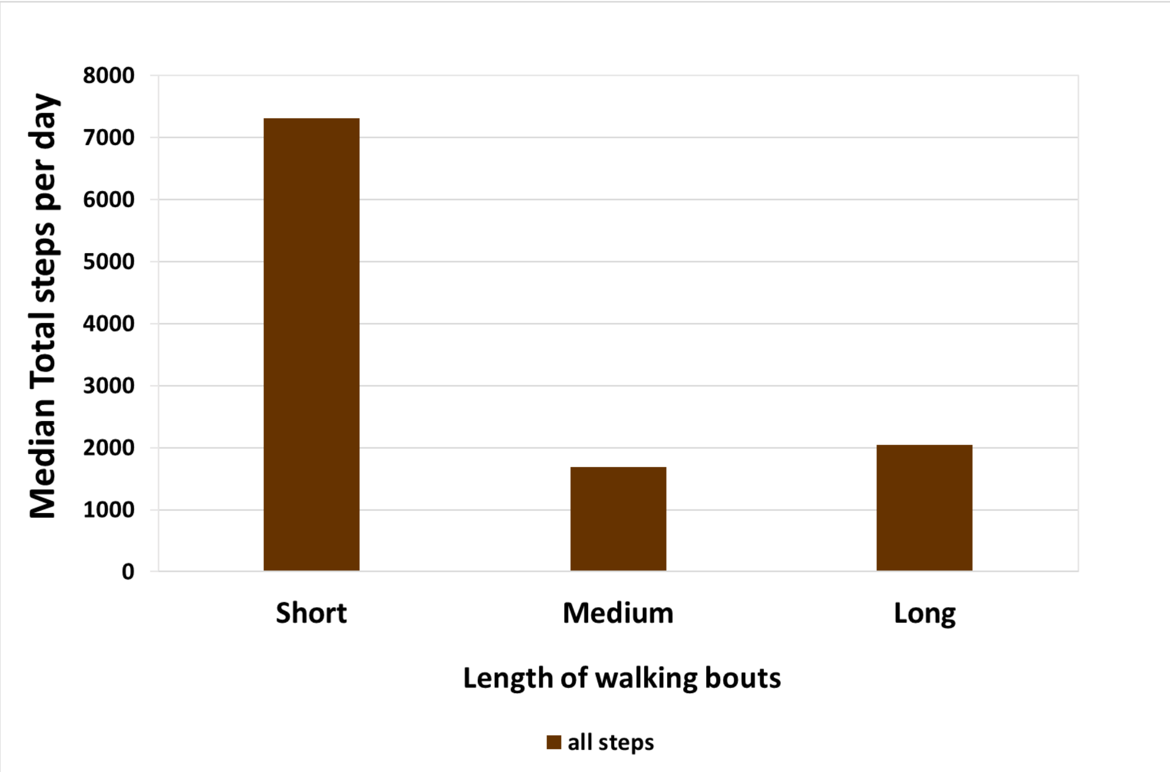

Figure 6.7: Walking bouts distribution of all steps in each walking bout category (Short, <5 minutes; Medium, 5-9.99 minutes; and Long, ≥10 minutes)

The distribution of the number of steps per day accumulated at different lengths of walking bout varied across commuting and non-commuting periods (Figure 6.8). The number of non-commute steps (6,161 steps) and commute steps (1,151 steps) per day accumulated at short walking bouts were greater than the number of non-commuting steps (1,109 and 1,118 steps) and commuting steps (573 and 858 steps) per day accumulated at medium and long walking bouts. The number of non-commuting steps per day accumulated at short walking bouts was greater than the number of commuting steps per day accumulated at short walking bouts (73% vs. 45%). However, at medium and long walking bouts, the number of commute steps per day were greater than the number of non-commute steps per day (55% vs. 27%) (Figure 6.8).

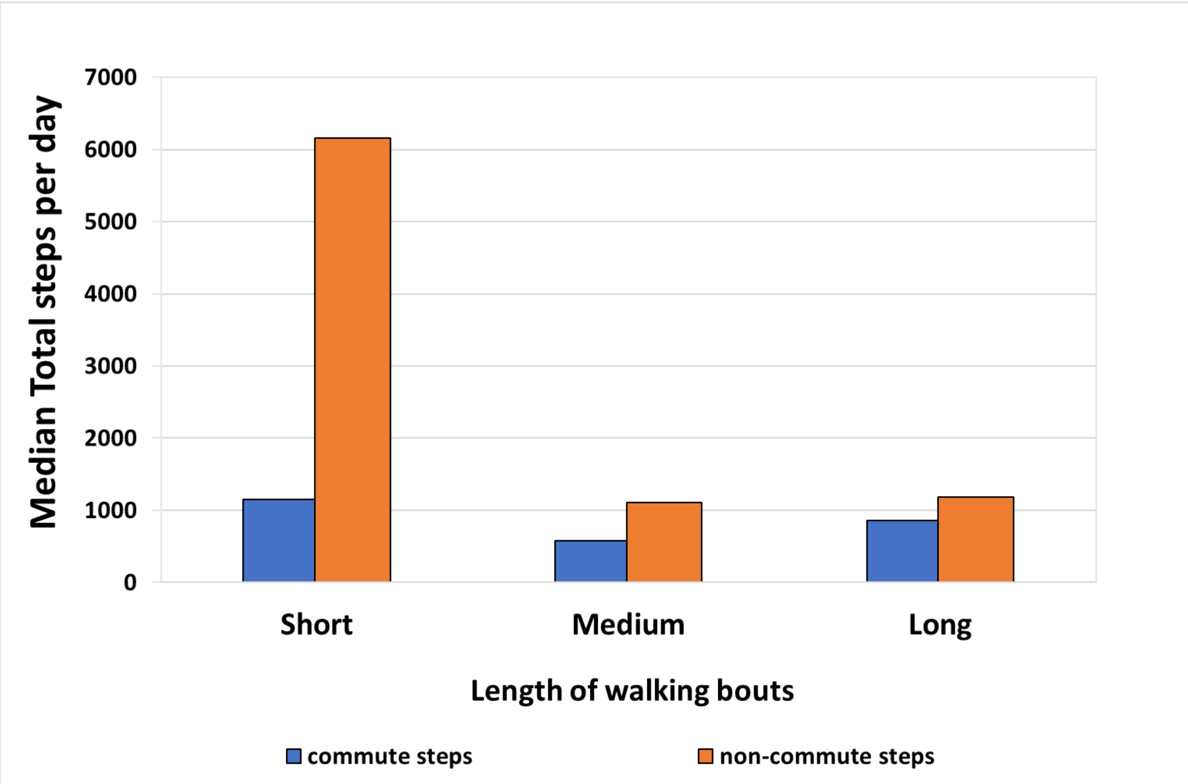

Figure 6.8: Walking bouts distribution of commute and non-commute steps in each walking bout category (Short, <5 minutes; Medium, 5-9.99 minutes; and Long, ≥10 minutes)

Commute steps were further broken down according to the mode of commute for all participants (Figure 6.9). The car commuters accumulated 91% of their commute steps (318 steps) at short walking bouts, 5% (18 steps) at medium walking bouts, and 4% (13 steps) at long walking bouts. Compared to the car commuters, the walking commuters accumulated

22% of their commute steps (131 steps) at short walking bouts, 24% (149 steps) at medium walking bouts, and 54% (326 steps) at long walking bouts. Although the mixed-mode commuters accumulated more commute steps (40%) at short walking bouts than the walking commuters, the greater proportion of their commute steps were accumulated at medium and long walking bouts (26% and 34%).

Similar patterns were observed between the distribution of commute steps among car and mixed-mode commuters and the distribution of non-commute steps across the walking bout categories (Figure 6.10). All the commuters accumulated most of their non-commute steps during short walking bouts. However, the mixed-mode (18%) and walking (17%) commuters accumulated a greater proportion of non-commute steps at long walking bouts compared to the car commuters (11%).

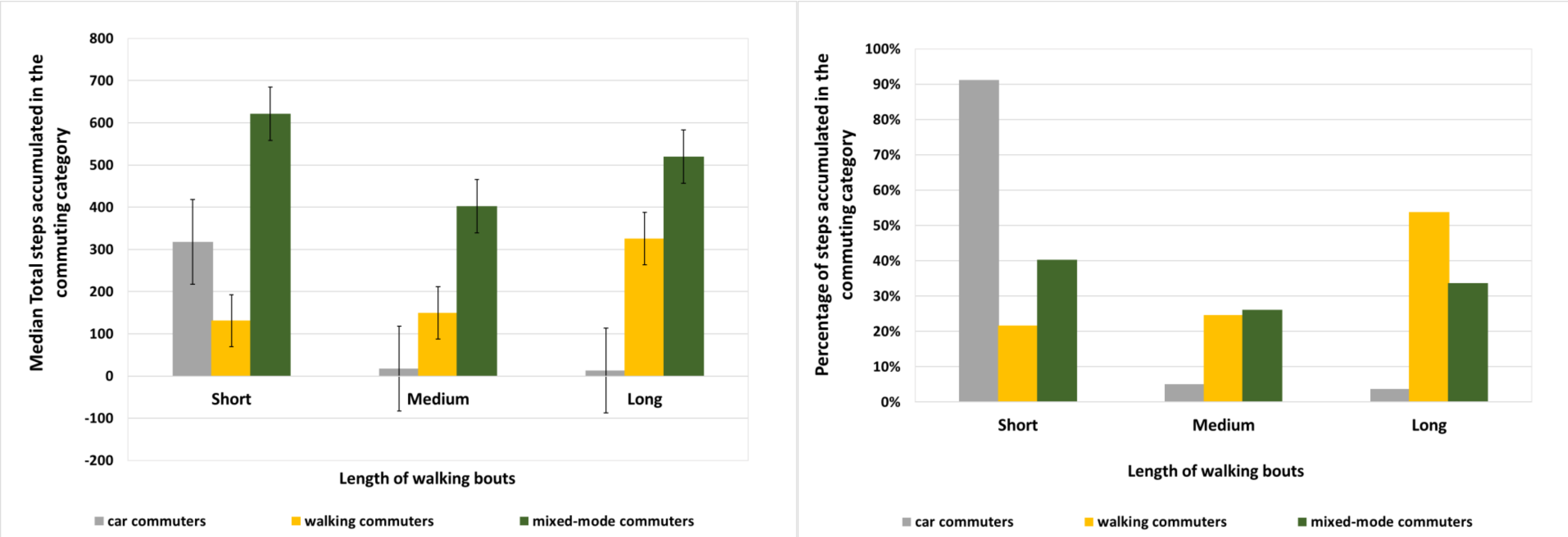

Figure 6.9: Walking bout distribution of commute steps grouped by commute mode, for both the total number of commute steps and the percentage number of steps, in each walking bout category

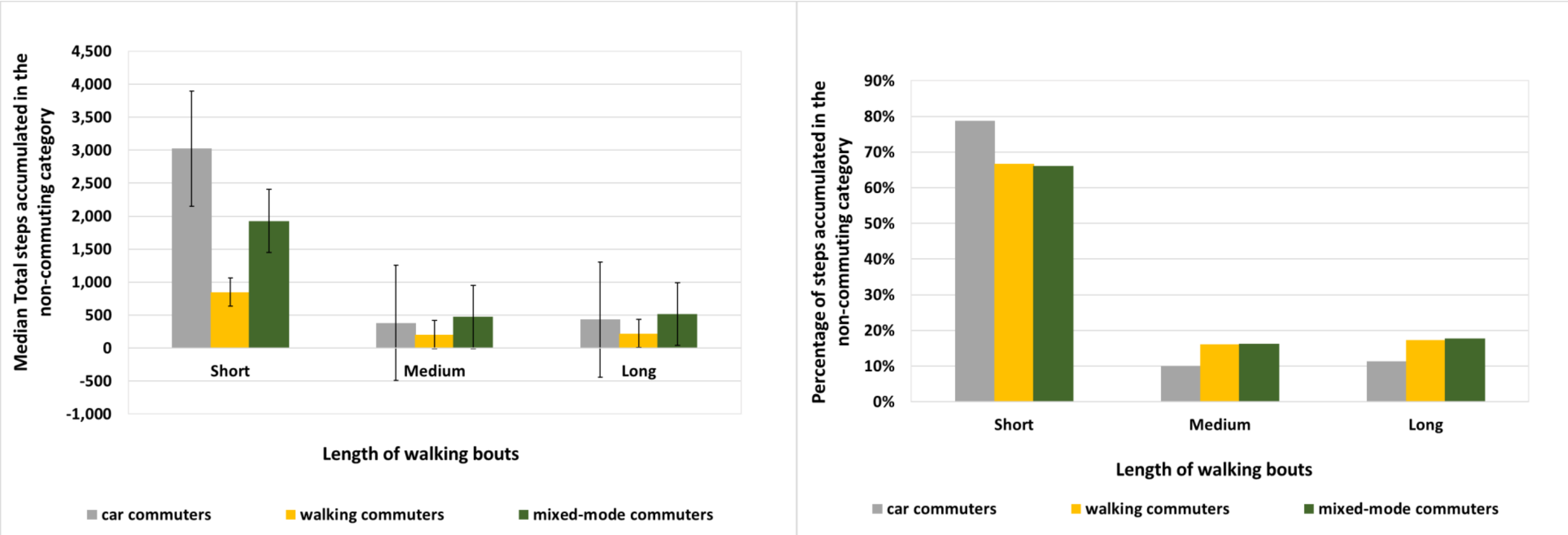

Figure 6.10: Walking bout distribution of non-commute steps grouped by commute mode, for both the total number of non-commute steps and the percentage number of steps, in each walking bout category

6.3.2 Walking bout distribution of commute and non-commute stepping

The different lengths of walking bouts were further reclassified into 30-second bins as a result of most steps (66%) accumulated in short walking bouts (Section 6.3.1): the total number of steps taken during commute and non-commute periods were broken down into different lengths of walking bouts (0-30, 30-60, 60-90, 90-120, 120-150, 150-180, 180-210, 210-240, 240-270, 270-300, 300-600, ≥600 seconds) (Figure 6.11). The distribution of the number of commute steps differed from the distribution of non-commute steps accumulated at short walking bouts (Figure 6.11). Non-commute steps were accumulated in mostly shorter bouts (<1 minute): 48% of non-commute steps (4,029 steps) were accumulated in bouts lasting up to one minute, and 27% were accumulated in longer bouts of greater than five minutes (2,294 steps). Conversely, commute steps were made up of fewer steps (452 steps) taken at shorter bout lengths lasting up to one minute (18%), and a greater proportion of steps (55%) accumulated at longer duration bouts of more than five minutes.

The pattern of distributions of the number of commute steps and non-commute steps at walking bout lengths between one to five minutes were similar. The total number of commute steps at walking bout lengths between one to five minutes were fewer than the number of non-commute steps (698 steps vs. 3,352 steps); however, the proportion of commute steps and non-commute steps accumulated in that walking bout length category were close (27% vs. 25%).

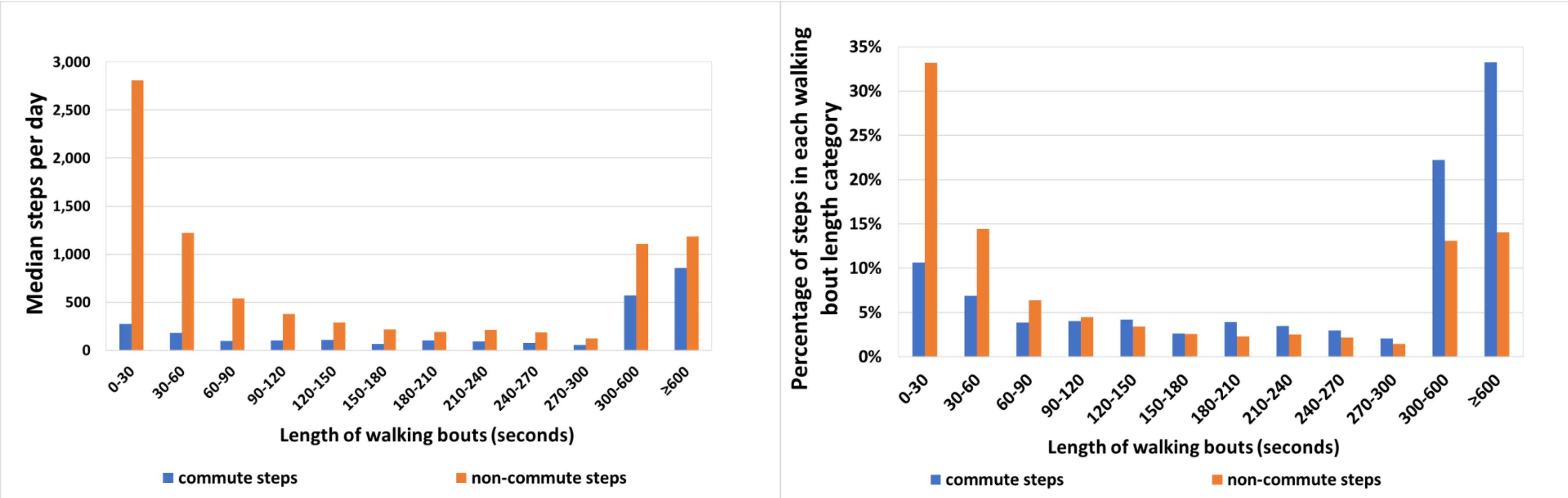

Figure 6.11: Walking bout distribution of commute and non-commute steps, showing percentage distribution in each walking bout category

6.3.2.1 Patterns of commute steps at different lengths of walking bouts based on the mode of commute

The total number of commute steps accumulated were categorised by type of commuters (car, walking, and mixed-mode commuters) (Figure 6.12). Mixed-mode commuters accumulated the highest number of median commute steps with 1,543 steps, followed by the walking commuters with 606 steps, and the car commuters with 348 steps. For car commuters, 47% of commute steps were accumulated in bouts that were less than 60 seconds. Also, car commuters accumulated a considerable proportion of their commute steps (44%) at walking bout lengths that lasted between 60 to 300 seconds compared to walking and mixed-mode commuters (13% and 28% respectively). The mixed-mode commuters contributed to each walking bout category, with the largest proportion of their commute steps taken at longer walking bout of greater than 300 seconds (60%). Walking commuters accumulated 78% of their contribution to commute steps at bouts of greater than 300 seconds and only 9% of commute steps were accumulated at bouts less than 60 seconds.

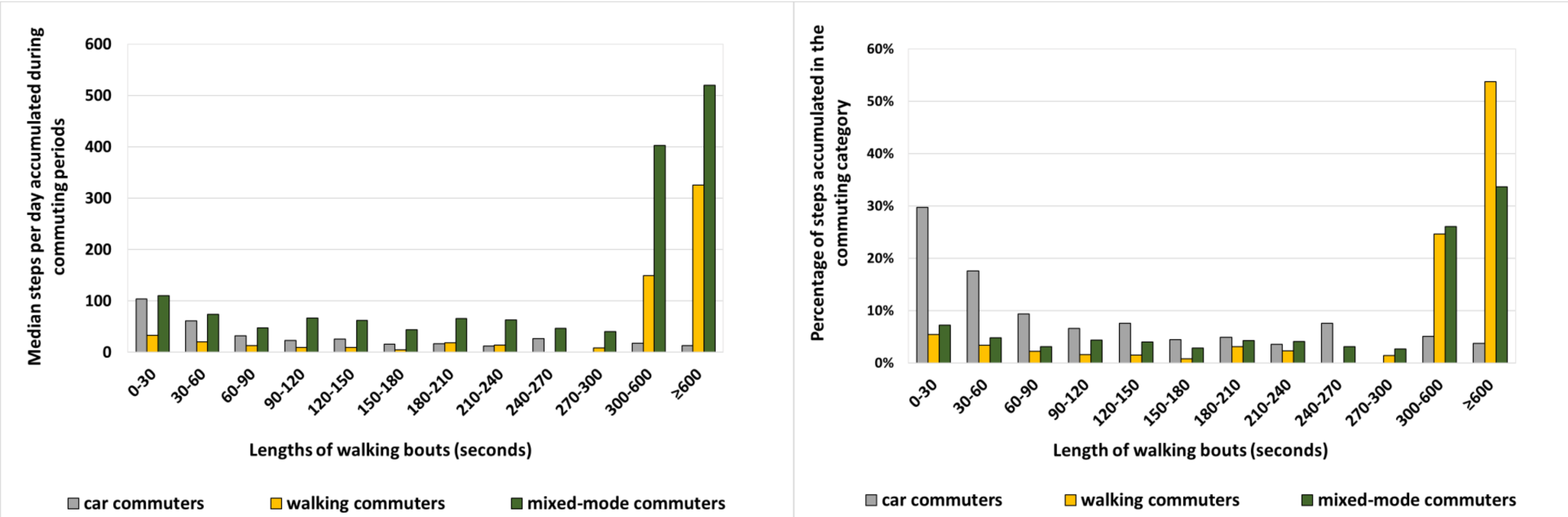

Figure 6.12: Walking bout distribution of commute steps grouped by commute mode, showing the percentage distribution of each mode in each walking bout category

6.3.2.2 Patterns of non-commute steps at different lengths of walking bouts based on the mode of commute

The total number of non-commute steps accumulated were categorised into the type of commuters (car, walking, and mixed-mode commuters) (Figure 6.13). Car commuters accumulated the highest number of median non-commute steps, followed by the mixed-mode commuters, and the walking commuters. The pattern of the distribution of non-commute steps at walking bouts lasting less than 60 seconds was similar among all the commuters, as most of the commuters accumulated over half of their total non-commute steps at walking bout lengths less than 60 seconds. The car commuters accumulated most of their non-commute steps at walking bout lasting less than 60 seconds (53%), followed by the mixed-mode commuters (42%), and finally the walking commuters (41%). The percentage of non-commute steps between one to five minutes of walking bout length were closely distributed (car commuters, 26%; walking commuters, 25%; and mixed-mode commuters, 24%). Although there was no apparent distinctive pattern in the distribution of non-commute steps, mixed-mode (34%) and walking (33%) commuters accumulated a greater proportion of non-commute steps at walking bout greater than five minutes compared to car commuters (21%).

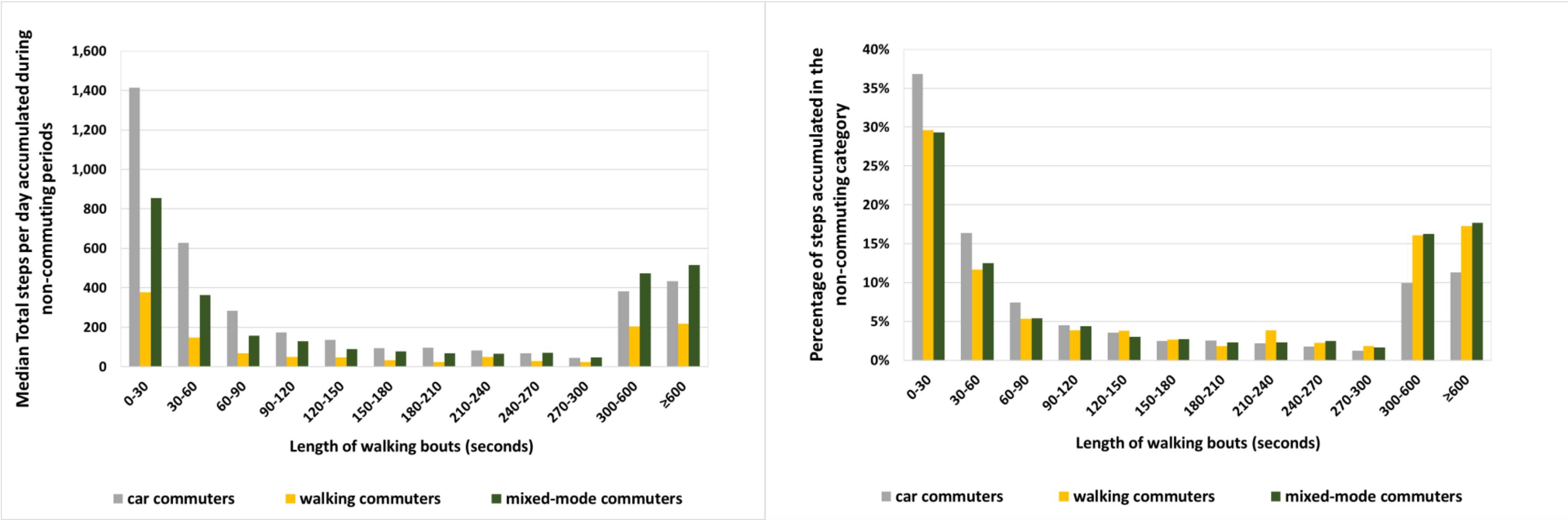

Figure 6.13: Walking bout distribution of non-commute steps grouped by commute mode, showing the percentage distribution of each mode in each walking bout category

6.3.3 Walking bout distribution of MVPA stepping taken at the three cadence thresholds for MVPA, both before and after grouping

6.3.4 Walking bout distribution of all MVPA stepping taken before grouping

The distribution of MVPA steps by the length of walking bouts was examined using the three cadence thresholds of MVPA (76, 100, and 109 steps/minute) (Figure 6.14). At shorter walking bout length (0-60 seconds), more MVPA steps were taken at 76 steps/minute compared to 100 steps/minute and 109 steps/minute. In terms of the percentage distribution of how the steps were accumulated within each category, as the threshold increased, the number of MVPA steps decreased; however, this was predominantly for MVPA steps taken at bouts less than 90 seconds as the MVPA steps taken between one to five minutes were similar across the thresholds. At longer walking bouts (greater than five minutes), the number of MVPA steps accumulated increased across the three cadence thresholds: there was a greater proportion of steps taken at 100 steps/minute (57%) and 109 steps/minute (66%) at longer bout duration of greater than five minutes compared to the MVPA steps taken at 76 steps/minute (43%).

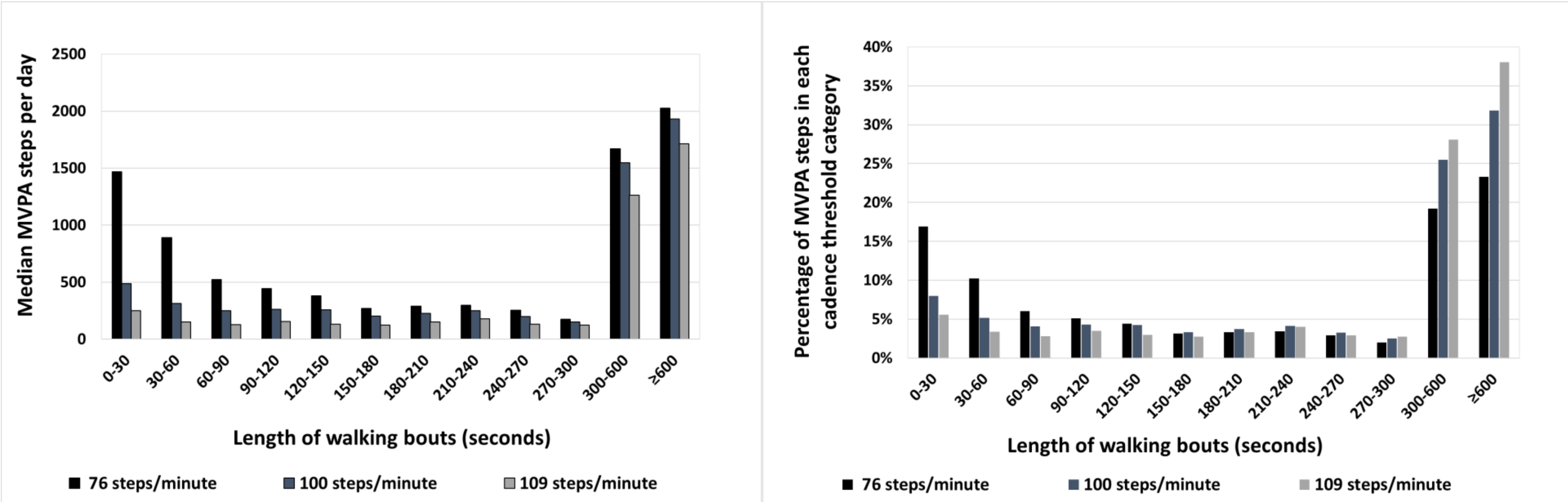

Figure 6.14: The distribution of MVPA steps by lengths of walking bouts for the three cadence thresholds of MVPA

6.3.5 Walking bout distribution of all MVPA stepping taken after grouping

After grouping, the number of MVPA steps taken at short walking bouts of less than five minutes decreased while the number of MVPA steps taken at greater than five minutes increased as a result of incorporating short walking bouts. The walking bout distribution of grouped total steps in MVPA (Figure 6.15), was similar to the distribution of ungrouped total steps in MVPA (Figure 6.14). At shorter walking bout lengths (0-60 seconds), more steps were taken at 76 steps/minute (1,807 steps), compared to at 100 steps/minute (702 steps) and 109 steps/minute (371 steps) (Figure 6.15). The percentage distribution of MVPA steps accumulated within each MVPA threshold category did not differ between walking bout length of one to five minutes. However, at longer walking bouts (≥five minutes), the number of steps accumulated increased across the three cadence thresholds. There was a greater proportion of steps taken at 109 steps/minute (76%) and 100 steps/minute (70%) at longer bout duration of five minutes and more, compared to the steps taken at 76 steps/minute (62%).

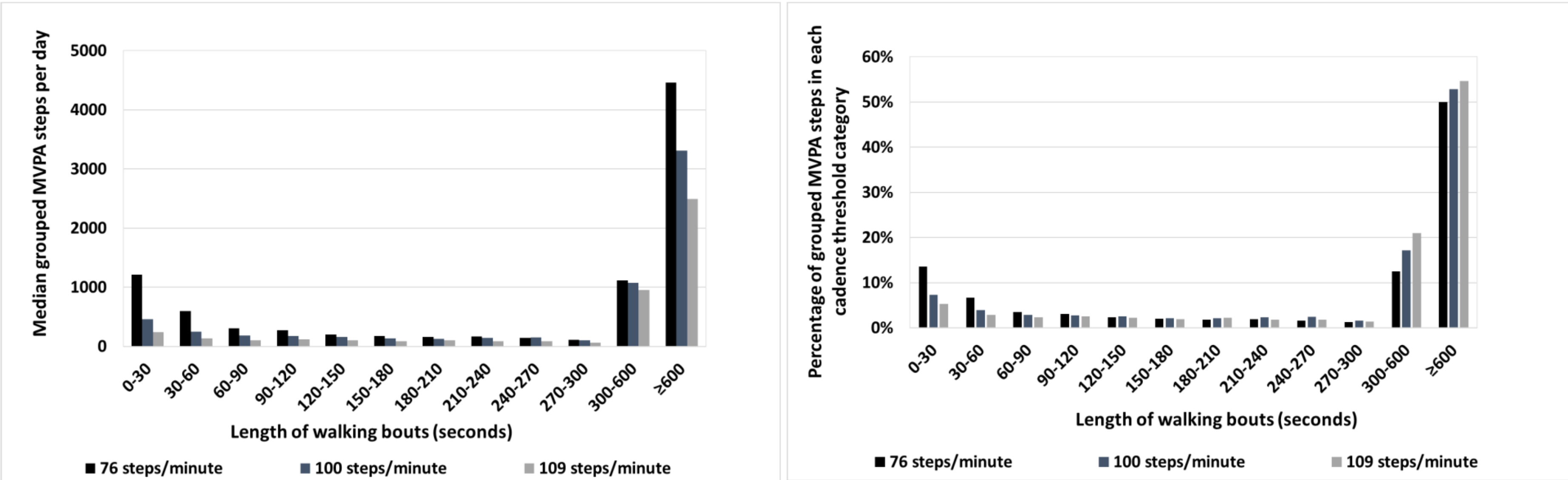

Figure 6.15: The distribution of grouped MVPA steps by lengths of walking bouts for the three cadence thresholds of MVPA

6.3.6 Patterns of commute and non-commute MVPA stepping based on cadence thresholds for MVPA at different lengths of walking bouts before and after grouping

Further analysis was conducted on the number of MVPA steps taken at all the three cadence thresholds of MVPA during commuting and non-commuting periods at different lengths of walking bouts (Figure 6.16). As the cadence threshold for MVPA increased, the number of commuting and non-commuting MVPA steps decreased; however, the decrease for commuting steps was much smaller compared to non-commute steps: for walking bouts greater than five minutes, there was a greater reduction of 23% in the number of non-commute MVPA steps (1,166 steps to 897 steps) compared to a 5% reduction in the number of commute MVPA steps (858 steps to 817 steps) when the definition of MVPA was changed from 76 steps/minute to 109 steps/minute.

After grouping, the proportion of the number of commute MVPA steps taken at bouts of 10 minutes and more was much greater than the number of non-commute steps taken at bouts of 10 minutes and more (76 steps/minute: 67% vs. 42%; 100 steps/minute: 64% vs. 46%; 109 steps/minute: 62% vs. 50%) (Figure 6.17). The number of commute and non-commute MVPA steps taken at short walking bouts less than five minutes reduced compared to before grouping and resulted in the redistribution into MVPA steps taken at long walking bouts of greater than 10 minutes. Compared to before grouping, the number of commute MVPA steps taken at bouts less than one minute reduced at all cadence thresholds for MVPA (76 steps/minute: 293 vs. 176 steps; 100 steps/minute: 132 vs. 105 steps; 109 steps/minute: 74 vs. 67 steps). Similar observations were made for non-commute MVPA steps at all cadence thresholds for MVPA (76 steps/minute: 2,066 vs. 1,631 steps; 100 steps/minute: 667 vs. 597 steps; 109 steps/minute: 327 vs. 305 steps). Conversely, for bouts greater than and equal to 10 minutes, the number of commute and non-commute MVPA steps increased at all cadence thresholds for MVPA.

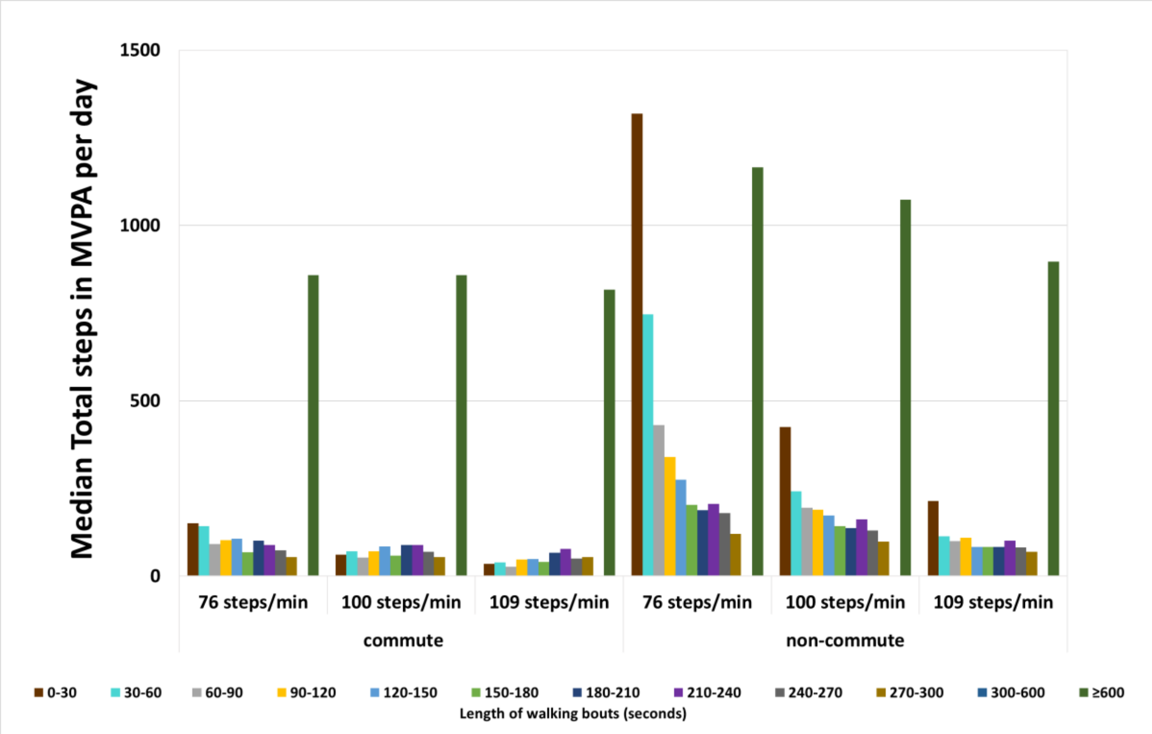

Figure 6.16: Comparison of the length of walking bouts of ungrouped MVPA steps with the cadence thresholds of MVPA during commuting and non-commuting periods

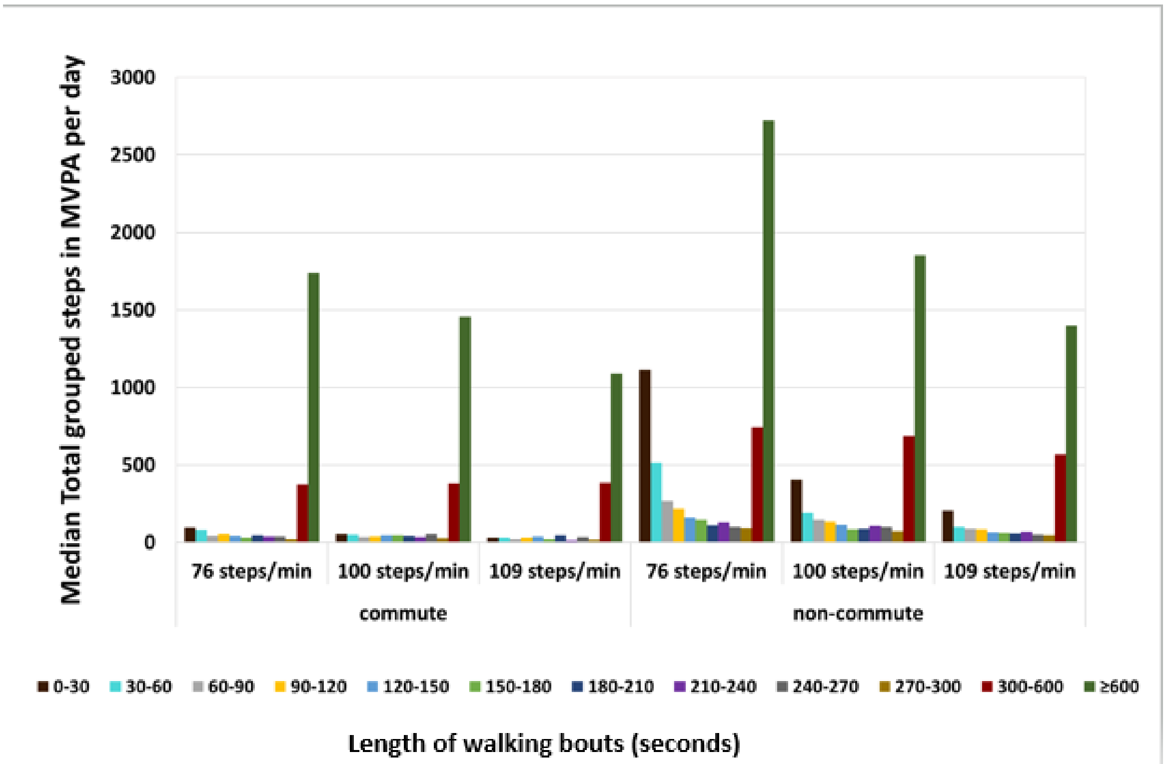

Figure 6.17: Comparison of the length of walking bouts of grouped MVPA steps with the cadence thresholds of MVPA during commuting and non-commuting periods

6.4 Compliance with Physical Activity guidelines

Objective 10: To determine the compliance to UK physical activity guidelines for all participants in terms of volume and lengths of walking bouts of MVPA accumulated, before and after grouping

The 2011 UK physical activity guidelines recommend that at least 150 minutes per week of moderate-intensity physical activity should be accumulated, or at least 30 minutes of moderate-intensity on at least 5 days a week, in bouts of 10 minutes or more (DH, 2011). The 2019 UK physical activity guidelines have the same wording except for the exclusion of a minimum bout length of 10 minutes (DHSC, 2019). Compliance with both guidelines is reported in this section: compliance to the 2011 physical activity guidelines was defined as on a minimum duration of 30 minutes of MVPA per day, in bouts of 10 minutes or more. For the 2019 guidelines, a minimum duration of 30 minutes of MVPA per day was considered compliant. As all participants had worn the accelerometer-based devices for more than 5 days a week, they were all included in this analysis. In the following sections for the graphical presentation of the compliance with the physical activity guidelines, MVPA was defined using a cadence of 100 steps/minute only; however, Table 6.7 presents the compliance to both the 2011 and 2019 physical activity guidelines using all three cadence thresholds for MVPA among all the participants

Table 6.7: Compliance with the 2011 and 2019 physical activity guidelines using the three cadence thresholds for MVPA

Cadence thresholds for MVPA (steps/minute)	Number of participants compliant with 2011 guidelines			Number of participants compliant with 2019 guidelines		
	ungrouped	grouped	% increase	ungrouped	grouped	% increase
76	16	32	100%	39	40	2.5%
100	16	26	63%	29	31	3%
109	15	20	33%	21	21	0%

6.4.1 Compliance to physical activity guidelines grouped by mode of commute before grouping

Using 100 steps/minute as the definition for MVPA, more than half of the participants (n=29/40) were compliant with the 2019 physical activity recommended guidelines, with ten participants being compliant during their commute alone (Figure 6.18). All of the mixed-mode commuters, walking commuters, cycle commuters, and eight of the car commuters were compliant. There were significant differences between the modes of commute for both commute time in MVPA[27] ($p<0.001$) and total time in MVPA[28] ($p<0.001$); however, there was no significant difference between modes of commute for the non-commute time in MVPA[29] ($p=0.289$) (Table 6.3).

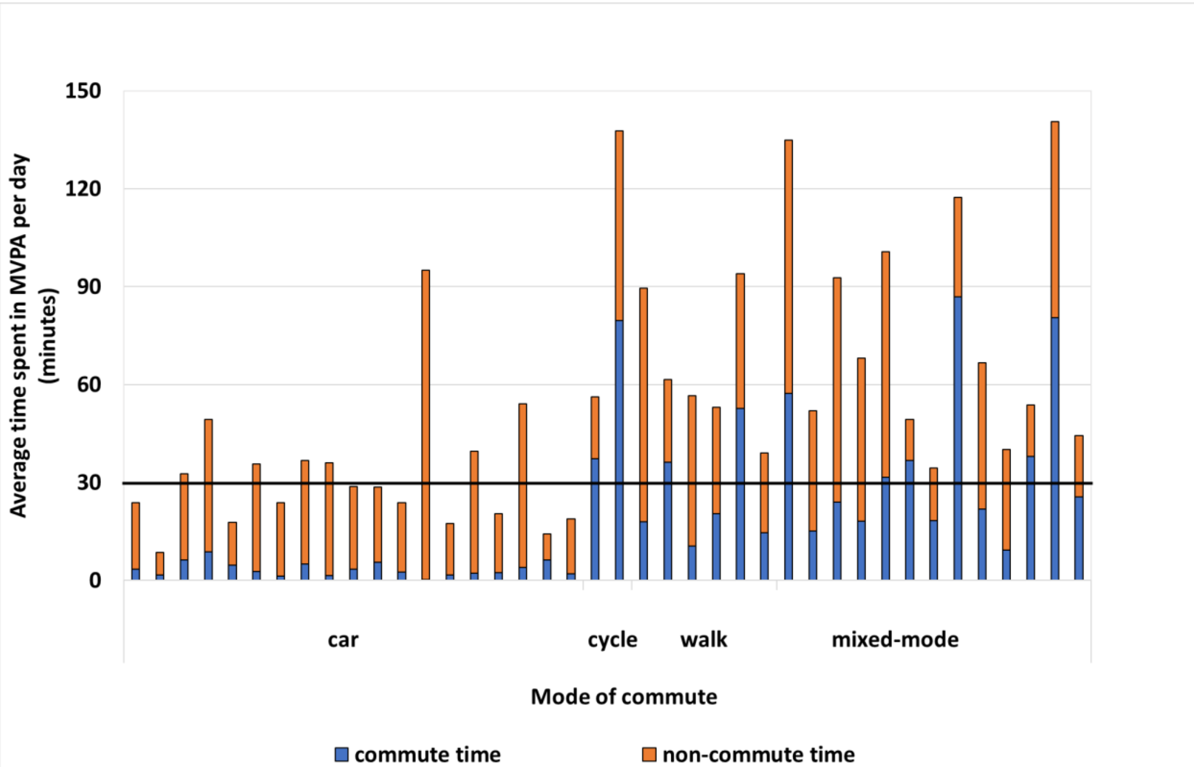

Figure 6.18: Commute time and non-commute time in MVPA at ≥100 steps/minute for all walking bouts for all subjects grouped by commute mode (The black line represents the physical activity cut-off for 30 minutes of MVPA per day)

[27] Kruskal-Wallis Test: H(3)=29.178
[28] Kruskal-Wallis Test: H(3)=18.189
[29] Kruskal-Wallis Test: H(3)=3.761

For the 2011 UK physical activity guidelines that included the minimum bout length of 10 minutes, the number of compliant participants was reduced (Figure 6.19). Only 16 participants were compliant (seven mixed-mode commuters, five car commuters, and four walking commuters). Three mixed-mode commuters and two walking commuters were compliant in their commute alone.

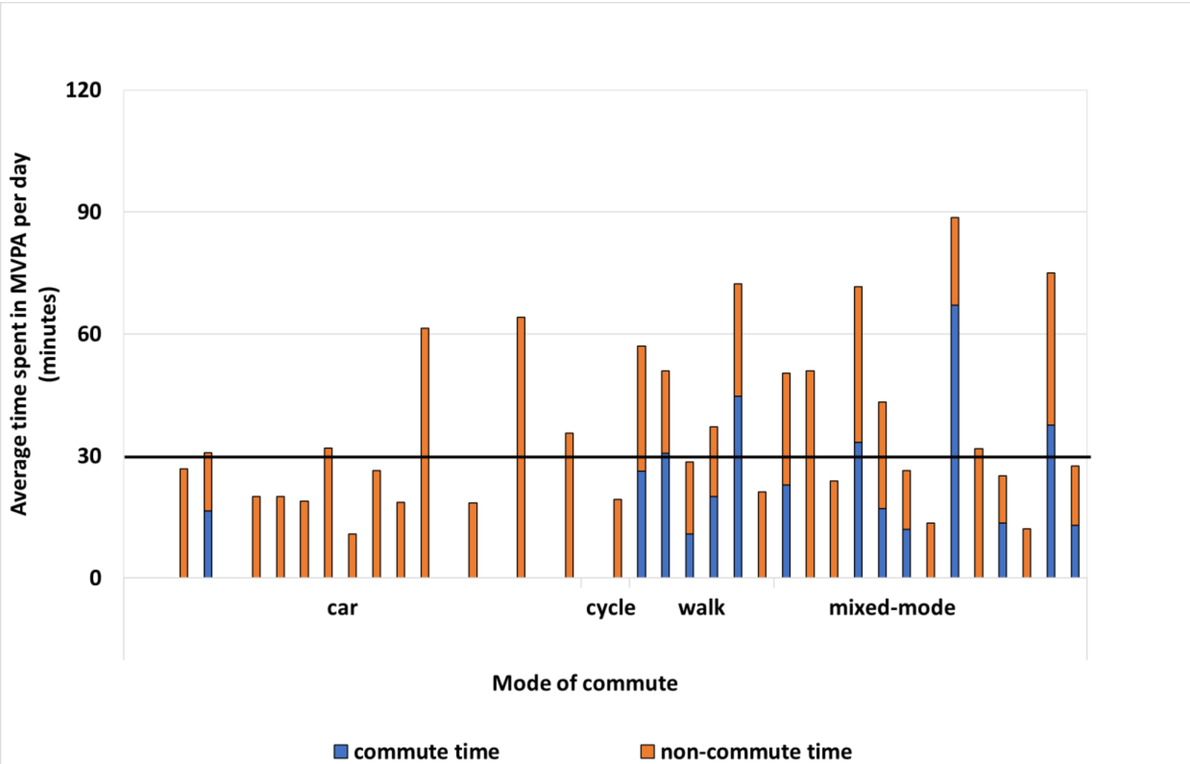

Figure 6.19: Commute time and non-commute time in MVPA at ≥100 steps/minute and at walking bouts greater than 10 minutes (The black line represents the physical activity cut-off for 30 minutes of MVPA per day)

6.4.2 Compliance to physical activity guidelines grouped by mode of commute after grouping

Figure 6.20 shows the compliance to current UK physical activity guidelines grouped by mode of commute. As a result of grouping, two more participants became compliant, making a total of 31 participants that achieved a minimum of 30 minutes per day on at least five days of a week. Eleven participants (six mixed-mode, two cycling, and three walking commuters) met this guideline in their commute alone. Figure 6.20 shows that all the mixed-mode, cycling, and walking commuters (n=31) achieved the recommended physical activity guidelines;

however, almost half of the car commuters (n=9) did not meet up with the recommended guidelines.

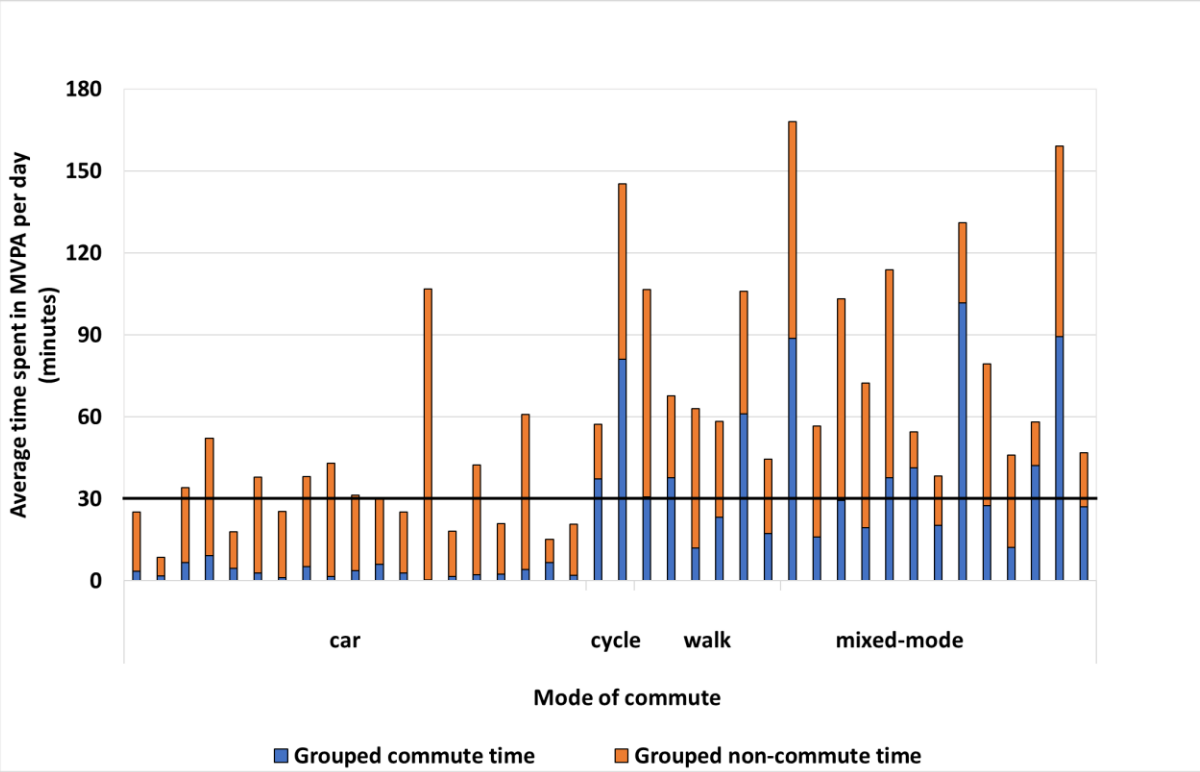

Figure 6.20: Grouped commute time and non-commute time in MVPA at ≥100 steps/minute for all walking bouts for all subjects grouped by commute mode (The black line represents the physical activity cut-off for 30 minutes of MVPA per day)

For the 2011 UK guidelines that included the minimum bout length of 10 minutes, the number of compliant participants increased from 16 participants to 26 participants after grouping (Figure 6.21). All the mixed-mode commuters were compliant (n=13), seven car commuters, five walking commuters, and one cycling commuter. Of the 26 compliant participants, 10 participants were compliant in their commute alone.

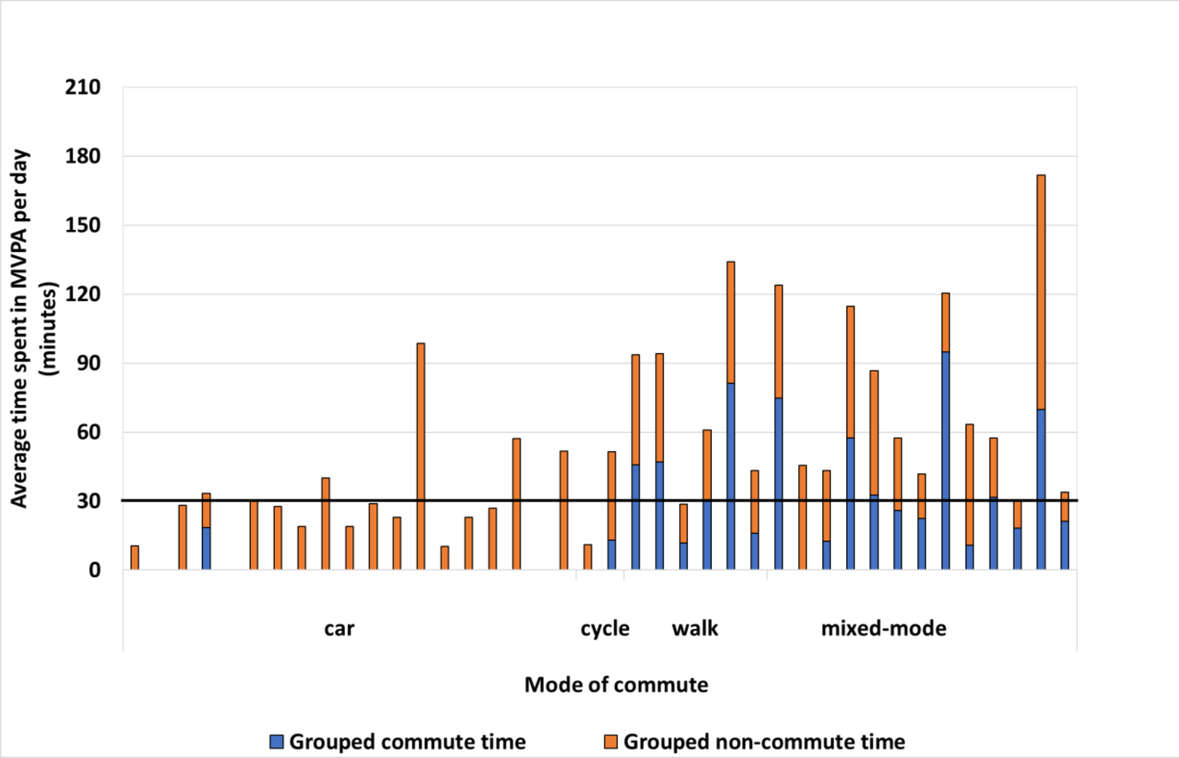

Figure 6.21: Grouped commute time and non-commute time in MVPA at ≥100 steps/minute and at walking bouts greater than 10 minutes (The black line represents the physical activity cut-off for 30 minutes of MVPA per day)

6.5 Regression Analyses: Association between commute time in MVPA and metabolic outcomes

Objective 11: To identify associations between commute time in MVPA and metabolic markers.

This section presents the results from the regression analyses showing the associations between commute time in MVPA, using the three cadence thresholds for MVPA, and metabolic outcomes. The first part of this section displays scatterplots between commute time in MVPA at 100 steps/minute and the different metabolic outcomes. The second part of this section presents the statistical results from the linear regression analyses to determine if the relationship between the two variables was significant. The final part of this section presents the results from the logistical regression analyses between binary outcomes of metabolic outcomes and commute time in MVPA at the different cadence thresholds.

The first step taken in the statistical analysis was to determine the normality of the data and the results showed that some of the dependent variables were normally distributed: fasting blood glucose, HDL-cholesterol, systolic blood pressure, and diastolic blood pressure. Body mass index (BMI), waist circumference (WC), and triglycerides were non-normally distributed. A linear regression analysis was used to predict the effect of MVPA during commuting on each metabolic outcome that was normally distributed. The rationale for using a linear regression model for all the variables have been described in Section 5.6.1. The non-normal variables did not satisfy the conditions to use a quantile regression; hence, linear regression was carried out.

6.5.1 Scatterplots of grouped commute time in MVPA and metabolic outcomes

The scatterplots displayed in this section shows the relationship between commute time in MVPA at the 100 steps/minute threshold and the metabolic outcomes. After grouping, the commute time in MVPA showed different results to the metabolic outcomes compared to commute time in MVPA before grouping at 100 steps/minute threshold. Therefore, the scatterplots presented in this section show the association between commute time in MVPA at 100 steps/minute threshold, when grouping was applied, and metabolic outcomes.

There was a negative relationship between commute time in MVPA at 100 steps/minute threshold and BMI (Figure 6.22), waist circumference (Figure 6.23), fasting blood glucose (Figure 6.24), systolic (Figure 6.27) and diastolic blood pressure (Figure 6.28). There was a negative relationship between commute time in MVPA and BMI (β= -0.053 (-0.104-(-0.001)). From the R-squared value (R^2 =0.10), the linear model explains only 10% of the variability of BMI around the mean. The correlation coefficient was 0.32, indicating a weak relationship between commute time in MVPA and BMI. Also, from the scatterplot, it was observed that some data points were outliers (extreme values) as defined by the SPSS software and eyeballing from the scatterplots.

There was a positive relationship between grouped commute time in MVPA at 100 steps/minute threshold and HDL-cholesterol (Figure 6.26). An interesting observation was seen in the scatterplot showing the relationship between grouped commute time in MVPA at 100 steps/minute threshold and triglycerides (Figure 6.25): there was a positive relationship between the two variables. The scatterplots (Figures 6.22-6.28) for the remaining metabolic outcomes shows no association between commute time in MVPA at 100 steps/minute threshold and metabolic outcomes as the values are dispersed away from the regression line.

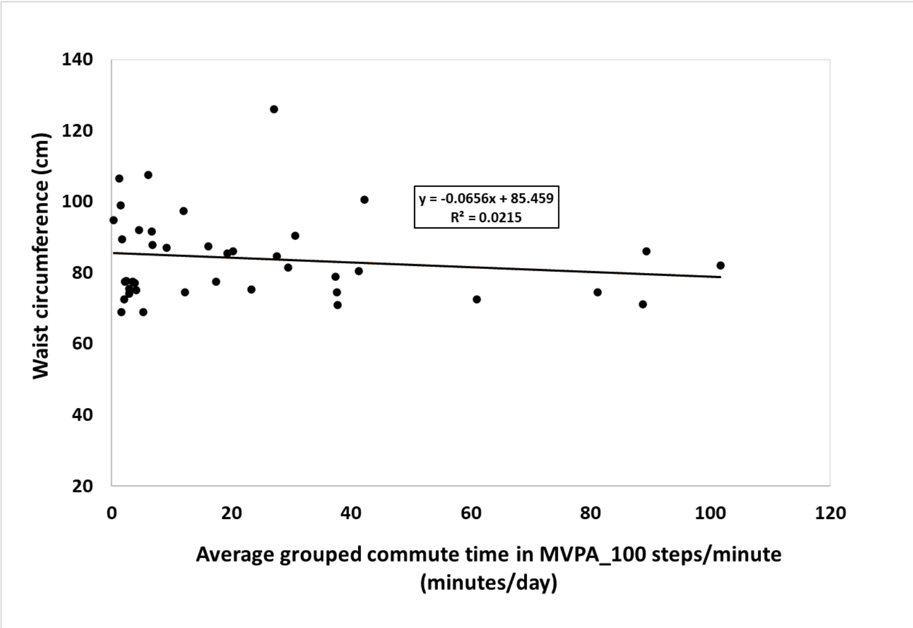

Figure 6.22: Scatterplot of the association between commute time in MVPA at 100 steps/minute, after walking bouts were grouped, and BMI

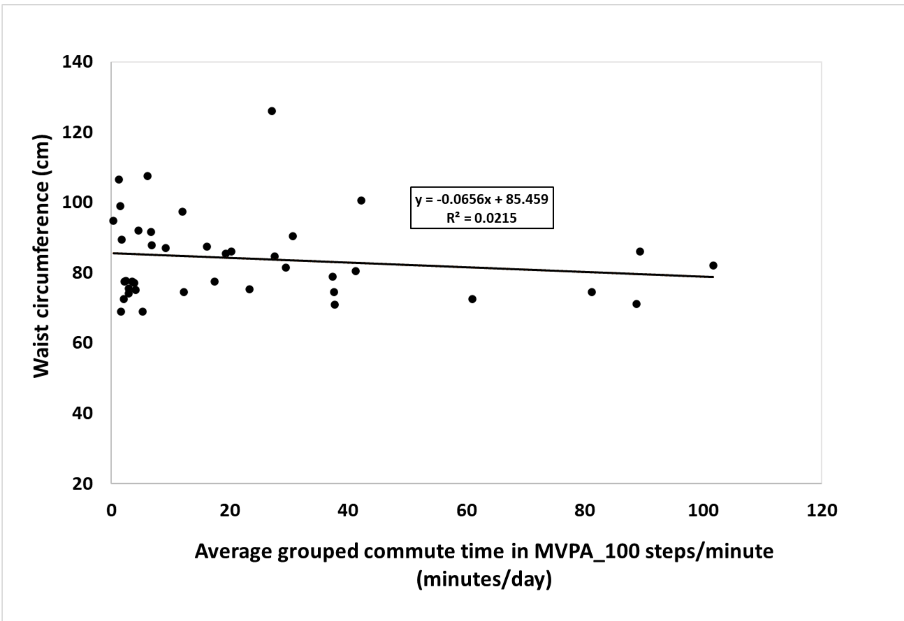

Figure 6.23: Scatterplot of the association between commute time in MVPA at 100 steps/minute, after walking bouts were grouped, and waist circumference

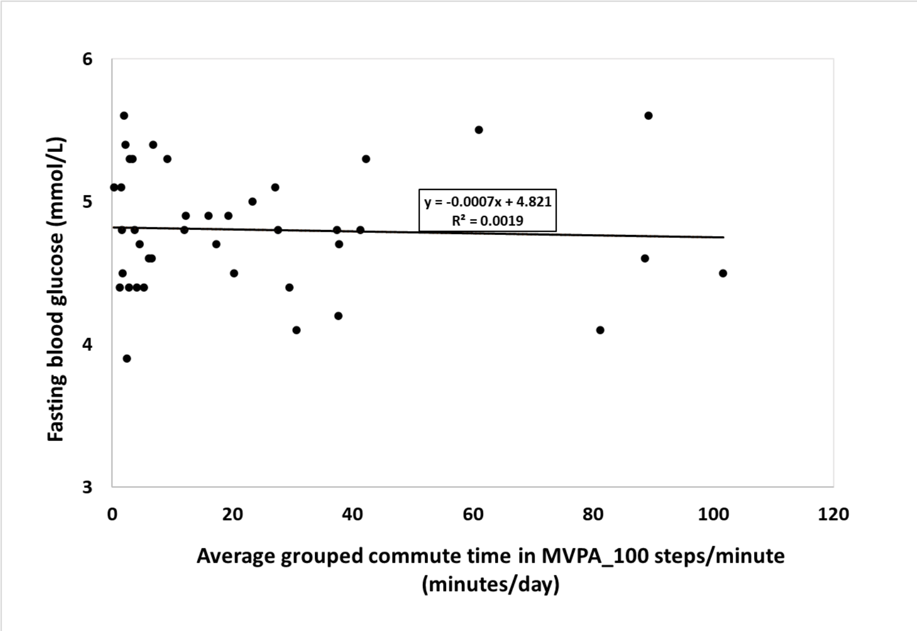

Figure 6.24: Scatterplot of association between commute time in MVPA at 100 steps/minute, after walking bouts were grouped, and fasting blood glucose

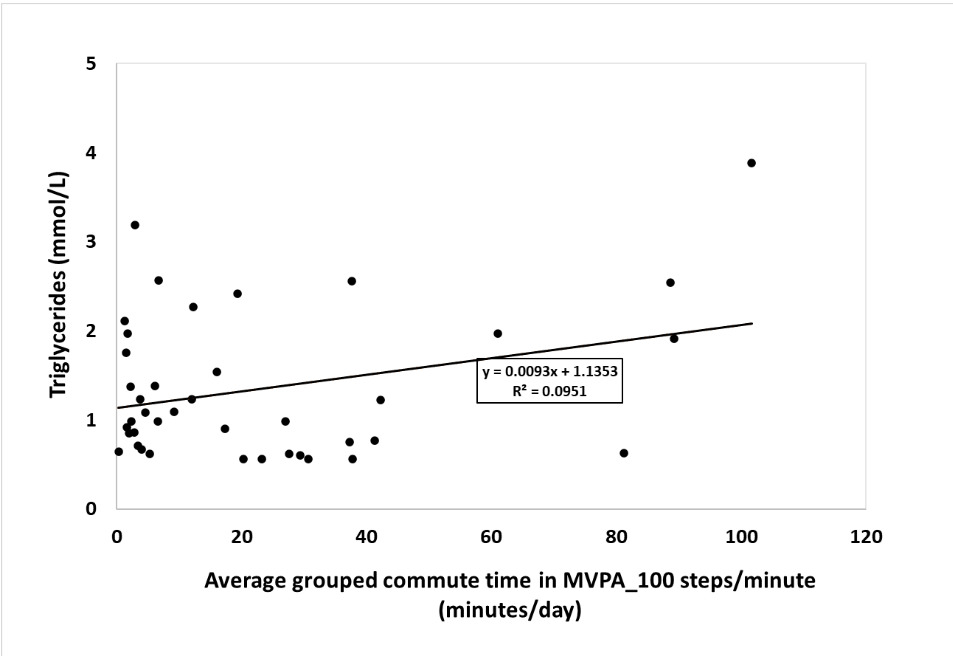

Figure 6.25: Scatterplot of the association between commute time in MVPA at 100 steps/minute, after walking bouts were grouped, and triglycerides

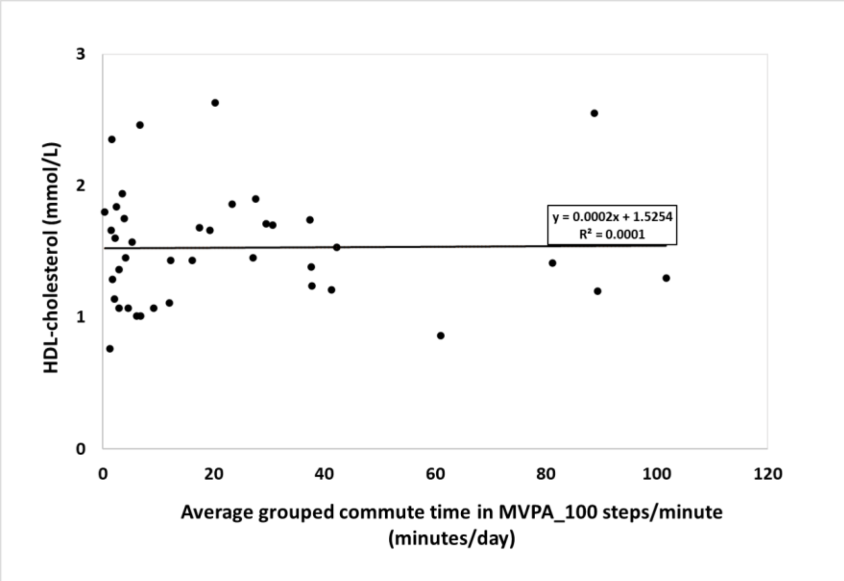

Figure 6.26: Scatterplot of the association between commute time in MVPA at 100 steps/minute, after walking bouts were grouped, and HDL-cholesterol

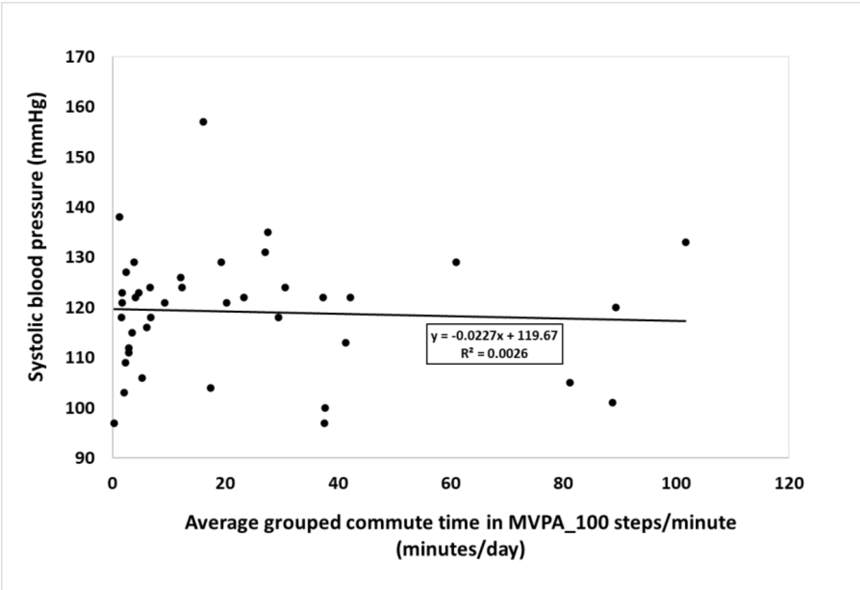

Figure 6.27: Scatterplot of the association between commute time in MVPA at 100 steps/minute, after walking bouts were grouped, and systolic blood pressure

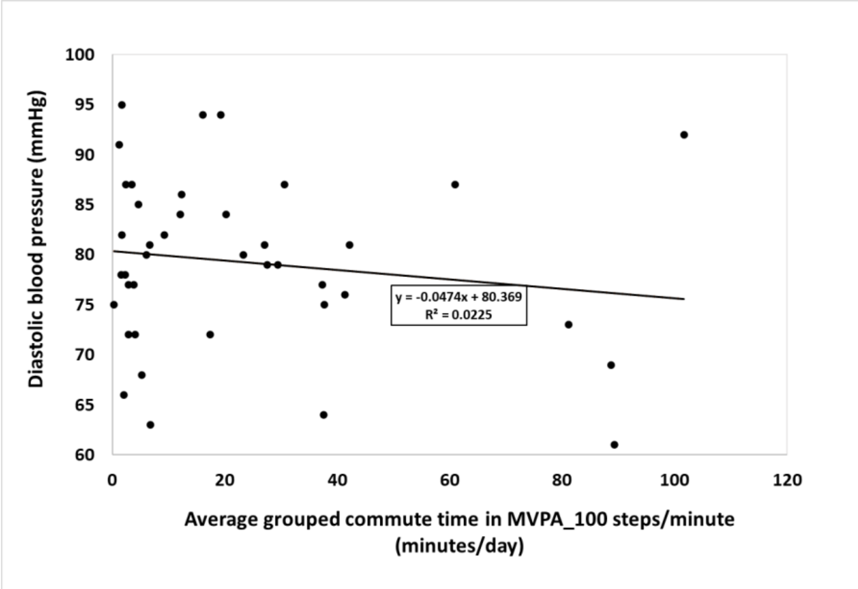

Figure 6.28: Scatterplot of the association between commute time in MVPA at 100 steps/minute, after walking bouts were grouped, and diastolic blood pressure

6.5.2 Linear regression of the association between commute time in MVPA and metabolic outcomes

The scatterplots showed that some extreme values could affect results obtained from regression analyses. However, it was observed that the SPSS software labelled very important values outliers, for example, a BMI value of 33.9 kg/m^2 was considered an outlier because most of the participants had a healthy BMI value. Also, some participants spent a long duration (>30 minutes) accumulating MVPA during commuting and those values were considered outliers by the SPSS software. Therefore, two analyses were conducted and presented in this section: first, all the participants were included, and the results are presented in Tables 6.8 and 6.9. Second, the outliers were excluded from the analysis and the results are presented in Tables 6.10 and 6.11: the method of identifying the outliers is explained in Section 6.5.2.2

The regression models adjusted for the confounding variables: age, fruit and vegetable intake, and non-commute MVPA. To select the relevant confounders, a forward selection procedure was performed, using a univariate analysis for the first step. In this case, the confounders were added to the model one by one. The strongest confounder in the model was first chosen and other important confounders were added to the model until no confounder had a relevant effect (p>0.1) (Bursac et al., 2008; VanderWeele, 2019). The models with BMI and clustered cardiometabolic risk score as an outcome were additionally adjusted for WC, and the model with waist circumference as an outcome was additionally adjusted for BMI.

6.5.2.1 Linear regression model including all data

The beta coefficients for the regression models for metabolic risk factors are presented in Table 6.8 and 6.9. The main findings were:

1. There were no significant associations between the ungrouped and grouped commute time in MVPA and metabolic outcomes, except for a negative significant association for both BMI and triglycerides.
2. Although the direction of association for BMI showed that an increase in commute time spent in MVPA may result in a reduction in BMI, it was not statistically significant after adjusting for confounding factors. Only the association between grouped commute time in MVPA at 109 steps/minute and BMI remained statistically significant after adjusting for potential confounders
3. There was a positive significant association between ungrouped and grouped commute time in MVPA at 109 steps/minute threshold and triglycerides before and after adjusting for potential confounding factors.

The association between ungrouped commute time in MVPA and BMI found a negative association (β= -0.05 (-0.14-(-0.01), p=0.026), showing that for every one-minute increase in commute time in MVPA, there was a reduction in BMI by 0.05kg/m^2. However, the association was not significant after adjusting for confounding factors (p=0.067). In contrast, grouped commute time in MVPA at 109 steps/minute threshold remained marginally significant for BMI after adjusting for confounding factors (p=0.054). Grouped commute time in MVPA at 109 steps/minute had a -0.03kg/m^2 reduction effect on BMI than the ungrouped commute time in MVPA at 109 steps/minute threshold.

The ungrouped commute time in MVPA at 76 steps/minute was associated with triglycerides before controlling for confounding factors (β= 0.01 (0.00-0.01), p=0.025), and 109 steps/minute (β= 0.02 (0.01-0.03), p=0.005); showing that an increase in commute time spent in MVPA at these thresholds are associated with an increase in triglycerides levels. The effect of this association at the 76 steps/minute threshold was attenuated after adjusting for confounding factors. However, the association between grouped commute time in MVPA at 100 (β= 0.00 (0.00-0.02), $p=0.045$), and 109 steps/minute (β= 0.02 (0.0-0.03), $p=0.030$), threshold remained significant after adjustment for confounding variables. The remaining metabolic outcomes were not associated with ungrouped and grouped commute time in MVPA.

Table 6.8: Associations between ungrouped commute time in MVPA and metabolic outcomes (including outliers)

Exposure	Commute time in MVPA at 76 steps/minute				Commute time in MVPA at 100 steps/minute				Commute time in MVPA at 109 steps/minute			
Metabolic risk factors /Model	**β**	**Low 95% CI**	**High 95% CI**	**p-value**	**β**	**Low 95% CI**	**High 95% CI**	**p-value**	**β**	**Low 95% CI**	**High 95% CI**	**p-value**
BMI												
• **Unadjusted**	-0.06	-0.12	0.01	0.083	-0.06	-0.12	0.01	0.074	**-0.07**	**-0.14**	**-0.01**	**0.026**
• **Adjusted**	-0.05	-0.08	0.01	0.135	-0.05	-0.12	0.02	0.166	-0.04	-0.14	0.01	0.067
WC												
• **Unadjusted**	-0.02	-0.21	0.16	0.811	-0.07	-0.24	0.10	0.420	-0.11	-0.28	0.10	0.181
• **Adjusted**	-0.07	-0.25	0.11	0.434	-0.08	-0.27	0.12	0.427	-0.12	-0.29	0.06	0.214
FBG												
• **Unadjusted**	-0.00	-0.01	0.01	0.604	0.00	-0.01	0.01	0.871	-0.00	-0.01	0.01	0.552
• **Adjusted**	-0.00	-0.01	0.01	0.759	0.00	-0.01	0.01	0.906	0.00	-0.01	0.01	0.960
Triglyceride												
• **Unadjusted**	**0.01**	**0.00**	**0.03**	**0.025**	0.01	-0.00	0.02	0.092	**0.01**	**0.01**	**0.02**	**0.056**
• **Adjusted**	0.01	-0.00	0.02	0.173	0.01	-0.00	0.02	0.099	**0.01**	**0.00**	**0.02**	**0.048**
HDL-cholesterol												
• **Unadjusted**	0.00	-0.01	0.01	0.995	-0.00	-0.01	0.01	0.765	-0.00	-0.01	0.01	0.636
• **Adjusted**	0.00	-0.01	0.01	0.776	0.00	-0.01	0.01	0.914	-0.00	-0.01	0.01	0.739
SBP												
• **Unadjusted**	0.04	-0.14	0.23	0.643	0.02	-0.19	0.15	0.834	0.01	-0.19	0.20	0.943
• **Adjusted**	-0.00	-0.17	0.17	0.976	0.01	-0.17	0.19	0.917	0.01	-0.17	0.19	0.901
DBP												
• **Unadjusted**	-0.03	-0.16	0.10	0.676	-0.05	-0.18	0.07	0.360	-0.05	-0.18	0.09	0.482
• **Adjusted**	-0.01	-0.15	0.12	0.873	-0.02	-0.15	0.12	0.789	-0.02	-0.15	0.10	0.712

Adjusted model for age, fruit and veg intake, non-commute time in MVPA. BMI=Body mass index, WC=waist circumference, SBP=Systolic blood pressure, DBP=Diastolic blood pressure, FBG=Fasting blood glucose, MVPA=Moderate-to-vigorous physical activity, Significant effects ($p<0.05$) are shown in bold; β is the coefficient change in the metabolic risk factor and are given with 95% confidence intervals (CI).

Table 6.9: Associations between grouped commute time in MVPA and metabolic outcomes (including outliers)

Exposure	Commute time in MVPA at 76 steps/minute				Commute time in MVPA at 100 steps/minute				Commute time in MVPA at 109 steps/minute			
Metabolic risk factors /Model	β	Low 95% CI	High 95% CI	p-value	β	Low 95% CI	High 95% CI	p-value	β	Low 95% CI	High 95% CI	p-value
BMI												
• **Unadjusted**	-0.04	-0.09	0.01	0.079	**-0.05**	**-0.10**	**-0.01**	**0.047**	**-0.07**	**-0.13**	**-0.01**	**0.020**
• **Adjusted**	-0.04	-0.09	0.01	0.133	-0.05	-0.11	0.01	0.113	**-0.07**	**-0.14**	**0.00**	**0.054**
WC												
• **Unadjusted**	-0.04	-0.17	0.09	0.560	-0.07	-0.21	0.08	0.367	-0.11	-0.28	0.06	0.191
• **Adjusted**	-0.05	-0.20	0.09	0.474	-0.08	-0.25	0.09	0.365	-0.12	-0.32	0.08	0.214
FBG												
• **Unadjusted**	-0.00	-0.01	0.00	0.690	0.00	-0.01	0.00	0.769	-0.00	-0.01	0.01	0.577
• **Adjusted**	-0.00	-0.01	0.00	0.594	-0.00	-0.01	0.01	0.762	-0.00	-0.01	0.01	0.673
Triglyceride												
• **Unadjusted**	0.01	-0.00	0.02	0.077	**0.01**	**0.00**	**0.02**	**0.053**	**0.01**	**0.00**	**0.02**	**0.044**
• **Adjusted**	0.01	-0.00	0.02	0.078	**0.00**	**0.00**	**0.02**	**0.045**	**0.02**	**0.00**	**0.03**	**0.030**
HDL-cholesterol												
• **Unadjusted**	0.00	-0.01	0.01	0.896	0.00	-0.01	0.01	0.946	0.00	-0.01	0.01	0.991
• **Adjusted**	0.00	-0.00	0.01	0.636	0.00	-0.01	0.01	0.735	-0.00	-0.01	0.01	0.845
SBP												
• **Unadjusted**	-0.00	-0.13	0.13	0.962	0.02	-0.17	0.12	0.756	-0.03	-0.20	0.14	0.708
• **Adjusted**	-0.00	-0.14	0.13	0.974	0.01	-0.15	0.17	0.935	0.02	-0.17	0.21	0.840
DBP												
• **Unadjusted**	-0.03	-0.12	0.06	0.528	-0.05	-0.15	0.06	0.355	-0.05	-0.17	0.07	0.392
• **Adjusted**	-0.01	-0.11	0.09	0.848	-0.01	-0.13	0.11	0.891	0.02	-0.12	0.15	0.821

Adjusted model for age, fruit and veg intake, non-commute time in MVPA. BMI=Body mass index, WC=waist circumference, SBP=Systolic blood pressure, DBP=Diastolic blood pressure, FBG=Fasting blood glucose, MVPA=Moderate-to-vigorous physical activity, Significant effects ($p<0.05$) are shown in bold; β is the coefficient change in the metabolic risk factor and are given with 95% confidence intervals (CI).

6.5.2.2 Linear regression model excluding outliers

For this part of the analysis, the outliers were removed because it was observed from the scatterplot that some data points were spread out than others. Further analysis was carried out using the statistical software, SPSS, to identify the outliers. The SPSS software identifies outliers as an extreme value outside of the 25th and 75th percentile of the distribution. Also, the distribution is shown graphically with the aid of a box plot showing the median, 25th percentile, 75th percentile, and outliers (the extreme values). After excluding the outliers from the analysis, the statistical significance observed between commute time in MVPA and some of the metabolic outcomes (triglycerides and BMI) was no longer observed.

The association between ungrouped and grouped commute time in MVPA (using the three cadence thresholds for MVPA: 76, 100, and 109 steps/minute) and metabolic outcomes are presented as beta coefficients from the linear regression models in Table 6.10 and 6.11. The four main findings from the results are:

1. There were no significant associations between the commute time in MVPA and individual metabolic outcomes. The grouped commute time in MVPA at all thresholds did not affect the association differently.
2. Although the direction of association for body mass index and waist circumference showed that an increase in commute time spent in MVPA may result in a reduction in body mass index and waist circumference, it was not statistically significant.
3. The direction for the association between ungrouped and grouped commute time in MVPA at all the thresholds and triglyceride was negative, but it was not statistically significant.
4. After adjusting for confounding variables, the direction of association between commute time in MVPA at 76 steps/minute and HDL-cholesterol was positive; however, the direction changed to negative when the cadence threshold for MVPA was altered from 76 to 100 and 109 steps/minute.

At all cadence thresholds for MVPA, commute time in MVPA was not significantly associated with BMI; however, it showed an inverse relationship between commute time in MVPA and BMI. Age was a significant predictor for BMI as it was statistically significant when added independently to the model (p=0.033). Also, fruit and vegetable intake and WC were significant when added to the model univariately. However, when all the covariates (age, fruit and vegetable intake, WC, and non-commute MVPA) were added to the model together, only WC remained significant (p<0.001), and the remaining variables became insignificant. At a cadence threshold of 109 steps/minute, WC remained an important predictor for BMI (0.14 (0.01-0.23); p=0.002) and non-commute time in MVPA at 109 steps/minute was a significant predictor for BMI as well (0.04 (0.01-0.07); p=0.043). Similar observations were made for associations between grouped commute time in MVPA at all cadences and BMI. Also, commute time in MVPA at all cadence thresholds was not significantly associated with waist circumference; however, BMI was a significant predictor as it indicated that as waist circumference increased, BMI increased as well.

The removal of outliers changed the association between ungrouped and grouped commute time in MVPA from positive to negative at all thresholds; however, it was not statistically significant. The figure below (Figure 6.29) shows the scatterplot for the association between grouped commute time in MVPA at 100 steps/minute threshold and triglycerides (-0.00 (-0.02-0.01); p=0.638).

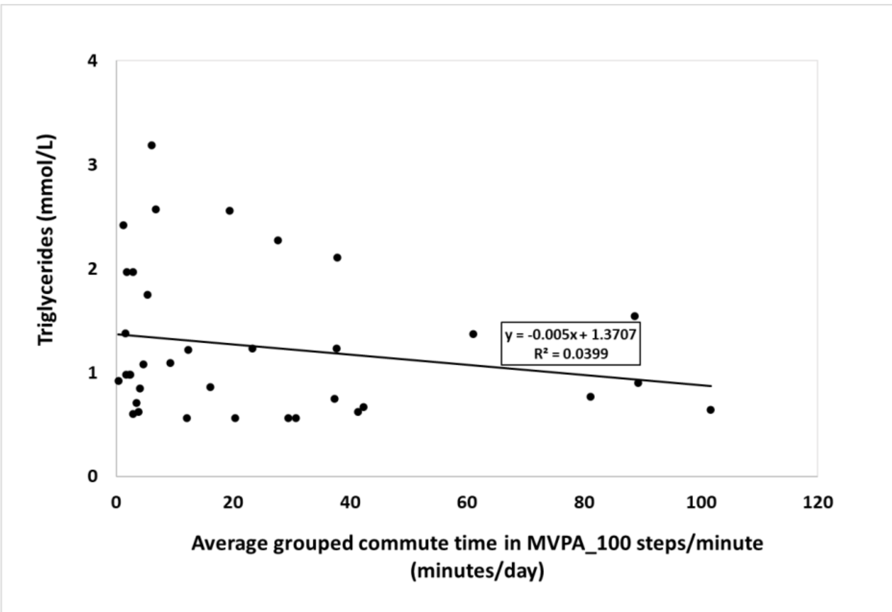

Figure 6.29: Scatterplot showing association between grouped commute time in MVPA at 100 steps/minute and triglycerides, excluding outliers

Table 6.10: Associations between ungrouped commute time in MVPA and metabolic outcomes (without outliers)

Exposure	Commute time in MVPA at 76 steps/minute				Commute time in MVPA at 100 steps/minute				Commute time in MVPA at 109 steps/minute			
Metabolic risk factors /Model	**β**	**Low 95% CI**	**High 95% CI**	**p-value**	**β**	**Low 95% CI**	**High 95% CI**	**p-value**	**β**	**Low 95% CI**	**High 95% CI**	**p-value**
BMI												
• **Unadjusted**	-0.03	-0.09	0.03	0.276	-0.04	-0.10	0.02	0.201	-0.05	-0.11	0.01	0.122
• **Adjusted**	-0.03	-0.08	0.01	0.144	-0.04	-0.08	0.02	0.161	-0.04	-0.09	0.01	0.135
WC												
• **Unadjusted**	-0.07	-0.31	0.18	0.580	-0.12	-0.39	0.15	0.367	-0.18	-0.45	0.09	0.191
• **Adjusted**	-0.09	-0.08	0.25	0.307	0.05	-0.17	0.24	0.573	-0.04	-0.16	0.23	0.719
FBG												
• **Unadjusted**	-0.00	-0.01	0.01	0.811	0.00	-0.01	0.01	0.871	-0.00	-0.01	0.01	0.847
• **Adjusted**	-0.00	-0.01	0.01	0.759	0.00	-0.01	0.01	0.906	-0.00	-0.01	0.01	0.960
Triglyceride												
• **Unadjusted**	-0.01	-0.02	0.01	0.487	-0.00	-0.02	0.01	0.648	-0.00	-0.02	0.02	0.920
• **Adjusted**	-0.01	-0.02	0.01	0.553	-0.00	-0.02	0.02	0.707	0.00	-0.02	0.02	0.988
HDL-cholesterol												
• **Unadjusted**	-0.00	-0.01	0.01	0.779	-0.00	-0.01	0.01	0.482	-0.00	-0.01	0.01	0.479
• **Adjusted**	0.00	-0.01	0.01	0.930	-0.00	-0.01	0.01	0.619	-0.00	-0.01	0.01	0.549
SBP												
• **Unadjusted**	0.05	-0.19	0.29	0.648	0.03	-0.23	0.30	0.793	-0.01	-0.28	0.26	0.931
• **Adjusted**	0.03	-0.20	0.26	0.806	0.05	-0.21	0.30	0.714	0.03	-0.23	0.30	0.797
DBP												
• **Unadjusted**	-0.04	-0.16	0.07	0.452	-0.05	-0.18	0.07	0.360	-0.06	-0.18	0.06	0.302
• **Adjusted**	-0.02	-0.15	0.10	0.712	-0.02	-0.15	0.12	0.789	-0.01	-0.15	0.12	0.873

Adjusted model for age, fruit and veg intake, non-commute time in MVPA. BMI=Body mass index, WC=waist circumference, SBP=Systolic blood pressure, DBP=Diastolic blood pressure, FBG=Fasting blood glucose, MVPA=Moderate-to-vigorous physical activity, Significant effects ($p<0.05$) are shown in bold; β is the coefficient change in the metabolic risk factor, and are given with 95% confidence intervals (CI).

Table 6.11: Associations between grouped commute time in MVPA and metabolic outcomes (without outliers)

Exposure	Commute time in MVPA at 76 steps/minute				Commute time in MVPA at 100 steps/minute				Commute time in MVPA at 109 steps/minute			
Metabolic risk factors /Model	**β**	**Low 95% CI**	**High 95% CI**	**p-value**	**β**	**Low 95% CI**	**High 95% CI**	**p-value**	**β**	**Low 95% CI**	**High 95% CI**	**p-value**
BMI												
• **Unadjusted**	-0.02	-0.07	0.03	0.449	-0.03	-0.09	0.03	0.288	-0.04	-0.11	0.03	0.213
• **Adjusted**	-0.02	-0.06	0.02	0.233	-0.03	-0.07	0.02	0.172	-0.05	-0.10	0.01	0.080
WC												
• **Unadjusted**	-0.04	-0.24	0.16	0.684	-0.10	-0.33	0.14	0.406	-0.14	-0.42	0.14	0.324
• **Adjusted**	-0.06	-0.08	0.19	0.390	0.04	-0.13	0.21	0.620	0.06	-0.15	0.26	0.576
FBG												
• **Unadjusted**	-0.00	-0.01	0.00	0.690	-0.00	-0.01	0.00	0.769	-0.00	-0.01	0.00	0.577
Adjusted	-0.00	-0.01	0.00	0.594	-0.00	-0.01	0.01	0.762	-0.00	-0.01	0.01	0.673
Triglyceride												
• **Unadjusted**	-0.01	-0.02	0.01	0.471	-0.00	-0.02	0.01	0.638	-0.00	-0.02	0.02	0.834
Adjusted	-0.00	-0.02	0.01	0.544	-0.00	-0.02	0.02	0.723	0.00	-0.02	0.02	0.992
HDL-cholesterol												
• **Unadjusted**	-0.00	-0.01	0.01	0.696	-0.00	-0.01	0.01	0.531	-0.00	-0.01	0.01	0.681
Adjusted	-0.00	-0.01	0.01	0.877	-0.00	-0.01	0.01	0.678	-0.00	-0.01	0.01	0.774
SBP												
• **Unadjusted**	0.04	-0.15	0.23	0.671	0.04	-0.19	0.27	0.734	0.04	-0.24	0.32	0.780
Adjusted	0.02	-0.16	0.21	0.804	0.06	-0.17	0.29	0.600	0.10	-0.18	0.38	0.462
DBP												
• **Unadjusted**	-0.03	-0.12	0.06	0.528	-0.05	-0.15	0.06	0.355	-0.05	-0.17	0.07	0.392
Adjusted	-0.01	-.011	0.09	0.848	-0.01	-0.13	0.11	0.891	0.02	-0.12	0.15	0.821

Adjusted model for age, fruit and veg intake, non-commute time in MVPA. BMI=Body mass index, WC=waist circumference, SBP=Systolic blood pressure, DBP=Diastolic blood pressure, FBG=Fasting blood glucose, MVPA=Moderate-to-vigorous physical activity, Significant effects ($p<0.05$) are shown in bold; β is the coefficient change in the metabolic risk factor, and are given with 95% confidence intervals (CI).

6.5.3 Logistic regression analyses between commute time in MVPA and binary metabolic outcomes (high blood pressure, high triglycerides, high BMI, high waist circumference, and low HDL-cholesterol)

Table 6.12 presents the odds ratio for the logistic regression for the metabolic outcomes: high blood pressure, high triglycerides, high BMI, high waist circumference, and low HDL-cholesterol. There were no differences in the effects of the models using commute time in MVPA before and after grouping; therefore, the grouped commute time in MVPA at all three cadence thresholds for MVPA are presented.

There was no association between high blood pressure, high triglycerides, and low HDL-cholesterol as the odds ratio was equalled to one. For every minute spent in accumulating MVPA during commuting was associated with the lower odds of being obese and having a high waist circumference; however, these results were not statistically significant. The odds of having an unhealthy range of metabolic outcomes changed as the definition for MVPA changed/ For example, the odds of being obese changed from 4% to 11% as the definition for MVPA was changed from 76 steps/minute to 109 steps/minute. Although there were no significant associations, increasing age and BMI were significant predictors of low HDL-cholesterol, high waist circumference, and high triglycerides. Every minute per day spent in accumulating MVPA during commuting was associated with the lower odds of being obese and having a high waist circumference; however, these results were not statistically significant.

Table 6.12: Logistic regression of the association between commute time in MVPA and metabolic risk factors

Metabolic outcomes	High BMI				High WC				High BP				High Triglycerides				Low HDL-cholesterol			
	Odds Ratio	Low 95% CI	High 95% CI	P value	Odds Ratio	Low 95% CI	High 95% CI	P value	Odds Ratio	Low 95% CI	High 95% CI	P value	Odds Ratio	Low 95% CI	High 95% CI	P value	Odds Ratio	Low 95% CI	High 95% CI	P value
adjusted model																				
Commute time in MVPA																				
• 76 steps/minute	0.96	0.87	1.06	0.389	0.99	0.96	1.02	0.382	1.02	0.98	1.05	0.291	1.02	0.99	1.05	0.180	1.01	0.96	1.07	0.712
• 100 steps/minute	0.96	0.87	1.05	0.335	0.98	0.95	1.02	0.284	1.02	0.98	1.05	0.305	1.02	0.99	1.05	0.116	1.01	0.96	1.07	0.663
• 109 steps/minute	0.89	0.73	1.09	0.253	0.97	0.93	1.01	0.162	1.01	0.98	1.05	0.437	1.03	0.99	1.06	0.070	1.01	0.96	1.07	0.583
Grouped Commute time in MVPA																				
• 76 steps/minute	0.97	0.91	1.03	0.333	0.99	0.97	1.02	0.453	1.02	0.99	1.04	0.223	1.02	0.99	1.04	0.114	1.01	0.96	1.05	0.836
• 100 steps/minute	0.96	0.88	1.04	0.314	0.99	0.96	1.01	0.301	1.02	0.99	1.05	0.313	1.02	0.99	1.05	0.076	1.01	0.97	1.06	0.667
• 109 steps/minute	0.89	0.74	1.08	0.240	0.98	0.94	1.01	0.212	1.02	0.98	1.05	0.388	1.03	0.99	1.06	0.069	1.01	0.96	1.07	0.698

The unadjusted model did not adjust for any of the variables, the adjusted model controlled for age, fruit and veg intake, non-commute time in MVPA, and WC [BMI]. BMI=Body mass index, WC=waist circumference, SBP=Systolic blood pressure, DBP=Diastolic blood pressure, FBG=Fasting blood glucose, MVPA=Moderate-to-vigorous physical activity, Significant effects ($p<0.05$) are shown in bold; β is the coefficient change in the metabolic risk factor, and are given with 95% confidence intervals (CI)

6.6 Summary of findings

Objectives	Main findings
7. To determine the difference between the different modes of commute and time spent in MVPA during commuting and non-commuting periods.	• Cycling commuters spent more time walking per day during commuting and non-commuting periods compared to the remaining groups, contributing 48% of their total time walking per day during commuting periods. • The car commuters spent the lowest time walking during commuting and non-commuting periods, with only 6% of their total time walking spent during commuting periods.
8. To objectively quantify MVPA using different cadence thresholds for MVPA to explore patterns of commute and non-commute steps.	• The distribution of median steps per day was accumulated differently across the three MVPA thresholds between commuting and non-commuting periods. • For commuting periods, MVPA steps were greater at all thresholds (76, 100, & 109 steps/minute) than non-MVPA steps. MVPA steps during commuting decreased from 90% at 76 steps/minute to 60% at 109 steps/minute; however, MVPA steps during non-commuting decreased from 76% to 28%. • There was a greater effect in the reduction of MVPA steps during non-commuting periods as the definition changes and vice versa. • For non-commuting periods, non-MVPA steps comprised a greater proportion as the definition was changed from 76 steps/minute to 109 steps/minute (25% to 72%). • In contrast, commute steps were made of fewer non-MVPA steps than the non-commute steps • Commute steps were mostly accumulated at higher cadences bands compared to non-commute steps (110 steps/minute: 37% vs. 16%; 120 steps/minute: 13% vs. 4%).

Objectives	Main findings
	• There was a steady increase in the accumulation of non-commute steps taken, with no distinctive patterns in accumulation across the cadence bands. • Conversely, commute steps show that the accumulation of steps at lower cadences bands occurs differently from the total number of steps accumulated at higher cadences bands (>110 steps/minute).
9. To explore the patterns of commute and non-commute stepping at different lengths of walking bouts, before and after grouping walking events;	• For all steps, most were taken at short walking bouts (66%) than at medium (15%) and long (19%) walking bouts. • Non-commute steps were mostly accumulated at short walking bouts (73%), followed by long walking bouts (14%), and then medium walking bouts (13%). • For commute steps, a greater proportion of the steps were taken at short walking bouts (45%), followed by long walking bouts (33%), and then medium walking bouts (22%). • Compared to commute steps, non-commute comprised of a far greater proportion of steps taken at short walking bouts (45% vs. 73%) and fewer steps taken at long walking bouts (33% vs. 14%). • Before grouping, there was a greater reduction of 23% in the number of non-commute MVPA steps compared to a 5% reduction in the number of commute MVPA steps when the definition of MVPA was changed from 76 steps/minute to 109 steps/minute. • After grouping, the number of total MVPA steps taken at short walking bouts of less than five minutes decreased while the number of total MVPA steps taken at greater than five minutes increased as a result of incorporating short walking bouts.

Objectives	Main findings
10. To determine the compliance to UK physical activity guidelines for all participants in terms of volume and lengths of walking bouts of MVPA accumulated, before and after grouping walking events;	• For the 2011 UK guidelines, 16 participants were compliant, with five commuters (three mixed-mode and two walking commuters) meeting this guideline in their commute alone. • For the 2019 UK guidelines, compliance among the participants increased: 29 participants were compliant, with ten participants being compliant in their commute alone. • After grouping, there was an increase in compliance for both 2011 and 2019 guidelines. The increase was greater with the 2011 guidelines, with an addition of 10 participants being compliant compared to the 2019 guidelines where only two additional participants were compliant.
11. To identify associations between commute time in MVPA and metabolic markers.	• There were no significant associations between the ungrouped and grouped commute time in MVPA and metabolic outcomes, except with BMI and triglycerides. • Although the direction of association for BMI showed that an increase in commute time spent in MVPA may result in a reduction in BMI, it was not statistically significant after adjusting for confounding factors. • Only the association between grouped commute time in MVPA at 109 steps/minute and BMI remained statistically significant after adjusting for potential confounders. • There was a positive significant association between ungrouped and grouped commute time in MVPA at 109 steps/minute threshold and triglycerides before and after adjusting for potential confounding factors. • However, after removing outliers, the direction for the association between ungrouped and grouped commute time in MVPA at all the thresholds and triglyceride was negative but it was not statistically significant.

Objectives	Main findings
	• For categorical responses, every minute per day spent in accumulating MVPA during commute was associated with the lower odds of being obese and having a high waist circumference; however, these results were not statistically significant. • For every minute spent in accumulating MVPA during commute, the odds of having an unhealthy range of metabolic outcomes change as the MVPA definition was changed. For example, the odds of being obese changed from 4% to 11% as the MVPA definition was changed from 76 steps/minute to 109 steps/minute. • Although there were no significant associations, increasing age, and high BMI were significant predictors of low HDL-cholesterol, high waist circumference, and high triglycerides.

Chapter 7: Discussion

Chapter	**Summary of each chapter**
1- Introduction	A background to physical activity, the role of commuting to contributing to physical activity, an overview of methods used in measuring commuting physical activity, and its association with health outcomes.
2- Literature review	A critical review and discussion of the literature surrounding measuring commuting MVPA, and its association to various health outcomes, especially metabolic risk factors
3- Methodology I – Methods for Study One and Two	Describes the methods for Study One:(*Commuting and MVPA)*; and Study Two: (*Gap analysis*) **Aim of Commuting and MVPA study**: To objectively determine the contribution of MVPA during commuting to total MVPA, using cadence to define MVPA, and explore how minimum walking bout length affects adherence to physical activity guidelines. **Aim of Gap analysis study**: To use an event-based approach to define continuous walking events, by combining walking events with short interruptions based on an average cadence threshold.
4- Results I – Results for Study One and Two	Presents the results for objectives one to six: 1. To objectively quantify MVPA during commuting using the definition of cadence. 2. To determine the difference between modes of commute and time spent in MVPA during commuting. 3. To determine the level of compliance to physical activity guidelines by examining the volume of MVPA and length of walking bouts accumulated. 4. To combine short interruptions between walking events to form a new continuous walking event called "grouped event" 5. To examine how grouping walking events changes total time walking and total time in MVPA 6. To ascertain whether combining walking events with short interruptions between them impacts compliance to physical activity guidelines.
5- Methodology II – Methods for Study Three	Describes the methods used in Study Three to address objectives seven to eleven **Aim**: To investigate the association between MVPA during commuting physical activity and metabolic markers.
6- Results II – Results for Study Three	Presents the results for objectives seven to eleven: 7. To determine the difference between the different modes of commute and time spent in MVPA during commuting and non-commuting periods. 8. To objectively quantify MVPA, using different cadence thresholds for MVPA, for both commute and non-commute stepping. 9. To explore the patterns of commute and non-commute stepping at different lengths of walking bouts, before and after grouping walking events. 10. To determine the compliance to the 2011 and 2019 UK physical activity guidelines for all participants before and after grouping walking events. 11. To investigate associations between commute time in MVPA (before and after grouping walking events) and metabolic markers.
7- Discussion	This chapter summarises the findings from Study One to Three, highlights their strengths and limitations within this thesis; Reflection on the impact of COVID-19 on commuting physical activity.
8- Conclusion	This chapter gives a concluding summary of the thesis and implications for policy and future research.

7.0 Chapter Overview

This chapter discusses the findings from Study One, Two, and Three, highlighting their contribution to the literature and examining their strengths and limitation within this thesis. The chapter also includes a reflection section that discusses the impact of Covid-19 on the potential findings for the commuting studies.

The findings in this thesis have contributed to understanding the role of commuting in contributing to total physical activity, with the choice of commute mode playing an important role. Also, the association of MVPA during commuting with metabolic markers in a group of working adults was explored. Additionally, the novel methodological approach for defining continuous walking, by grouping walking events with short interruptions has been developed: the impact of using this approach on compliance with physical activity guidelines may potentially improve metabolic health that would involve multi-levelled pathways in-between the change in measurement and change in health in achieving optimum health benefits.

With the use of a modified diary to correctly classify modes of commute and investigate the association of commuting MVPA and metabolic markers, the cycling and mixed-mode commuters accumulated the highest proportion of MVPA. Although the association between commute time in MVPA and metabolic markers was not statistically significant, there were significant results at 109 steps/minute threshold between commute time in MVPA and BMI. These observations were exclusive to commute time in MVPA alone as the associations of total time in MVPA and non-commute time in MVPA with any of the metabolic markers was much weaker.

7.1 Main findings for all studies

7.1.1 Study One: Commuting and MVPA study

7.1.1.1 Main findings

Commuting contributed 33% of total time in MVPA and 34% of the total steps taken daily. The mode of commute played a significant role in the total MVPA accumulated. For walking commuters, 54% of their total MVPA was accumulated during commuting, which was much larger than other commute modes. Compliance with 2011 physical activity guidelines was low among the participants when the minimum 10 minutes walking bout length was applied, with only seven out of the 23 participants meeting the recommendations. However, there were more participants (n=17) who met the 2019 physical activity guidelines.

There was a significant positive relationship between both commute time in MVPA, and non-commute time in MVPA, with total MVPA; however, causality cannot be established due to the cross-sectional design of this study (Bowling, 2014). A statistically significant difference was observed between commute time spent in MVPA and the three modes of commute. Further analysis on each pair of the commute modes showed that the significant differences in commute time in MVPA were between the car and mixed-mode commuters, and the car and walking commuters; however, there was no significant difference between the commute time spent in the walking category and the mixed-mode category.

7.1.2 Study Two: Gap analysis study

7.1.2.1 Main findings

This is the first study to use an intensity-based approach to define continuous walking events: combining walking events with interruptions and assessing the intensity of the new walking event using an MVPA cadence threshold. This method does not make any prior or arbitrary decision on the length of the walking event or the interruption. It can be used as a robust definition of continuous walking that reflects the health benefits associated with the activity.

There was a small increase in the total time spent in MVPA after grouping walking events and short standing events together compared to when the walking events were ungrouped. After grouping, the total time spent walking increased by 8% for the 76 steps/minute threshold, 3% for the 100 steps/minute threshold, and 1% for the 109 steps/minute threshold. All the changes were significant ($p<0.001$) and the post-hoc pairwise comparison using the Tukey test showed there were significant differences between all the cadence thresholds for MVPA ($p<0.05$). Also, the grouped events comprised of standing events that were of short durations and walking events of longer durations, which resulted in grouped events having bouts of longer walking events compared to the ungrouped events.

Compliance to 2011 UK physical activity guidelines increased after grouping, with seven additional participants, making a total of 14 participants. While the effect of grouping on the 2019 guidelines was smaller, the number of participants meeting up with the guidelines increased from 17 to 22 participants. Furthermore, this highlights the impact that short interruptions have on the assessment of time spent in MVPA, which is likely to impact the assessment of health outcomes and physical activity prescription.

7.1.3 Study Three: Association between Commute time in MVPA and metabolic markers

7.1.3.1 Main findings

The contribution of commute time in MVPA towards total daily MVPA was 17% at the 76 steps/minute threshold, 21% at the 100 steps/minute threshold, and 26% at the 109 steps/minute threshold. For all MVPA thresholds, both during commuting and non-commuting periods, cycling, mixed-mode, and walking commuters accumulated more steps and spent more time in MVPA than the car commuters. For commuting periods, the proportion of MVPA steps were far greater than the proportion of non-MVPA steps (76 steps/minute: 90% vs. 10%; 100 steps/minute: 76% vs. 24%; 109 steps/minute: 60% vs. 40%). Furthermore, for all MVPA thresholds, non-commute MVPA steps were fewer than commute MVPA steps.

Commute steps comprised of a smaller proportion of steps taken at short walking bouts (<5 minutes) when compared to non-commute steps (45% vs. 73%); however, at medium (5 to <10 minutes) and long (≥10 minutes) walking bouts, commute steps were greater than non-commute steps (22% vs. 13% and 33% vs. 14% respectively). During commuting periods, car commuters accumulated 91% of their steps at short walking bouts while mixed-mode and walking commuters accumulated a greater proportion of their steps at long walking bouts (60% and 54% respectively).

After grouping, there was an increase in compliance to both the 2011 and 2019 guidelines. The increase was greater for the 2011 guidelines, with an addition of 10 participants being compliant (making a total of 26 participants) compared to the 2019 guidelines where only two additional participants were compliant (making a total of 31 participants).

Although the direction of association for BMI and waist circumference showed that an increase in commute time spent in MVPA may be associated with a reduction in BMI and waist circumference, only associations between commute time in MVPA at 109 steps/minute and BMI remained statistically significant after adjusting for confounding factors.

7.2 Comparison with previous studies

7.2.1 Total time in MVPA in previous commuting studies

The median total time spent in MVPA varied between the studies included in this thesis and previous literature. In Study Three, the median total time in MVPA using the 100 steps/minute threshold (46.8 minutes per day) was similar to Study One (Chapter 4), which reported the median total time in MVPA was 49.6 minutes per day. In comparison, other studies have reported varied higher and lower total times spent in MVPA (Table 7.1); Yang et al. (2012) reported an average duration of 55 minutes of MVPA per day among Cambridge commuters; Audrey et al. (2014) reported an average of 69.0 minutes of MVPA per day and another study reported an average of 27.9 minutes per day (195 minutes per week) (Sahlqvist et al., 2012) while Rafferty et al. (2016) reported an average duration of 32.7 minutes per day. The differences in the total time spent in MVPA across these studies may be due to differences in the measuring tools used (Panter et al., 2012), differences in the population, research study location, or even the period of data collection as shown in Table 7.1.

In terms of the period of the year the data were collected, different times of the year have different weather conditions that are known to affect the uptake of physical activity or some deviation from the usual mode of commuting (Herrador-Colmenero et al., 2018; Rissel et al., 2014). Therefore, the use of a large, all-year-round collected dataset will be valuable in assessing the impact of variability in weather conditions on the total time spent in MVPA. Although measuring the variability in weather conditions was not the focus of this thesis, the total time spent in MVPA for Study One and Three were quite close despite having different data collection periods, with Study One's data collection in the spring season and Study Three's data collection period in the summer and autumn seasons. Another reason for the differences in total time spent in MVPA could be the location: Yang et al. (2012) reported that the reason for the relatively high level of MVPA could be as a result of the study location being in Cambridge, which is regarded as a leading cycling city and a high prevalence of 65% engagement in active commuting among the participants in the study.

Another reason for the differences in the total time spent in MVPA could be due to the measurement methods of physical activity as previous studies mentioned in Table 7.1 quantified MVPA using different methods: Yang et al. (2012) and Audrey et al. (2014) used the cut-points threshold by Freedson et al. (1998) for the ActiGraph accelerometer, Sahlqvist et al. (2012) used a travel and physical activity questionnaire in obtaining data on MVPA. Rafferty et al. (2016) used the activPAL™ accelerometer, with MVPA defined as a cadence threshold of 109 steps/minute. The time spent in MVPA reported by Yang et al. (2012) and Audrey et al. (2012) using the waist-worn ActiGraph were higher than the time reported in MVPA using the studies that measured using the activPAL™. The ActiGraph has been reported to overestimate vigorous activities and underestimate light-intensity activities (Crouter et al., 2003; Berntsen et al., 2010); therefore, this could be a plausible explanation as to why the time spent in MVPA reported by the studies that measured using the ActiGraph was higher than those that measured using activPAL™ accelerometer-based device. In addition, depending on the cut-point thresholds used, the estimates of the time spent in MVPA will vary; however, Yang et al. (2012) and Audrey et al. (2012) both used the Freedson cut-point thresholds for the ActiGraph accelerometer and the time spent in MVPA reported were far apart (69.0 and 55.0 minutes respectively). Meanwhile, Rafferty reported an average total time in MVPA of 32.7 minutes per day in university office workers, with MVPA defined as a cadence threshold of 109 steps/minute; when compared with Study One, the total time spent at 109 steps/minute MVPA threshold was 31.2 minutes. Similarly, in Study Three, at 109 steps/minute, the total time spent in MVPA was 32.0 minutes. The average duration reported in the activPAL™ studies (in this thesis and the study by Rafferty et al. (2016) was very close and comparable because of the use of the same objective measuring tool and the same quantification of MVPA using cadence.

Overall, only four previous studies (Audrey et al., 2014; Rafferty et al., 2016; Sahlqvist et al., 2012; Yang et al., 2012) have explored the contribution of total time spent in commuting to total physical activity: most commuting studies have focused on the use of active commuting and the impact of active commuting on health outcomes. Therefore, Study One and Three provide further evidence to support the importance of commuting towards total daily physical activity.

Table 7.1: Commuting studies that have previously investigated total time spent in MVPA

Study	Sample size	Study Design	Study population	Total time in MVPA (minutes)	Methods used
Yang et al., 2012	475	Cross-sectional	Employees in Cambridge	55.0	- Physical activity questionnaire, RPAQ - Travel Diaries - ActiGraph GT1M & GT3X+
Sahlqvist et al., 2012	3339	Cross-sectional	Residents of Cardiff, Southampton, and Kenilworth	29.7	- Travel diary - Physical activity questionnaire, IPAQ
Audrey et al., 2014	103	Cross-sectional	Office workers in Bristol	69.0	- Questionnaire, - Travel Diaries - ActiGraph GT3X+ - GPS receiver (QStarz BT1000XT)
Rafferty et al., 2016	26	Cross-sectional	University office workers in Glasgow	32.7	- ActivPAL™ - GPS receiver (Amod AGL3080
Study One	23	Cross-sectional	University office workers in Salford	31.2	- ActivPAL™ - Activity diary
Study Three	40	Cross-sectional	University office workers and postgraduate research students in Salford	32.0	- ActivPAL™ - Activity diary

7.2.2 Contribution of commuting and modes of commute to total MVPA

In Study Three, the contribution of commute MVPA steps towards total MVPA steps ranged from 18% to 26% as the definition of the cadence threshold for MVPA changed from 76 to 109 steps/minute. Similarly, in Study One, where commute MVPA steps contributed 34% towards the total MVPA steps per day. This finding is similar to Rafferty et al. (2016) who reported that commuting contributed 32% towards total daily steps. Similarly, the Commuting and Health study in Cambridge found that 30% of the recommended level of

MVPA (150 minutes of MVPA per week) was accrued in commute (Yang et al., 2012). Although there are small differences between these studies in the percentage contribution of commute to total daily physical activity, these results suggest that commuting presents a potential opportunity for increasing levels of MVPA in the population.

In Study One, the walking (37.6 minutes) and mixed-mode (26.9 minutes) commuters accumulated far more total MVPA than the car commuters (5.8 minutes). In Study Three, there were marked differences in time spent in MVPA by the mode of commute: during commuting at 100 steps/minute MVPA threshold, cycling commuters and mixed-mode commuters spent a considerably higher percentage of time in MVPA than the remaining modes of commute. Cycling commuters spent more time in total in MVPA (97.0 minutes), followed by mixed-mode commuters (66.7 minutes), then the walking commuters (59.1 minutes), and the car commuters (28.5 minutes); this is consistent with other studies that have found greater activity levels in people that commute by walking or public transport than car commuters (Audrey et al., 2014; Ferrer et al., 2018; Medina et al., 2020).

A UK cross-sectional study that recruited 103 participants and objectively measured their commute using GPS and waist-worn ActiGraph GT3X+ accelerometer found that time spent in MVPA was 60% higher in participants who walked to work compared to those who drove to work (78.1 minutes vs. 49.8 minutes per day) (Audrey et al., 2014). Medina et al. (2020) also reported cycling commuters accumulating more levels of vigorous-intensity physical activity; however, physical activity intensity was quantified using the subjective GPAQ. Ferrer et al. (2018) using the ActiGraph GT3X and GPS receivers, found that both walkers (71.3 minutes) and public transport users (59.5 minutes) accumulated more MVPA throughout the day in comparison to car users (46.3 minutes). They also reported that walkers (34.3 minutes) and public transport users (25.7 minutes) were also on average more active during the commute than car users (7.3 minutes). These results accentuate the important role that the mode of commuting plays in increasing the amount of time spent in MVPA. It is important to note that the mixed-mode commuters accumulated a high amount of MVPA compared to car commuters and one of the gaps in commuting studies is that mixed-mode journeys are not often considered. These results highlight the importance of mixed-mode journeys and may be a practical method for long distance commuters to increase their physical activity by incorporating walking or cycling into their commute journeys.

7.2.3 Classification of modes of commute

In Study One, the activity diary (Section 3.2.4) allowed participants to report their commute modes without specifying how long they had spent in each mode. This was problematic, especially among mixed-mode commuters. The diary was modified in Study Three (Section 5.3.2) and allowed for participants to report the actual time spent in each mode. There was a possibility that some car commuters had reported being mixed-mode commuters because there were a few instances where participants had reported travelling by car and by walking, but they had only reported walking for less than two minutes. For such occurrences, the activPAL™ data had to be checked to ensure that actual walking had taken place. The use of a modified diary in Study Three allowed for more robust classification of the modes of commute among the participants.

Cycling was not included in Study One as a result of the activPAL™ software classifying time spent cycling as a stepping event. However, by the time Study Three was being conducted, the proprietary software for the activPAL™ had been upgraded to differentiate between the time spent cycling from stepping. Therefore, cyclists were included in Study Three. Most studies do not report how they classify cycling, as it can be misclassified using objective measurement tools (Steeves et al., 2015). The activPAL™ was used in assessing physical behaviour and with the recently updated proprietary software, it was possible to see periods of cycling; therefore, the time spent cycling was included as time spent in MVPA. Cycling is considered a moderate-to high intensity activity (Ainsworth et al., 2011; DHSC, 2019) and thus it was considered that all the time spent cycling should be included as the time spent in MVPA. In previous studies, most studies have reported time spent cycling per week using a self-reported questionnaire. Other studies have used GPS technology in detecting the time of departure and the mode of commute being used (Audrey et al., 2014; Costa et al., 2015; Ferrer et al., 2018).

The classification of modes of commute has been primarily categorised into walking, cycling, private transport or car, and the use of public transport (Flint et al., 2014). In this thesis, the use of public transport was not included as a classification, rather it was categorised as a mixed-mode. This is because the use of public transport such as bus, tram, or train will involve some degree of walking or cycling; therefore, classifying public transport as a mixed-mode presented as a more practical terminology for these groups of commuters (Lorenzo et al., 2020). In addition, some individuals that drive to work may also use other modes of commuting such as the train. For example, in Study One, two participants drove to the train station, took the train, and walked to their places of work; it would be a false classification to classify these individuals either as car commuters or public transport commuters; therefore, classifying such individuals as mixed-mode commuters is most applicable as it accurately describes the mode of commute undertaken by these individuals. Flint and Cummins (2016) used the dataset from the UK Biobank to categorise various modes of commuting to fully encapsulate different variations of modes of commuting. The modes of commute were classified into seven different categories: car only, car and public transport, public transport only, car and other mixed-modes[30], public transport and active transport (walking and/or cycling), walking only, cycling only or walking and cycling; to capture various commute mode combinations (Flint & Cummins, 2016). However, due to the sample size, these classifications were not possible in the studies included in this thesis.

Within Study Three, alternative modes of commute on different days were observed: while this may be the case for the general population, most of the participants maintained the same mode of commute throughout the entire data collection period. Also, for those individuals that used an alternative mode of commute on a different day, they stated that they had to attend an off-site meeting, which means that it was not a usual journey to work for such individuals. Commuting is a habitual activity that is resistant to change because it is an everyday activity that is performed regularly and repetitively, at specific times (Jones & Ogilvie, 2012), which most people undertake instinctively. While there are factors that can inform the decision of the mode of commute to use, it is a behaviour that is not easily changed and a pattern that is difficult to break, except perhaps when a pandemic occurs (Harrington & Hadjiconstantinou, 2020)

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[30] A heterogenous category comprising combinations of car, public transport, walking and cycling

7.2.4 Compliance with physical activity guidelines

Compliance with physical activity guidelines is a tool used to measure the physical activity level of the population and serve as a guide for comparison between physical activity studies (DHSC, 2019).

In Study One, in terms of compliance to the 2019 physical activity guidelines, a total of 17 out of 23 participants achieved the minimum recommendation and five in their commute alone: this finding is similar to Rafferty et al. (2016), with 18 participants meeting with the physical activity guidelines (at least 30 minutes of MVPA per day) and five participants achieving this minimum requirement in their commute alone. The compliance level for Study One was 73% while that of Rafferty's was 69%; both studies quantified MVPA using the activPAL™; however, Rafferty et al. (2016) defined MVPA as a cadence of 109 steps/minute while for Study One, MVPA was defined as 100 steps/minute. For Study One, in consideration of a minimum bout length of 10 minutes (that is, 2011 guidelines), only seven participants were compliant with the physical activity guidelines. However, Rafferty et al. (2016) did not report on the minimum bout length in terms of compliance with physical activity guidelines and compliance to the 2011 physical activity guidelines is largely dependent on how continuous walking bout is defined (Granat, 2012). A reduction in the number of participants complying with guidelines indicates that the stricter the definition of continuous walking, the more unlikely people are to meet these guidelines (Chastin et al., 2009).

This finding in Study One is consistent with Troiano et al. (2008), who found that lower compliance with physical activity guidelines is observed when bout length is considered. In the 2003-2004 NHANES study, Troiano et al. (2008) used ActiGraph accelerometer cut-point thresholds and compared total accumulated MVPA, irrespective of bout length, to MVPA calculated using modified 10 minute bouts (where interruptions of two minutes below the threshold was allowed). The authors found that when bout length was taken into consideration, compliance with physical activity recommendations in adults was 3.5%. In Study One, the compliance level was 3%; the small difference observed in both studies could have been as a result of the use of different accelerometers with different outputs (Section 2.3.5). Another explanation for the differences in compliance could have been the allowance of interruptions of two minutes below the intensity threshold; therefore, increasing the duration of time spent in MVPA. These observations of reduced compliance to 2011 physical activity guidelines suggest that the recommendation of walking continuously for 10 minutes or more might not be achievable in free-living environments because different factors can interrupt continuous walking, for example: stopping at traffic lights or waiting to cross the road. The updated physical activity guidelines for the UK, US, and WHO, focus more on encouraging any amount of physical activity as every form of movement is reported to be beneficial to health (DHSC, 2019, US Department of Health and Human Services, 2018, WHO, 2020). In order to accurately measure compliance with the 2011 guidelines, it is important to consider the interruptions between walking events and how to account for them using objective measurement techniques.

To address the issue of interruption during walking, the novel method of grouping (combining walking events with short interruptions between them) was employed. The impact of the grouping method was evident in the 2011 guidelines because of the requirement of the minimum bout length of 10 minutes to meet up with the guidelines. In Study Two, before grouping, seven participants met the 2011 guidelines and 17 participants met the 2019 physical activity guidelines. After grouping using the 100 steps/minute cadence threshold, this increased to 14 (100% increase) and 22 (18% increase) respectively. Similarly, in Study Three, over half of the population (n=29) were compliant with the 2019 UK guidelines; however, the numbers reduced to 16 participants when the 2011 UK guidelines were considered. This reduction was due to the minimum bout duration of 10 minutes being applied. Notably, when grouping was applied, the number of participants compliant with the 2019 UK guidelines increased to 31 participants (3% increase) and an additional 10 participants (63% increase) became compliant with the 2011 UK guidelines. The increase in the number of compliant participants with the 2011 UK guidelines was due to the grouping process that involved combining short interruptions between walking bouts.

Barry et al. (2015) also observed a 32% increase from 6% to 40% among the participants in compliance to the 2011 physical activity guidelines when the minimum length of interruption was increased to 30 seconds. The increase observed in the compliance with physical activity guidelines was a result of the allowance of 30 seconds interruption, which simply increases the duration of time spent in MVPA. In Study Three, a 25% increase in compliance to the 2011 physical activity guidelines was observed after grouping at 100 steps/minute. Unlike Barry et al. (2015) that assumed an arbitrary minimum length of interruption, the methods used in Study Three did not assume the length of interruption; rather, it focused on grouping walking events and short interruptions to calculate an average cadence threshold based on MVPA. It can be assumed that removing the use of the minimum bout length from the 2011 guidelines was partly due to the difficulty in defining continuous walking and that continuous walking bouts of 10 minutes may not be practical in free-living settings. For both guidelines, combining walking events can have a significant impact on compliance levels.

The presented grouping method could enable the inclusion of a minimum bout length, given it reflected an associated health benefit. Future studies may consider the use of this method in estimating continuous walking and level of compliance with physical activity guidelines.

7.2.5 Effects of grouping walking events

In Study Two, the overall headline finding was similar to Barry et al. (2015), which showed an increase in the total volume of activity accumulated by participants when short interruptions were considered. Barry et al. (2015) proposed a maximum length of interruption and only reclassified standing events as walking events only if they fell below the time threshold of 30 seconds. The method could incorporate interruptions as long as the corresponding walking events were less than or equal to the maximum length of the interruption. On the other hand, in Study Two, the short interruptions (standing events included) varied depending on the cadence threshold used and notably, the interruptions were longer than the interruptions included in Barry's method. The average duration of short interruptions included at 109 steps/minute was from 30 seconds and this may translate that the average duration of interruptions added in the Barry's approach may have been included at steps taken at higher cadence. However, Barry and colleagues' method does not account for the change in intensity of the total walking (cadence) and therefore, there is no way to know if the intensity of the steps included were at moderate intensity. Using a cadence as a proxy for physical activity intensity when combining walking events with interruptions reflects physiological processes associated with continuous physical activity (Slaght et al., 2017), and is likely to be more associated with the health benefits of this activity.

In Study Two, the grouping process changed the composition of the events within each dataset, with the largest percentage change being seen in events longer than 60 minutes in duration. Continuous walking longer than 60 minutes increased by 200% for the 100 steps/minute and 500% at the 76 steps/minute threshold. However, these changes can also be seen in events lasting longer than 10 minutes. These longer walking events were predominantly composed of a combination of short and medium-length walking events, with a small proportion of this time coming from the inclusion of standing events. This demonstrates that there are few opportunities for walking continuously for long periods without interruption in the free-living environment and highlights the need for a robust definition of a continuous walking bout.

The grouping process may also be useful for assessing populations whose walking is impaired and where it would not be appropriate to use the same threshold as a healthy non-impaired population. For example, it has been shown that people with intermittent claudication walk with a slower cadence than matched healthy controls (Granat et al., 2015), and perhaps the cadence threshold should be altered to suit this population. The method of grouping provides a simple way to define the cadence threshold that would be suitable for different populations once this threshold has been established. Future work should aim to derive suitable cadence thresholds for different populations.

7.2.6 Cadence and walking bouts distribution of commute and non-commute steps

In Study One, it was reported that commuting walking occurred at higher cadence bands with longer bout lengths when compared to walking during non-commuting. Changing the definitions of the minimum level of cadence did not significantly affect the total MVPA accumulated during commuting. This could be due to people walking at higher cadence during commuting and therefore, changing the minimum value of cadence for MVPA definitions did not have any effect on total MVPA accumulated.

In Study Three, there was a clear, distinctive distribution of steps accumulated during commuting periods compared to steps accumulated during non-commuting periods. Similar to Study One, where the accumulation of commute steps differed from non-commute steps, with a greater proportion of commute steps being accumulated at cadence thresholds of 110 to 130 steps/minute. This observation could be explained by the fact that steps taken during commuting involves a greater intensity, which could be because of the importance of arriving at work on time or the urgency to be in time for a bus or train (Figure 7.1): the highlighted part in figure 7.1 shows more stepping taken during commute time between 9am to 9:40 am. Tudor-Locke et al. (2011) suggested that steps accumulated at higher cadence values are more likely to represent more purposeful and greater speeds of stepping as seen in the case of commute steps. Furthermore, the results showed that more steps were accumulated continuously between bouts of 30 seconds to two minutes, but only during commuting did people walk continuously for five minutes or more. Although this could have been a result of highly active commuters, the observations made from the results in Study Three suggest that commuting involves walking at a high cadence and much longer bouts compared to during non-commuting periods. Thus, these results suggest that steps taken during commuting and non-commuting periods differ in both intensity and bout length.

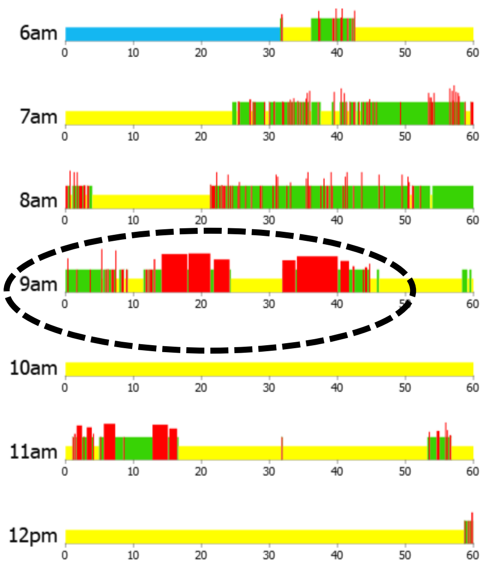

Figure 7.1: Excerpt from the activPAL™ software, highlighting the greater number of steps taken during the commute to work between 9 am to 9.40 am (blue bars represent lying, yellow bars represent sitting, green bars represent standing, and red bars represent stepping)

No study has previously examined the cadence distribution of steps taken during commuting and non-commuting periods: Tudor-Locke et al. (2011) investigated cadence patterns using 2005 to 2006 NHANES data using step accumulation method but did not explore the difference in the patterns of commute and non-commute steps. Previous studies have explored the domains of physical activity: occupational, leisure, and transportation (Byambasukh et al., 2020) but this is the first study to explore this cadence distribution in commuting and non-commuting periods. The finding in this thesis show that the steps accumulated in other domains outside of commuting are not as purposeful as the steps accumulated during commuting. Therefore, stepping whilst commuting is of great importance in the contribution to total MVPA.

The accumulation of steps was explored across different walking bout lengths (short, <5 minutes; medium, 5-9.99 minutes; and long, ≥10 minutes). The results from this study reaffirm the rationale behind Study Two: where it was established that walking for 10minutes or more was not readily achievable in a free-living environment. Chastin et al. (2009) reported that the amount of physical activity that is deemed health-enhancing (moderate-intensity) is taken in short walking bout lengths. This is seen in Study Three as walking at short and medium bouts was mostly common compared to walking at long bouts. Further breakdown of steps accumulated showed that although non-commute steps had a greater proportion of short walking bout steps compared to commute steps, commute steps also had more steps taken at short walking bouts than at long walking bouts. There was a far greater proportion of short walking bouts non-commute steps than short walking bout commute steps (73% vs. 45%). There were significant differences between commute and non-commute steps from 0 to 90 seconds and ≥5 minutes. Non-commute steps were predominantly accumulated in bouts of less than two minutes, while commute steps were predominantly accumulated at bouts greater than five minutes. Study One also reported a high proportion of commute steps accumulated at medium and long walking bouts (greater than five minutes) compared to non-commute steps that were mainly taken at short walking bouts. However, during non-commuting periods, the pattern of step accumulation among the commuters was very similar with no distinctive differences (Figure 6.14). These findings could have been due to mixed-mode and walking commuters accumulating most of their commute steps at medium and long walking bouts; thereby, adding to the evidence of the importance of stepping during commuting.

7.2.7 Key considerations of the methods used in this thesis

7.2.7.1 Self-reported vs. Objective measures

Among previous commuting studies, there have been differences in the definition of commuting MVPA: a few studies have classified commuting based on self-reported responses using physical activity questionnaires or travel activity diaries (Chris et al., 2013; Sahlqvist et al., 2012), which has led to over-estimation of time spent in physical activities (Scheers et al., 2013). In a study where the use of heart rate monitors and GPS were combined to define time spent using active and non-active modes of commute, it was found that self-reported measures showed poor agreement with objective measures, especially in journeys to work involving more than one mode (Panter et al., 2014). Furthermore, a systematic review that included eight studies comparing self-report and GPS duration of travel journey times reported that the self-reported measures overestimated journey times by 2.2 to 13.5 minutes per journey (Kelly et al., 2013). In population-level surveillance, the use of self-reported measures is often more feasible than objective measures because of the large sample size (Panter et al., 2014). However, objective measures such as accelerometers have been employed in many large-scale population studies (NHANES 2003-2004, UK Biobank, 1970 British Birth Cohort Study UK, The Maastricht study, The Netherlands, The Nord-Trondelag Health Study, HUNT4, Norway) and they could be considered to have higher feasibility but might be more costly than self-reported measures (Dall et al., 2018; Doherty et al., 2017; Stamatakis et al., 2020).

In this thesis, the use of an activity diary for reporting commute times was via self-report, which could have resulted in response bias as some participants may enter an approximate time rather than the actual times of commute; however, the activity diary was used in combination with a validated objective measuring instrument – the activPAL™ accelerometer-based device. Using the events file downloaded from the activPAL™, the commute times reported in the activity diary were manually checked against each activPAL™ data to eliminate some of this bias. For example, if a participant reported in the activity diary that the departure time from home was 8 am but from the activPAL™ data, there was no activity until 8.05 am, then the departure time was adjusted to 8.05 am. This use of a self-reported tool in combination with an objective measure may reduce bias in estimating physical behaviour and estimate the time spent in different types of activities (Hamer et al., 2014). This process may be automated and openly-accessibly to researchers in physical activity measurement studies, with the aim of providing a template for activPAL™ data cleaning procedure: as seen in the case of Prospective Physical Activity, Sitting, and Sleep consortium, which aims to provide a platform for research collaboration by drawing together existing and future epidemiological studies that collect data using thigh-worn accelerometers (Stamatakis et al., 2019). Also, the use of GPS device allows the objective identification of locations and journeys and therefore the computation of journey times, but provide no measure of activity or intensity other than the speed at which the wearer has moved at a given time (Panter et al., 2014)

7.2.7.2 Cadence vs. counts

Some other studies have quantified commute MVPA using objective measures; however, different objective measurement tools have different outputs. For example, the ActiGraph converts acceleration signals into activity counts per minute while the activPAL™ provides outputs based on postural classifications. The quantification of MVPA in commuting studies based on cut-points derived from the ActiGraph accelerometer vary from study to study. While these cut-points are widely accepted, there are multiple different cut-off thresholds to define intensity categories (moderate-intensity cut-points range from 191 to 2743 cpm, and vigorous-intensity cut-points range from 4945 to 7526 cpm), showing a lack of agreement and comparison between studies (Bassett et al., 2012; Crouter et al., 2006). The use of cadence in quantifying MVPA has been described in the literature as a more practical way of measuring MVPA (Chastin et al., 2009). Compared to a threshold on some value of the acceleration signals, cadence emphasises the rate of stepping, which can be used to estimate intensity (Slaght et al., 2017). Previous commuting studies have employed the use of waist-worn ActiGraph, which provides information on activity intensity using cut-point thresholds (Ridges et al., 2012; Mathews et al., 2008); however, the ActiGraph tend to overestimate light- and moderate-intensity activities and underestimate vigorous activities Crouter et al., 2006; Bassett, 2012; Berntsen et al., 2010; Granat, 2012): this is seen in the case of the time spent in MVPA reported being higher in studies that measured using the ActiGraph than those that measured using activPAL™ (Section 7.2.1) The choice of an accelerometer-based device used in this thesis allowed for in-depth analysis of commute MVPA based on true cadence.

7.2.7.3 Using true cadence

As previously discussed (Section 2.4.1), cadence differs from step accumulation and produce different results (Dall et al., 2013). The use of the activPAL™ accelerometer-based device allowed for a complete understanding of stepping intensity and detailed analysis into the cadence distribution and walking bout analysis (Granat et al., 2015). The results presented in this thesis include a detailed breakdown of cadence and walking bouts distribution using the information on steps taken within cadence bands, rather than as the number of steps taken with arbitrary minute epochs, to fully understand the intensity of the population. The event-based analysis made it possible to re-define continuous walking bouts by combining short interruptions between walking bouts to produce novel physical activity outcomes. From these novel outcomes, the results showed that combining short interruptions between walking bouts increases the level of compliance with physical activity guidelines. In addition, using cadence as the objective measurement of physical activity intensity in free-living conditions may be useful in assessing individuals with clinical conditions (such as intermittent claudication), and developing suitable interventions for such conditions (Granat et al., 2015). For example, it has been shown that people with intermittent claudication walk with a slower cadence than matched healthy controls (Granat et al., 2015).

The use of MVPA cadence thresholds in the studies included in this thesis were useful for comparability to obtain the varying effects of these different thresholds on the total time spent in physical activity and its associated benefits to metabolic markers. Although the focus was not to derive cadence thresholds for MVPA or determine which thresholds was obtainable by the population under investigation, it was observed that the lower the threshold, the more the time accumulated in MVPA. The most used cadence threshold definition for MVPA is 100 steps/minute and it has been based on different calibration studies; however, future studies should consider the population being investigated, age-specificity, and other parameters like body mass or leg lengths while applying specific cadence thresholds for MVPA. Also, the impact of these cadence thresholds on designing walking interventions that may improve population health and associated health-outcomes.

7.2.8 Associations between Commute time in MVPA and metabolic markers

Commuting is measured in terms of duration and modes (Cass & Faulconbridge, 2016); therefore, it is important to investigate the effect of time spent commuting at MVPA and how it is associated with health-related outcomes. Another reason why time in MVPA during commuting was used as the exposure variable was to include the time spent cycling since it is an activity categorised as moderate-to-vigorous intensity and contributes to the total time spent in MVPA (DHSC, 2019). Previous studies have fully explored the effect of different modes of commute on various health outcomes; however, MVPA time during commuting has not been extensively investigated in this context. Steell et al. (2017) reported that increasing time spent in active commuting from 30 minutes to ≥60 minutes per day was associated with lower odds of obesity (0.90; 95% CI: 0.84–0.96, p=0.001), type 2 diabetes (odds ratio, OR: 0.81; 95% CI: 0.75-0.88, p<0.001), and metabolic syndrome (OR: 0.86; 95% CI: 0.80-0.92, p<0.001), compared to those not actively commuting. Although this study had a large sample size from a representative dataset (Chilean National Household Survey), commuting was self-reported using the GPAQ and the authors did not consider the intensity of the reported activities. This study is the only study that has considered the dose-response relationship between time spent in commuting and metabolic risk factors.

The associations between commute time in MVPA and metabolic markers (waist circumference, triglycerides, HDL-cholesterol, systolic and diastolic blood pressure) before and after grouping were not significant after adjusting for confounding factors. However, at 109 steps/minute, commute time in MVPA before and after grouping was associated with BMI, and this association remained after adjusting for confounding factors. This finding shows that commute MVPA could be of great importance in increasing physical activity and reducing obesity levels, unlike the total time in MVPA and non-commute time in MVPA. Also, there were no significant associations between commute time in MVPA and the metabolic markers except for BMI: this may have been due to the small sample size or as a result of recruiting healthy participants. Healthy participants are prone to engage with active modes of commuting than their non-healthy counterparts (Vaara et al., 2020; Panter et al., 2018), therefore, providing a protective effect against the risk of metabolic syndrome. In Study Three, only three out of 40 participants were at risk of developing metabolic syndrome: the remaining 37 participants had an overall healthy metabolic profile.

Total time in MVPA and non-commute time in MVPA at all cadence thresholds were not significantly associated with any of the metabolic markers. Similar observations have been noted with the domains of sedentary time: it has been reported that the associations between sedentary time and cardiometabolic markers are domain-specific (Dempsey et al., 2018). Occupational sedentary time is not associated with cardiometabolic markers; however, total sedentary time and leisure sedentary time are associated with an increased risk of cardiometabolic risk factors (Pinto Pereira & Power, 2012; Saidj et al., 2013). The independent association that exists between total and leisure sedentary time but does not exist in occupational sedentary time may be a possible explanation for the association between commute time in MVPA and metabolic markers, and no association with total time in MVPA and non-commute time in MVPA.

In terms of the association between modes of commute and metabolic markers, there have been studies with significant associations between active commuting and metabolic markers (Medina et al., 2020). However, the aim of this thesis was not focused on investigating the association between the modes of commute and the metabolic markers, and due to sample size, the analyses could not be grouped by the modes of commute to test associations with metabolic markers. Further analyses of grouping modes of commute into active and non-active commuting showed that compared to non-active commuting, active commuting was negatively associated with BMI, waist circumference, fasting blood glucose, and metabolic syndrome.

Previous studies have reported significant associations with metabolic risk factors; for example, a study conducted using UK Biobank participants, reported that compared to cars travellers, BMI levels were lower for those who cycle (−1.71 kg/m^2) or walk (−0.98 kg/m^2) as part of their travel (Flint & Cummins, 2016). Another found that active commuting (walking or cycling) was negatively associated with triglycerides (0.88, 95% CI 0.80 to 0.98), diastolic blood pressure (-1.54, 95% CI -3.07 to -0.01), and fasting insulin (0.84, 95% CI 0.77 to 0.92); and positively associated with HDL (1.05, 95% CI 1.00 to 1.10) in men only, but these associations were attenuated with BMI adjustment and all outcomes were insignificant (Gordon-Larsen et al, 2009). Kuwahara et al. (2019) found that maintaining inactive commuting within five years was associated with higher adiposity levels, compared to switching to an active form of commuting or public transport use (0.20 kg/m^2 (0.18 to 0.22)). Similar findings were reported by Flint et al. (2016), who found that when people change from active to non-active modes of commute, it reduces the level of BMI and vice versa.

Previous studies with larger sample sizes have found significant associations with mixed-mode commuting with cycling components with a reduced risk of cardiovascular diseases (Celis-Morales et al., 2018). Similar findings were also reported by Vaara et al. (2020) in young men aged 19 to 33 years between cycling commuters and reduced cardiometabolic risk. Medina et al. (2020) found that cycling, walking, and public transport users with a cycling or walking component had a significantly lower risk of adiposity levels compared to car commuters. Although the regression analyses in Study Three were not grouped based on modes of commute, there was a negative relationship between commute time in MVPA at 109 steps/minute and anthropometric measures (BMI and waist circumference), after adjusting for confounding factors. This relationship may have been as a result of the time spent in MVPA by cycling and mixed-mode commuters at a 109 steps/minute threshold (56.2 and 20.7 minutes respectively). From the analysis in Study Three (Table 6.4), cycling and mixed-mode commuters had the highest duration in MVPA and with larger sample size, significant associations may have been obtained between these modes of commute and metabolic markers.

7.3 Strengths and Limitations

7.3.1 Strengths

An important strength of the studies included in this thesis was the use of a valid and reliable accelerometer-based device with the capacity to quantify walking behaviour in line with current physical activity recommendations (Ryan et al., 2006). The activPAL™ allowed for the quantification of the intensity of walking (MVPA) using event-based analysis of stepping and was useful in redefining continuous bouts of walking. In Study One, a novel methodological approach was conducted in quantifying MVPA based on cadence, and other measures such as the mode of commute and the walking bout lengths. There has been only one previous study that has quantified MVPA during commuting using this device (Rafferty et al., 2016), and the results obtained in this study are comparable. Rafferty's study did not include analysis of walking bout length and information on the commute mode. In Study Three, metabolic markers were objectively-measured and were not based on self-report, which can be subject to response bias (Bowling, 2014).

7.3.2 Limitations

The main limitation for all studies included in this thesis was the relatively small sample population in a similar cohort of people, which makes it hard to generalise the findings. As a result of the cross-sectional design of this study, causality could not be inferred between the variables of interest; therefore, findings should be interpreted with caution. The findings in this thesis can be used to inform studies with robust designs in establishing causality between commute time in MVPA and health outcomes (Bailey, 2005).

Previous studies that have conducted research based on a convenience sample had a sample size, ranging from 26 (Rafferty et al., 2016), 103 (Audrey et al., 2014), 114 (Chastin et al., 2009) to 117 (Dall et al., 2013) participants. For Study Three, the upper limit for recruitment was 80 participants; however, because of recruitment taking place during the summer holidays into the start of a new session at the university and ending up in the middle of the Covid-19 pandemic; the total number of participants recruited and analysed was 40. The sample size of this study is within the range of previous studies conducted based on the convenience sampling method. In addition, participants were from a convenience sample, which can lead to selection bias. The commute mode was self-reported using the diary; however, commuting being a regular and repeated activity makes it less likely to be prone to recall bias. The reporting of commute times was checked manually against accelerometer data to make sure the time of activity reported in the diary correlates with the accelerometer data.

For Study One, a further limitation was that the study did not account for any stops on the way to or from work, that is, if the trip was direct or indirect. In addition, in the mixed commute mode category, time spent commuting in each mode was not known. Therefore, some car commuters might have reported using mixed-mode but were predominantly car commuters, which could have resulted in misclassification of commuters into the correct mode of commute. The diary used in Study One was modified for Study Three, and the modified diary allowed for mixed-mode commuters to report the actual time spent in each mode. These self-reported responses were verified using the activPAL™ data by manually and visually checking that the commute times and modes reported were in synchronisation with the activPAL™ data.

For Study Two, one limitation was the inability to determine the context of walking or standing events. The data were collected in a university population that predominantly commuted to work by car and some long-distance travelling participants were part of the cohort. The composition of the grouped events comprised of walking events longer than 10 minutes after grouping; however, the analysis did not stratify the walking events into the domains they occurred in because this was not the purpose of the study. In addition, all walking events, regardless of the length of the walking event, were described by a single average cadence value. It is recognised that the cadence of walking would probably vary within each walking event; however, the longer the walking event, the lesser the variability (Granat et al., 2015). Sellers et al. (2012) demonstrated that there was variability in cadence within a 30-min period of walking in an urban environment, but it is unclear how this relates to individual walking events. This intra-event cadence variability should be investigated in further studies.

For Study Three, participants were not able to report if it was a direct trip or not: the activity diary only allowed for information on the different modes used during commute and the time spent in each mode; however, there is no way to identify the purpose of the trip. An alternative method that has been used in research is the use of GPS in combination with accelerometers and activity diary data (Iveson et al., 2020). Using the GPS receivers gives real-time information on the context of an activity. However, one major limitation with previous commuting studies is the lack of detailed information on the data processing methods of the GPS data and this hinders replication in other studies (Loveday et al; 2016; Panter et al., 2014). In addition, the data cleaning process requires technical expertise and makes the process burdensome (Panter et al., 2014). The GPS devices are power-hungry and require regular charging, making it less convenient for data monitoring for more than a few days (Krenn et al., 2011). Previous commuting studies that have combined the use of objective measures such as accelerometer-based devices or heart rate monitors and GPS receivers have reported on the ability to provide context to the activity of the participant; however, it is also dependent on the participant wearing the GPS receiver (Loveday et al; 2016; Panter et al., 2014). For future research to consider the use of GPS receivers alongside objective measures of physical activity, it is important that there is a practical guideline for the participants in ensuring data protection and for the researchers in data cleaning the data collected.

It was observed that the activPAL™ recorded some steps for two of the car commuters; however, all of the steps were fewer than 50 steps in each case. While this should not be the case as they are classified as being sedentary (that is, sitting during the drive). This step accumulation could have been as a result of the participant having the device on the right leg or even driving a manual car that involves moving your leg quite frequently during gear change compared to automatic cars that do not require such frequent movements. This could be as a result of the placement of the device on the right thigh that is used in pressing down the clutch causing involuntary movements on the right leg. This observation could also be an indication that although the activity is done while being sat and is not of moderate-intensity, it can be classified as light intensity and may apply to the population with reduced mobility as a physical activity intervention.

7.4 Reflective Commentary – The impact of the Covid-19 Pandemic

7.4.1 Covid-19 Pandemic and Commuting

After the initial outbreak in Wuhan, China (WHO, 2020), the Covid-19 virus began to spread rapidly across the nations of the world, including the UK. Due to the increasing spread of the virus in the UK[31], a major lockdown that involved school closure, commercial, hospitality, leisure, and all non-essential services to shut down, while introduces measuring such as the two-metre social distancing, wearing of face masks in public spaces, and continuous handwashing techniques to help reduce the spread of the virus (WHO, 2020). As a result of this major disruption in day-to-day activities, physical activity was greatly impacted (Woods et al., 2020). Physical activity has been evidenced to help combat various non-communicable diseases and the restrictions during the lockdown prevented several people from being physically active (Stockwell et al., 2020; Woods et al., 2020). Various countries including Australia, the USA, and the UK, and organisations such as the WHO published guidelines to

[31] https://www.gov.uk/government/speeches/pm-statement-on-coronavirus-16-march-2020

help people stay active while at home and made these documents publicly available (Dwyer et al., 2020). Social media platforms were employed in promoting physical activity during the pandemic; however, these alternatives were not without limitations that included limited open space and lack of equipment (Dwyer et al., 2020).

Due to the lockdown and the work from home mandate from the government in the UK and most countries around the world, commuting became almost non-existent for all non-essential workers (Thomas et al., 2021). Essential workers were the only ones allowed to travel to and from work. Most workers had to work from home and only travelled to the shops for essential supplies. Commuting has been evidenced in this thesis serves as a means of being physically active by incorporating a form of activity in one's daily routine (NICE, 2011). Commuting is a targeted intervention tool for most workers as it is a repeated and regular activity: this was lost due to the pandemic for most workers.

Overall, levels of physical activity have declined since the start of the Covid-19 pandemic, making it important as we resume to the 'new normal' activities: public health organisations should consider introducing new interventions to aid active commuting among the working population (Woods et al., 2020). Most workplaces have embraced the hybrid working system incorporating both working at the office and working from home. Thereby, allowing workers to decide on what works best for them and most importantly, be encouraged to commute actively on the days they travel to work.

Seeing the importance and benefits derived from commuting and that which has been lost to the pandemic, rebuilding what has been lost with a view of creating opportunities for more people to travel by cycling or making public transportation more attractive for people travelling long distances. According to an online survey conducted in the UK, 3.6% of car commuters intend to change to walking and 6.5% to change to cycling mode when restrictions are lifted (Harrington & Hadjiconstantinou, 2020). Although a major percentage of car users did not plan to change their modes of commute after restrictions are lifted, they recognised the benefits associated with walking and cycling (Harrington & Hadjiconstantinou, 2020).

Therefore, initiatives like giving out bicycles to essential workers during the pandemic[32] can be extended to multiple organisations to encourage active commuting and potentially influence the health of the working population.

As the world heals from the deleterious physical and mental health effects of the Covid pandemic, the need to look after one's health is non-negotiable. The findings of this thesis highlight the importance of commuting and contribution to compliance with physical activity guidelines. Commuting can provide an avenue to incorporate and increase physical activity and should be part of a global policy response to population-level prevention of mental health issues and cardiovascular diseases.

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[32] https://www.cyclinguk.org/press-release/cycling-uk-keep-covid-19-key-workers-pedalling-free-services

Chapter 8: Conclusion

Chapter	Summary of each chapter
1- Introduction	A background to physical activity, the role of commuting to contributing to physical activity, an overview of methods used in measuring commuting physical activity, and its association with health outcomes.
2- Literature review	A critical review and discussion of the literature surrounding measuring commuting MVPA, and its association to various health outcomes, especially metabolic risk factors
3- Methodology I – Methods for Study One and Two	Describes the methods for Study One:(*Commuting and MVPA)*; and Study Two: (*Gap analysis*) **Aim of Commuting and MVPA study**: To objectively determine the contribution of MVPA during commuting to total MVPA, using cadence to define MVPA, and explore how minimum walking bout length affects adherence to physical activity guidelines. **Aim of Gap analysis study**: To use an event-based approach to define continuous walking events, by combining walking events with short interruptions based on an average cadence threshold.
4- Results I – Results for Study One and Two	Presents the results for objectives one to six: 1. To objectively quantify MVPA during commuting using the definition of cadence. 2. To determine the difference between modes of commute and time spent in MVPA during commuting. 3. To determine the level of compliance to physical activity guidelines by examining the volume of MVPA and length of walking bouts accumulated. 4. To combine short interruptions between walking events to form a new continuous walking event called "grouped event" 5. To examine how grouping walking events changes total time walking and total time in MVPA 6. To ascertain whether combining walking events with short interruptions between them impacts compliance to physical activity guidelines.
5- Methodology II – Methods for Study Three	Describes the methods used in Study Three to address objectives seven to eleven **Aim**: To investigate the association between MVPA during commuting physical activity and metabolic markers.
6- Results II – Results for Study Three	Presents the results for objectives seven to eleven: 7. To determine the difference between the different modes of commute and time spent in MVPA during commuting and non-commuting periods. 8. To objectively quantify MVPA, using different cadence thresholds for MVPA, for both commute and non-commute stepping. 9. To explore the patterns of commute and non-commute stepping at different lengths of walking bouts, before and after grouping walking events. 10. To determine the compliance to the 2011 and 2019 UK physical activity guidelines for all participants before and after grouping walking events. 11. To investigate associations between commute time in MVPA (before and after grouping walking events) and metabolic markers.
7- Discussion	This chapter summarises the findings from Study One to Three, highlights their strengths and limitations within this thesis; Reflection on the impact of COVID-19 on commuting physical activity.
8- Conclusion	**This chapter gives a concluding summary of the thesis and implications for policy and future research.**

8.0 Concluding summary of this thesis

This thesis aimed to investigate the contribution of commuting during MVPA towards total daily MVPA and its association with metabolic markers. Using seven-day activity monitoring, the activPAL™ accelerometer-based device was used to quantify MVPA in terms of cadence, and to determine the contribution of MVPA during commuting towards total daily MVPA. Commuting provided a significant contribution to the total daily MVPA, both before and after grouping (that is, combining walking events and short interruptions based on an average cadence): the contribution of ungrouped commute time towards total daily MVPA was 17% at 76 steps/minute, 21% at 100 steps/minute, and 25% at 109 steps/minute; while the contribution of grouped commute time towards total daily MVPA was 20% at 76 steps/minute, 25% at 100 steps/minute, and 26% at 109 steps/minute. The classification of commute mode type was not limited to walking, cycling, public transport, and private transport alone. The classification was reflective of free-living commute journeys that may involve using more than one mode (that is, mixed-mode journeys). Mode of commute plays an important role in terms of contributing towards total daily MVPA: mixed-mode, cycling, and walking commuters obtaining a significantly larger amount of MVPA during commuting and towards total daily MVPA, compared to car commuters.

Compliance with 2011 physical activity guidelines was low, with its definition of minimum walking bout length of 10 minutes compared to the 2019 physical activity guidelines; therefore, it was important to explore how walking bout lengths affect the compliance with physical activity guidelines. Further analysis of defining continuous walking events in a process called grouping was developed. This provided a more robust methodological approach of defining continuous walking that had not been previously explored in the literature. After grouping, using the 100 steps/minute threshold as the definition for MVPA, compliance with the 2011 guidelines increased by 63%, while compliance with the 2019 guidelines increased by 3% using the 100 steps/minute threshold as the definition for MVPA. Both before and after grouping, all cycling, mixed-mode, and walking commuters met with the 2019 guidelines compared to the car commuters. Furthermore, all the mixed-mode commuters were compliant with the 2011 guidelines. These findings provide demonstrate that commuting contributes has a substantial contribution to both daily physical activity and total MVPA.

The results demonstrated that commute stepping was accumulated at higher cadence and longer walking bouts lengths compared to non-commute stepping. Furthermore, the mixed-mode and walking commuters accumulated a far greater proportion of their steps during commuting. This was at much longer walking bouts and higher cadence bands than the car commuters. Non-commute steps did not show any distinct differences in step accumulation between modes of commute. The proportion of commute steps accumulated at MVPA were greater than the proportion of non-commute steps.

The use of these commute MVPA outcomes (ungrouped vs. grouped at the three MVPA cadence thresholds) was used to investigate the association between time spent in accumulating MVPA during commuting with metabolic markers. The results showed a significant negative relationship between commuting MVPA and BMI, that is, the higher the MVPA accumulated during commuting, the lower the values of BMI. The association between grouped commute time in MVPA at 109 steps/minute with BMI remained significant after controlling for potential confounding factors. These findings were exclusive to commute time in MVPA alone as total time in MVPA and non-commute time in MVPA were not associated with metabolic markers. Therefore, further studies should ascertain the dose-response relationships between MVPA during commuting (using the methods developed in this thesis – the amount of combined MVPA with light-intensity physical activity (standing)) and different health outcomes, especially metabolic markers.

In summary, the main finding of this thesis were:

- Objectively-measured MVPA during commuting contributes substantially (20% to 31%) to the total time spent in MVPA per day.
- The mode of commuting plays an important role in the contribution of commuting to total MVPA, with mixed-mode, cycling, and walking commuters having the highest contribution compared to car commuters
- There was a far greater proportion of commute MVPA steps than non-commute MVPA steps (76 steps/minute (90% vs. 75%), 100 steps/minute (76% vs. 46%), 109 steps/minute (60% vs. 28%)); however, there was a greater proportion of non-

commute non-MVPA steps than commute non-MVPA steps (76 steps/minute (10% vs. 25%), 100 steps/minute (24% vs. 54%), 109 steps/minute (40% vs. 72%)).

- The process of grouping, that is, combining walking events with short standing/non-sedentary events makes it possible to define continuous walking in a methodologically robust manner.
- After grouping, the number of total MVPA steps taken at short walking bouts of less than five minutes decreased, while the number of total MVPA steps taken at greater than five minutes increased.
- After grouping, there was an increase in compliance for both 2011 and 2019 guidelines. The increase was greater with the 2011 guidelines (63%), with an addition of 10 participants being compliant compared to the 2019 guidelines (3%) where only two additional participants were compliant (out of 40 participants).
- After grouping, of the 26 participants that were compliant with the 2011 guidelines, 10 participants were compliant in their commute alone
- The association between commute time in MVPA and BMI indicated that commuting MVPA may reduce BMI.
- The relationship between non-commute time in MVPA and the total time in MVPA to metabolic markers did not show any significant results before and after adjusting for confounding factors.

Therefore, the main findings of this thesis elucidate the importance of the accumulation of MVPA during commuting as a potential intervention tool for health benefits at population level: this is due to the purposefulness and repetitious nature of commuting, and its association with health-related outcomes.

8.1 Implications for Policy and future research

The primary prevention of cardiovascular diseases is multifaceted, requiring multiple approaches in interventions delivered effectively: it can comprise lifestyle changes, including engaging in more physical activity, improving diet, and other modifiable lifestyle factors such as smoking and drinking (Singh, Pattisapu, & Emery, 2020). Being active during commuting is one way of increasing total daily physical activity and this should be carried out in combination with reducing a sedentary lifestyle throughout the day (DHSC, 2019; WHO, 2020).

The studies in this thesis have shown that meaningful contributions to the adherence to physical activity guidelines are achieved during commuting and can be incorporated into everyday life, with the mode of commuting playing an important role. Panter et al. (2013) reported that commuters who find a supportive environment for walking and cycling were more likely to incorporate walking or cycling into commuting. For long-distance commuters, the use of mixed-mode journeys may be the key to incorporating active modes into parts of their journey. As seen in Study One and in Study Three, mixed-mode and cycling commuters spent the highest duration in MVPA, with all the commuters in this category meeting the recommended physical activity guidelines. Giles-Corti et al. (2016) and Sallis (2016) suggest that the use of adequate infrastructure and transportation planning to incorporate active commuting for residents by discouraging frequent car use to make the use of active commuting and engaging in physical activity a more desirable choice for users, especially for those travelling long distances. In terms of classification, future studies need: an improved definition of active commuting to include mixed-mode journeys, in terms of type, duration, intensity, and frequency; better standardized methods to evaluate active commuting; and appropriate consideration of several confounding factors to help determine the relationship between MVPA during commuting and health outcomes (Dinu et al., 2019).

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Appendices

Appendix 1: Search Strategies

MEDLINE	WEB OF SCIENCE	CINAHL
1. *"Commuting (Travel)"/ or active commuting.mp. 2. active commute*.mp. 3.walking.mp. or exp WALKING/ 4. Bicycling.mp. 5. exp Transportation/ or exp Traveling/ or automobile travel.mp. 6. exp Transportation/ or exp Public Transportation/ or public transport.mp. 7. 1 or 2 or 3 or 4 or 5 or 6 8. metabolic syndrome.mp. or *Metabolic Syndrome/ 9. *Metabolic Syndrome/ or *Risk Factors/ or cardiometabolic factors.mp. 10. body mass index.mp. or exp Body Mass Index/ 11. exp TYPE 2 DIABETES/ or *DIABETES/ or exp DIABETES MELLITUS/ or diabetes.mp. 12. Cardiovascular diseases.mp. 13. cardiovascular risk factors.mp. 14. 12 or 13 15. body weight.mp. or *Body Weight 16. exp OBESITY/ or obesity.mp. 17. 10 or 15 or 16 18. 7 and 8 and 9 19. 7 and 11 20. 7 and 14 21. 7 and 17	#1 TS=(commut* AND MVPA AND physical activity) #2 TS=(Metabolic Syndrome OR Cardiovascular Diseases OR Diabetes Mellitus OR Type 2 OR cardiovascular risk OR Obesity) #3 #2 AND #1 #4 #2 AND #1 Refined by: RESEARCH AREAS: (PUBLIC ENVIRONMENTAL OCCUPATIONAL HEALTH) #5 #2 AND #1 Refined by: RESEARCH AREAS: (PUBLIC ENVIRONMENTAL OCCUPATIONAL HEALTH) AND TOPIC: (adults)	S1 commute S2 active travel S3 walking S4 bicycl* S5 public transport S6 active commute S7 body mass index S8 BMI S9 S1 OR S2 OR S3 OR S4 OR S5 OR S6 S10 S7 OR S8 S11 S9 AND S10 S12 metabolic syndrome S13 metabolic risk factors S14 S12 AND S13 S15 S9 AND S14 S16 S9 AND S14 S17 S1 AND S3 AND S4 AND S5 AND S14 S18 (MM "Cardiovascular Risk Factors") S19 S9 AND S18 S20 S9 AND S18 S21 S6 AND S14 AND S18

Appendix 2: Criteria for metabolic syndrome definitions in adults

World Health Organization criteria (1998)

- Insulin resistance is defined as type 2 diabetes mellitus (DM) or impaired fasting glucose (IFG) (> 100 mg/dl) or impaired glucose tolerance (IGT), plus two of the following:

- Abdominal obesity (waist-to-hip ratio > 0.9 in men or > 0.85 in women, or body mass index (BMI) > 30 kg/m2.

- Triglycerides 150 mg/dl or greater, and/or high-density lipoprotein (HDL)-cholesterol < 40 mg/dl in men and < 50 mg/dl in women.

- Blood pressure (BP) 140/90 mmHg or greater.

- Microalbuminuria (urinary albumin secretion rate 20 μg/min or greater, or albumin-to-creatinine ratio 30 mg/g or greater).

European Group for the Study of Insulin Resistance criteria (1999)

- Insulin resistance defined as insulin levels > 75th percentile of non-diabetic patients, plus two of the following:

- Waist circumference 94 cm or greater in men, 80 cm or greater in women.

- Triglycerides 150 mg/dl or greater and/or HDL-cholesterol < 39 mg/dl in men or women.

- BP 140/90 mmHg or greater or taking antihypertensive drugs.

- Fasting glucose 110 mg/dl or greater.

National Cholesterol Education Program Adult Treatment Panel III (NCEP:ATPIII) criteria (2001)

Any three or more of the following:

- Waist circumference > 102 cm in men, > 88 cm in women.

- Triglycerides 150 mg/dl or greater.

- HDL-cholesterol < 40 mg/dl in men and < 50 mg/dl in women.

- BP 130/85 mmHg or greater.

- Fasting glucose 110 mg/dl* or greater.

* In 2003, the American Diabetes Association (ADA) changed the criteria for IFG tolerance from 110 mg/dl to 100 mg/dl.

American Association of Clinical Endocrinology criteria (2003)
IGT plus two or more of the following:

- BMI 25 kg/m2 or greater.
- Triglycerides 150 mg/dl or greater and/or HDL-cholesterol < 40 mg/dl in men and < 50 mg/dl in women.
- BP 130/85 mmHg or greater.

International Diabetes Federation (IDF) criteria (2005)
Central obesity (defined as waist circumference but can be assumed if BMI > 30 kg/m2) with ethnicity-specific values,* plus two of the following:

- Triglycerides 150 mg/dl or greater.
- HDL-cholesterol < 40 mg/dl in men and < 50 mg/dl in women.
- BP 130/85 mmHg or greater.
- Fasting glucose 100 mg/dl or greater.

*To meet the criteria, waist circumference must be: for Europeans, > 94 cm in men and > 80 cm in women; and for South Asians, Chinese, and Japanese, > 90 cm in men and > 80 cm in women. For ethnic South and Central Americans, South Asian data are used, and for sub-Saharan Africans and Eastern Mediterranean and Middle East (Arab) populations, European data are used.

American Heart Association/National Heart, Lung, and Blood Institute (AHA/NHLBI) criteria (2004)
Any three of the following:

- Waist circumference 102 cm or greater in men, 88 cm or greater in women.
- Triglycerides 150 mg/dl or greater.
- HDL-cholesterol < 40 mg/dl in men and < 50 mg/dl in women.
- BP 130/85 mmHg or greater.
- Fasting glucose 100 mg/dl or greater.

Consensus definition (incorporating IDF and AHA/NHLBI definitions)
Any three of the following:

- Elevated waist circumference (according to population and country-specific definitions).
- Triglycerides 150 mg/dl or greater.

- HDL-cholesterol < 40 mg/dl in men and < 50 mg/dl in women.
- BP 130/85 mmHg or greater.
- Fasting glucose 100 mg/dl or greater.

Appendix 3 – Permission from Journal

must be received by Human Kinetics before the work can be published.

Permission FAQs

. . . for Authors

In which ways may authors of a manuscript published in a Human Kinetics journal reuse their manuscript without first seeking permission from Human Kinetics?
With proper acknowledgment, authors may reuse all or part of their accepted manuscript in the following ways without first seeking permission:

- Printed copies for their own lectures and teaching use
- In future noncommercial works of their own, such as a thesis or dissertation

Appendix 4– Ethics approval letter (Study One)

School Ethical Approval Panel for Taught Programmes

Research Centres Support Team
Research and Enterprise
G0.3 Joule House
University of Salford
M5 4WT

T +44(0)161 295 3362

www.salford.ac.uk

2 February 2017

Dr Paul Sindall, with support from Dr Anna Robins, Prof Malcolm Granat and Prof Peter Hogg

Dear All

RE: ETHICS APPLICATION HST1617-202 - Quantifying the free-living activity levels and patterns of University staff using body-worn monitors.

Based on the information you have provided, I am pleased to inform you that application HST1617-202 has been approved.

If there are any changes to the project and/ or its methodology, please inform the Panel as soon as possible by contacting Health-TaughtEthics@salford.ac.uk.

Yours sincerely,

Dr John McMahon

Chair of the Joint School Approval Ethical Panel for Taught Programmes

Appendix 5 – Participants Information Sheet for Study One

Research informed teaching project

You are being invited to take part in a research project to help students at the University of Salford understand the process of physical activity (PA) monitoring. Before you decide, it is important for you to understand why the research is being done and what it will involve. This document gives you important information about the purpose, risks, and benefits of participating in the study. Please take time to read the following information carefully. If you have any questions then feel free to contact the project supervisor, whose details are given at the end of this document. Take time to decide whether or not you wish to take part.

1. Project title

Quantifying the free-living activity levels and patterns of University staff using body-worn monitors.

2. Background to the study

Physically active persons live longer and have better physical and mental health than inactive counterparts. In contrast, physical inactivity increases disease and disability risk. In the UK there is a worrying trend for inactivity with one in two women and one-third of men classed as sedentary. With 131 million UK working days lost due to sickness and absence in 2013, most notably due to back, neck and muscle-pain, the costs of absence are considerable (approximately £5 billion per year to UK business). This has prompted a growing interest in associations between PA and work performance. Most adults spend half of their waking hours at work and, therefore, the workplace represents an ideal setting for PA promotion. The economic benefits of a well-constructed PA programme are clear, with improvements in productivity, cognitive performance, decision-making and an increased tolerance to stressor being likely outcomes. Furthermore, work-based PA interventions which reduce annual employee absence rates by relatively small amounts (~ 1%) are associated with considerable savings (£2,870 to £6,244 per employee per year), with proportionately greater savings associated with further decreases in absence rates.

This project is in essence a teaching and learning activity, designed to embed researchinformed teaching into the BSc (Hons) Exercise Nutrition & Health curriculum. Such activity is desirable in-light of institutional targets at the University of Salford as it allows students to understand the process of data collection and analysis. Collection of movement data using a single, lightweight accelerometer which is discretely attached to the thigh will enable students to capture the movement patterns and PA behaviour of University workers in freeliving and work-based environments.

3. What will happen to me if I participate in this study?

3.1 How long will it take?

If you agree to participate in the study, you will be required to wear a thigh worn activity monitor for an initial period of 7 days whilst continuing your normal routine.

3.1 What will you do?

a. complete informed consent and medical screening (PAR-Q)
b. the device will be attached to the anterior aspect of the thigh with a hydrogel pad (PAL Technologies Ltd. Glasgow, UK)
c. continue with your normal daily activity routine (the activity monitor is left in-place) for 7 days
d. complete an activity diary

Am I able to participate?

To participate:

- You must NOT have an existing skin condition such as psoriasis or eczema that would be affected by the application of a medical dressing of a medical grade adhesive dressing
- you must NOT be wheelchair bound at all times
- you MUST be a member of staff at the University of Salford

4. Risks and potential benefits of the study

4.1 What risks are involved in participating in the study?

This is a very simple study with no apparent risks to you. Some participants may experience some mild skin irritation from the hydrogel Stickie Pads and / or medical grade dressing used to attach the monitor. The activPal activity monitor has been used for many years in a number of studies involving thousands of users. Hence, risks are minimal.

4.2 If I participate in this study, can I also participate in other studies?

As the testing for the project requires continuous use for a period up to 7 days, some other additional studies may interfere with data collection. If, however you are already taking part in other research, or would like to do so, please discuss this with the research supervisor (contact details below).

4.3 What benefits are involved in participating in the study?

You will not benefit directly from taking part in the study. However, the data we will collect during the observation period will improve our knowledge regarding the activity patterns of University staff. You may also benefit from hearing about the types of intervention that increase movement activity, which is information that we hope will arise from this study.

4.4 What if something goes wrong?

If you are harmed by taking part in this research project, there are no special compensation arrangements. If you are harmed due to someone’s negligence, then you have grounds for legal action but you may have to pay for it. In case of a complaint you can contact Anish Kurien (Research Centres Manager), Joule House G.08, University of Salford, M5 4WT (Phone: 0161 295 5276 Email a.kurien@salford.ac.uk).

5. Ending the study

5.1 What if I want to leave the study early?

You can withdraw from this study at any time without loss of any non-study related benefits to which you would have been entitled before participating in the study. There is no danger to you if you leave the study early. If you want to withdraw you may do so by notifying the project supervisor (contact details below).

6. Financial Information

6.1 Who is organising and funding the research?
The University of Salford is organising and funding this research.

6.2 Will I be paid for participating?
Unfortunately, financial reward will not come from taking part in this research. However, you will be participating in a study with a novel idea and it could have a positive impact on student learning and understanding of research processes and outcomes.

7. Confidentiality of participant records

7.1 Will my taking part in this study be kept confidential?
Yes. We take great care to protect the confidentiality of the information we are given, and we take careful steps to ensure that data is secure at all times. The information collected is used for research purposes and statistical only and is dealt with according to the 1998 Data Protection Act.

7.2 How will my data be used?
Anonymised research data will be archived in the University of Salford data repository. Information from this study will be made available for future research studies; however, no information collected and recorded can be used to identify individuals in the dataset.

7.3 What will happen to the results of the research study?
A summary of the research findings will be sent to everyone who participates in the experiments. Significant findings may be published in clinical and engineering journals.

8. Contact Information
If you require more information about the study, want to participate, or if you are already participating and want to withdraw, please contact:

Dr Paul Sindall
Email: p.a.sindall@salford.ac.uk
Address: School of Health
Sciences University of Salford,
Salford, M6 6PU.

9. Record of Information provided
Your will receive a copy of the information sheet and a signed consent form to keep for your personal records.

Thank you very much for taking time to read this document; we appreciate your interest in this study. Your involvement will greatly help the students with their learning and specifically, their understanding of the research process.

University of Salford MANCHESTER

Appendix 6 – Consent form for Study One

Research informed teaching project consent form

Project Title:

Quantifying the free-living activity levels and patterns of University staff using body-worn monitors.

University of Salford Researchers:

Dr Paul Sindall, Dr Anna Robins, Dr Chris Pickford, Dr Sathish Sankarpandi, Prof. Malcolm Granat, Prof. Peter Hogg and Rob Higgins. School of Health Sciences, The University of Salford, Salford, M6 6PU.

	Initial box to confirm
I confirm that I have read and understand the **Participant Information Sheet** for the above study and have had the opportunity to ask questions.	
I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my care or legal rights being affected.	
I agree that my anonymised data can be kept in the repository within the University of Salford and accessed, with permission, by researchers at the University.	
To participate: □ You must NOT have an existing skin condition (such as psoriasis or eczema) that would be affected by the application of a medical grade dressing. □ you MUST be a member of staff at the University of Salford □ you must NOT be wheelchair bound at all times. I confirm that I am not in breach of any of the above conditions.	

By signing this consent form I understand that after the study my anonymised data may be made available to other researchers at the University of Salford data and elsewhere. However, it will not be possible to identify me from these data.

Name of participant:

____

Signature: ______________________ **Date:** _________________________

[If participant is not able to consent themselves:]

I give informed consent as the carer / family member with executive authority over the named participant to take part in the study.

Name of participant: ____

Nature of authority: __________________________________ (e.g. Enduring Power of Attorney)

Signature: ______________________ **Date:** _________________________

Name of person taking consent: ____

Signature: ______________________ **Date:** _______________________

Appendix 7- Activity diary used for Study One- Commuting and MVPA

DAY/DATE	DID YOU LEAVE THE HOUSE TO GO TO WORK?	WHAT TIME DID YOU LEAVE YOUR HOUSE?	HOW DID YOU TRAVEL TO WORK?	WHAT TIME DID YOU ARRIVE AT WORK ?	WHAT TIME DID YOU LEAVE WORK?	HOW DID YOU TRAVEL HOME?	WHAT TIME DID YOU GET BACK INTO THE HOUSE?	COMMENTS (please write in the space provided if you removed the device, time the device was removed, and the reason why you did)
DAY 1 - e.g. Monday	*06:30*	*07:30*	*Drove to Station, took the train and walked*	*08:30*	*16:40*	*Walked to the station, took the train and drove*	*17:30*	*I went swimming between 17:30 and 18:30 and removed the activity monitor*
DAY 1 –								
DAY 2 –								
DAY 3 –								
DAY 4 –								
DAY 5 –								
DAY 6 –								
DAY 7 –								

How many miles do you travel to and from work?

E.g. I travel 6miles to work and 6.5miles back home.

Appendix 8: Participant Information Sheet for Study Three

PARTICIPANT INFORMATION SHEET

Title of study: Commuting moderate-to-vigorous physical activity and metabolic risk factors

Name of Researcher: Abolanle Gbadamosi

1. Invitation paragraph

I would like to invite you to take part in a study. The purpose of the study and your role in the study will be explained and you will need to understand this before making a decision. Please take time to read the following information carefully and ask questions if anything you read is not clear or you would like more information. The study involves how being active during travel to and from work affects health

2. What is the purpose of the study?

The purpose of this study is to objectively quantify physical activity during commuting to and from work and investigate how this activity affects our metabolic health. The best way to measure physical activity is through the use of an activity monitor, activPAL^{TM} that records information about activity and posture. There are evidence to suggest that total physical activity reduces the risk of metabolic syndrome; however, there are few commuting studies investigating this association and this will be the focus of this study.

3. Why have I been invited to take part?

You have been invited to participate in this study because you work (or are a postgraduate research student) at the University of Salford and travel to and from work by car, bus, train or walking. In order to look at the impact of being active during commuting on health, it is necessary to study a group of working individuals that travel to and from work regularly.

4. Do I have to take part?

Participation is entirely voluntary. This participant information sheet contains detailed information about the study, and you can ask questions if anything is unclear. You will be asked to sign a consent form to show that you have agreed to take part. You are under no obligation to go through with the study if you do not want to, and you can withdraw at any time

5. What will happen to me if I take part?

Participants will be asked to wear an activity monitor for seven days while carrying out your normal daily activities to measure physical activity. You will be asked to fill out a simple activity diary that will be used to record commute times to and from work and your mode of commute. You will be asked to participate in a health check that will involve finger prick testing to measure glucose and cholesterol levels. You will have to fast for 8hours overnight before testing. Testing will usually take place in the morning at the University and last for a period of 15 minutes and results will be given at the end of the tests.

6. Expenses and payments?

There will be no expenses for you as the research will take place in the University building where your office is. Also, there will be no payments. Your participation will be appreciated

7. What are the possible disadvantages and risks of taking part?

There are no disadvantages or risks with taking part in this study. The only burden to the participant is wearing of the activPAL™ device for seven days, but the activity monitor is light-weight and the medical dressing is skin and hair friendly. This should not cause any discomfort or irritation, but if it does you can either place the activity monitor on the opposite leg or remove it and return it to the researcher. The chances of skin irritation are negligible; however, if irritation does occur, participants are advised to seek medical advice from a pharmacist or GP, and also inform the researcher.

The finger prick test will cause a tiny scratch to the pricked finger. There will be minimal harm to you as single-use sterile lancets will be used and clean antibacterial wipes/cotton wools will be provided. In addition, if any of the test results indicate a health problem, participants are advised to seek medical advice from the GP.

8. What are the possible benefits of taking part?

The results of the health checks carried out will be given to you at the end of the test. We cannot promise the study will help you but the information we get from the study will help increase the understanding of how activity during travel to and from work can benefit metabolic health outcomes.

9. What if there is a problem?

If you have a concern about any aspect of this study, you should ask to speak to the researcher **(Abolanle Gbadamosi, Tel: 07341325464**) who will do their best to answer your questions. If you remain unhappy and wish to complain formally you can do this by contacting the Research Supervisor **(Malcolm Granat; Tel: 016129552568**). If the matter is still not resolved, please forward your concerns to Professor Susan McAndrew, whose details are provided at the end of this document.

10. Will my taking part in the study be kept confidential?

Yes. All the information provided by you in this study will remain confidential. The information that you provide from the accelerometers and the activity diary will be stored anonymously on a computer. None of the information held by the researcher will identify you by name. The procedures for handling, processing, storage and destruction of your data are compliant with the Data Protection Act 1998.

11. What will happen if I don’t carry on with the study?

If you decide to withdraw from this study all the information and data collected from you, to date, will be destroyed and your name removed from all the study files.

12. What will happen to the results of the research study?

The results from the study may be published in a peer-reviewed journal or elsewhere without giving your name or disclosing your identity.

13. Who is organising or sponsoring the research?

This research study is being organised by the School of Health Sciences at the University of Salford and forms part of a postgraduate research degree programme.

14. Further information and contact details:

For more information concerning this research, please contact the researcher

Abolanle Gbadamosi (Researcher)

Email: a.r.gbadamosi@edu.salford.ac.uk
Phone no: 07341325464
Room L731, Allerton Building
Building,
Frederick Road Campus,
University of Salford, Salford
M6 6PU

If unhappy with study, please contact:

Professor Susan McAndrew(Chair of the Health Research Ethical Approval Panel)
E: s.mcandrew@salford.ac.uk
Tel: 0161 295 2778
Room MS1.91, Mary Seacole

Frederick Road Campus,
University of Salford, Salford
M6 6PU

Thank you very much for taking the time to read this document and many thanks for your participation.

Appendix 9: Consent form for Study Three

CONSENT FORM

Title of study: Commuting moderate-to-vigorous physical activity and metabolic risk factors

Name of Researcher: Abolanle Gbadamosi

Please complete and sign this form **after** you have read and understood the study information sheet. Read the following statements and select 'Yes' or 'No' in the box on the right hand side.

1.	I confirm that I have read and understand the study information sheet version ***[3]***, dated ***[02/10/2018]***, for the above study. I have had the opportunity to consider the information and to ask questions Which have been answered satisfactorily.	Yes/No
2.	I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, and without my rights being affected.	Yes/No
3.	If I do decide to withdraw I understand that the information I have given, up to the point of withdrawal, will be used in the research. The timeframe for withdrawal is voluntary.	Yes/No
4.	I agree to participate by wearing the activPAL™ activity monitor for seven and fill out the activity diary given during the study.	Yes/No
5.	I agree to participate in the finger prick test	Yes/No
6.	I understand that my personal details will be kept confidential and will not be revealed to people outside the research team.	Yes/No
7.	I understand that my anonymised data will be used in the researcher's thesis, other academic publications, conferences and presentations, and further research.	Yes/No
8.	I agree to take part in the study:	Yes/No

Name of participant	**Date**	**Signature**

Name of person taking consent	**Date**	**Signature**

Appendix 10 – Ethics approval letter: Study Three (First approval)

University of Salford
MANCHESTER

Research, Enterprise and Engagement
Ethical Approval Panel

Doctoral & Research Support
Research and Knowledge Exchange,
Room 827, Maxwell Building,
University of Salford,
Manchester
M5 4WT

T +44(0)161 295 2280

www.salford.ac.uk

29 November 2018

Dear Abolanle,

RE: ETHICS APPLICATION–HSR1819-019 – Commuting moderate-to-vigorous physical activity and metabolic syndrome: do bouts play a significant role?

Based on the information that you have provided, I am pleased to inform you that application HSR1819-019 has been approved.

If there are any changes to the project and/or its methodology, then please inform the Panel as soon as possible by contacting Health-ResearchEthics@salford.ac.uk

Yours sincerely,

Professor Andrew Clark
Deputy Chair of the Research Ethics Panel

Appendix 11: Ethics approval letter: Study Three (Second approval after minor amendment)

MANCHESTER

1.1.1.1

Research, Enterprise and Engagement
Ethical Approval Panel

Doctoral & Research Support
Research and Knowledge Exchange,
Room 827, Maxwell Building,
University of Salford,
Manchester
M5 4WT

T +44(0)161 295 2280

www.salford.ac.uk

20 May 2019

Dear Abolanle,

RE: ETHICS APPLICATION–HSR1819-019 – Commuting moderate-to-vigorous physical activity and metabolic syndrome: do bouts play a significant role?

Based on the information that you have provided, I am pleased to inform you that application HSR1819-019 has been approved.

If there are any changes to the project and/or its methodology, then please inform the Panel as soon as possible by contacting Health-ResearchEthics@salford.ac.uk

Yours sincerely,

Professor Andrew Clark
Deputy Chair of the Research Ethics Panel

Appendix 12: Activity Diary for Study Three

DAY/DATE:

Did you travel to work today? ____________________

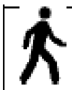
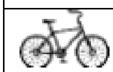
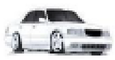
What time did you leave the house? ____________________

What time did you arrive at work? ____________________

What time did you leave work? ____________________

What did you get back into the house? ____________________

How much time in total did you spend travelling **to and from work** by:

	HOURS	**MINUTES**
 **Walking**		
 **Cycle**		
 **Car**		
 **Public transport (including bus, train, and taxis)**		

COMMENTS (Please in the blank spaces below if you removed the device, the time the device was removed, and the reason why you did)

Time removed: ____________________

Time put back on: ____________________

Reason: ____________________

Appendix 13: Proof of training

UNIVERSITY OF LEICESTER

SMART WORK and LIFE

STUDY: SMART WORK & LIFE **Sponsor Number:** UNOLE 0657 **CHIEF INVESTIGATOR:** Dr Charlotte Edwardson

RESEARCHER NAME: ABOLANLE GBADAMOSI **Role:** DATA COLLECTION ASSISTANT **RESEARCH SITE:** SALFORD

TRAINING TYPE	TRAINING DATE	RESEARCHER SIGN	TRAINER NAME	TRAINER SIGN
Study Specific SOPs	15/05/18	[illegible]	READ AND UNDERSTOOD	n/a
Standing Desk Installation (USER MANUAL)	15/05/18	[illegible]	READ AND UNDERSTOOD	n/a
Protocol & Site Initiation Training Inc. CRFs & Safety Reporting (Version 1.1)	15/05/18 28/9/18	[illegible]	PRESENTATION	[illegible] 28/9/18
Blood Fingerprick Testing: - Quo-Test Analyser Fingerprick Test - CardioChek Plus Fingerprick Test	15/05/18	[illegible]	DEMO	SEAN ROURKE [illegible] 15/05/18
ActivPal Training (Patient use, Initialisation and Downloading)	15/05/18	[illegible]	DEMO	SEAN ROURKE [illegible] 15/05/18
Axivity Training (Patient use, Initialisation and Downloading)	15/05/18	[illegible]	DEMO.	SEAN ROURKE [illegible] 15/05/18.
QPulse Training (Quality Management System) n/a.	~~15/05/18~~	~~[illegible]~~		
Site File Training	15/05/18	[illegible]		
Data Protection / Identifiable Data.	28/09/18	[illegible]	PRESENTATION/PACK	[illegible] 28/9/18

INDIVIDUAL SMART WORK AND LIFE TRAINING LOG Version 1.0; 13/04/2018 Page 1 of 2

Appendix 14: Test results sheet

TEST RESULTS

Glucose: Blood glucose is the sugar that the bloodstream carries to all cells in the body to supply energy.

HDL-cholesterol: is also called the good cholesterol and it carries the extra cholesterol that is not needed from the bloodstream to the liver, where it is either broken down or passed out of the body as a waste product.

Triglycerides: is a blood lipid that is stored in the body's fat cells. It can be found in dairy products, meat, and cooking oils.

Blood pressure: is the amount of pressure in the arteries needed to keep blood flowing in the body.

Waist circumference: is the measurement of the waist to check that there isn't too much fat around the abdomen.

Body mass index: provides an estimate whether an individual is within the healthy weight, underweight, overweight or obese range. It uses the height and the weight of an individual to derive an estimate of total body fat.

Measures	Results	Desirable ranges
Fasting blood glucose		<5.6mmol/L
HDL-cholesterol (good cholesterol)		>1mmol/l(men); >1.2mmol/l(women
Triglycerides (fat in the blood)		<1.7mmol/l
Blood Pressure		<130/85mmHg
Waist circumference		<94cm in men <80cm in women
Body mass index (BMI)		<25kg/m^2

ADDITIONAL MEASURES

HEIGHT:

WEIGHT:

BP 1: 2: 3:

LDL:

TOTAL CHOLESTEROL: