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Are all sedentary behaviours equal? Different sedentary behaviours and indicators of disease risk

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Abstract

There is evidence to suggest that sedentary behaviour has a negative impact on the risk of some non-communicable diseases, however associations differ within different contexts (e.g., leisure time, occupational). The current study examined the association between different types of sedentary behaviour and disease risk, in women, using objectively measured sedentary data.

Methods: The study was conducted in two parts. A validation study ($n = 20$) was conducted using direct observation and objective measurement of common sedentary behaviours (e.g., reclining, sitting and sitting typing) were used to classify sedentary behaviour into four categories: 1) lying down; 2) sitting (non-active); 3) sitting (active); and 4) standing. In a cross-sectional study ($n = 348$, age = 16-45 years) accelerometer-derived sedentary behaviour classifications were correlated with body composition, metabolic, inflammatory and blood lipid variables, from the women's EXPLORE study.

Results: Participants spent an average of 7 hours 42 minutes per day in sedentary behaviour. Of the time spent sedentary, 58% was classified as non-active sitting and 26% as active sitting. Non-active sitting showed weak positive correlations with BMI ($r = 0.244$, $p \leq 0.001$), body fat percent ($r = 0.216$, $p \leq 0.001$), body mass ($r = 0.236$, $p \leq 0.001$), waist:hip ($r = 0.141$, $p = 0.009$), fat mass ($r = 0.241$, $p \leq 0.001$), insulin ($r = 0.160$, $p = 0.003$), leptin ($r = 0.237$, $p \leq 0.001$), systolic and diastolic blood pressure ($r = 0.137$, $p = 0.010$ and $r = 0.135$, $p = 0.011$), and weak negative correlations with HDL-cholesterol ($r = -0.117$, $p = 0.031$). Conversely, active sitting was weakly negatively correlated with BMI ($r = -0.300$, $p \leq 0.001$), body fat percent ($r = -0.249$, $p \leq 0.001$), body mass ($r = -0.305$, $p \leq 0.001$), waist:hip ($r = -0.164$, $p = 0.002$), fat mass ($r = -0.320$, $p \leq 0.001$), insulin ($r = -0.180$, $p = 0.001$), leptin ($r = -0.259$, $p \leq 0.001$), and a weak positive correlation with HDL-cholesterol ($r = 0.115$, $p = 0.035$).

Conclusion: The current study demonstrates a favourable association between active sitting and markers of disease risk. It provides a new focus for the development of public health initiatives and

sedentary behaviour guidelines by showing that different types of sedentary behaviours might have different effects on markers of disease risk.

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Abbreviations

BMI – body mass index

CVD – cardiovascular disease

HDL – high density lipoproteins

IL-6 - interleukin-6

IL-10 - interleukin-10

LDL – low density lipoproteins

MET – metabolic equivalent unit

NZHS – New Zealand Health Survey

NZMOH – New Zealand Ministry of Health

TNF-a - tumour necrosis factor alpha

T2DM – type two diabetes mellitus

Chapter 1: Introduction

It is estimated that adults spend between 55 and 70% of time awake being sedentary (An, Kim, & Lee, 2017; Dempsey, Owen, Biddle, & Dunstan, 2015; Gupta et al., 2016; Peterson, Sirard, Kulbok, DeBoer, & Erickson, 2015). The New Zealand Time Use Survey: 2009/10 reported that New Zealanders over the age of 12 years spent more than 80% of their leisure time watching television or video, socialising, and reading and writing (Statistics New Zealand, 2011). Additionally, there has been a 3.4% increase in self-reported 'little to no physical activity' among New Zealand adults over the past 10 years (New Zealand Ministry of Health, 2017). Research is conflicting on the relationship between sedentary behaviour and prevalent non-communicable diseases (e.g., obesity, metabolic diseases, cardiovascular diseases), as well as the biomarkers associated with increased risk of said chronic diseases (An et al., 2017; Bassett et al., 2014; Dempsey et al., 2015; Froberg & Raustorp, 2014; Gupta et al., 2016; Machado-Rodrigues et al., 2015; Peterson et al., 2015). Given the contradictory evidence, it is important to define and measure sedentary behaviour accurately so that outcomes on markers of health or incident health can be understood (Peterson et al., 2015).

There are two methods commonly used to measure sedentary behaviour. Subjective methods for assessing sedentary behaviour involve questionnaires, activity diaries, or interviews where individuals report their activities or behaviours retrospectively (Biddle et al., 2017; Same et al., 2016; Young et al., 2016). Self-report of sedentary behaviours and physical activity through subjective methods can lead to over reporting of activity (Moy, Scragg, McLean, & Carr, 2008; Prince et al., 2008). In contrast, objective methods of measuring sedentary behaviour include accelerometers and inclinometers that are built into wearable devices and are fitted to the waist, thigh, or wrist, and measure body position and movement (ActiGraph, 2018; Holtermann et al., 2017; PAL Technologies, 2018; Steeves et al., 2015). Objective methods of measuring sedentary behaviour can be more precise and detailed than self-report methods (Young et al., 2016).

The definition of sedentary behaviour has been subject to interpretation for many years. These differing definitions (New Zealand Ministry of Health, 2016a; Pate, O'Neill, & Lobelo, 2008; Tremblay, Colley, Saunders, Healy, & Owen, 2010) have led to inconsistencies in research. In 2012, the Sedentary Behaviour Research Network defined sedentary behaviour as any waking behaviour with an energy expenditure ≤ 1.5 metabolic equivalents (MET) (1 MET is defined as 3.5 ml of oxygen per kg bodyweight per minute, consumed while sitting at rest) while in a sitting or reclining posture (Tremblay et al., 2017). Activities and behaviours of daily living fall into four different lifestyle combination categories (Dempsey et al., 2015), which include: sedentary work and leisure time; sedentary work and physically active leisure time; physically active work and sedentary leisure time; and physically active work and leisure time (Dempsey et al., 2015). Different body postures and activities fall within the sedentary behaviour and light to moderate physical activity categories and changes in those postures and activities can alter metabolic rate (Bassett et al., 2014). Light to moderate physical activity, such as standing and walking slowly, can increase metabolic rate in comparison to more sedentary behaviours of sitting and lying (Steeves et al., 2015), and thus provide positive effects on health indicators (Edwardson et al., 2016). Replacing sitting with light intensity activities improves insulin action in healthy individuals (Duvivier et al., 2013) and in those suffering from type two diabetes mellitus (T2DM) (Duvivier et al., 2017). Light intensity activities also decrease fasting triacylglycerol, total cholesterol, and non-high density lipoprotein cholesterol while increasing high density lipoprotein (HDL) cholesterol, apo B and non-esterified fatty acids (Duvivier et al., 2018; Duvivier et al., 2017), all of which affect mechanisms involved in cardiovascular disease (CVD) and obesity. Based on these physiological differences, current trends in public health initiatives encourage changing work activities from sedentary to light to moderate physical activity (standing and light walking) with the goal of promoting accomplishable and sustainable changes in behaviour (Dempsey et al., 2015; Healy, Wijndaele, et al., 2008). Therefore, it is important to quantify sedentary behaviour and light intensity activities which can be measured using self-report or accelerometers/inclinometers.

1.1 Significance

It is important to consider the effect of time spent in different sedentary behaviours on health outcomes while utilising the most appropriate measurement strategies for sedentary behaviour in a free-living environment. Although all seated or reclining activities ≤ 1.5 METs are considered sedentary behaviour, there is variation in metabolic rates associated with differing postures within the sedentary range. If different sedentary postures have an effect on metabolic rate and therefore energy expenditure, there might also be varying impacts on health outcomes to consider. Further research on this topic would allow an evidence-based approach to development of meaningful and effective sedentary behaviour guidelines.

1.2 Validation study

1.2.1 Aim:

To develop and validate an algorithm that differentiates between different sedentary behaviours (lying, non-active sitting, active sitting, and standing) using accelerometer data collected from a hip/waist worn accelerometer.

1.2.2 Objectives:

- Apply a classification algorithm to raw accelerometer data to differentiate between the various body postures during sedentary behaviours.
- Compare direct observation of predetermined activities and body postures to accelerometer data in order to calculate percentage agreement.

1.3 Cross-sectional study

1.3.1 Aim:

To describe the relationship between different sedentary behaviours and risks of disease, using accelerometer, anthropometric and metabolic variable data, previously collected for the women's EXPLORE Study.

1.3.2 Objective:

Calculate the proportion of time spent in different sedentary postures and relate it to markers associated with disease risk.

1.3.3 Hypothesis:

More time spent in postures that have higher energy requirements will have positive associations with health markers.

1.4 Structure of thesis

This thesis is presented in four chapters. Chapter one introduces the topic and discusses justification for the research. Chapter two reviews the current literature regarding sedentary behaviour and the relationship with non-communicable diseases. Chapter three provides a research study manuscript including methods, results and a brief discussion. Finally, chapter four discusses the impact of findings on contribution to health, strengths, limitations and recommendations for future studies.

1.5 Researchers contributions

Contributor	Research Role
Claire Beale	Main researcher; participant recruitment and data collection for validation study, statistical analysis, interpretation of results, author of thesis.
Dr Sarah Shultz	Main academic supervisor; development of study design, analysis and interpretation of results, thesis revision and approval.
Dr Philip Fink	Assistance with academic supervision, development of classification algorithm, thesis revision.
Dr Wendy O'Brien	Assistance with academic supervision, participant recruitment, assistance with equipment for data collection, data collection for cross-sectional study, assistance with statistical analysis, thesis revision.

Chapter 2: Literature Review

2.1 Introduction

The aim of this review is to examine the current literature regarding time spent in sedentary behaviour and the associated health outcomes of such behaviour. The review includes various types of studies using a range of definitions and measures of sedentary behaviour. The current health and lifestyle climate in New Zealand were considered when looking at associations of sedentary behaviour with health outcomes. Topics covered in this review include: the definition of sedentary behaviour and how it is measured; the prevalence of sedentary behaviour in New Zealand; the impact of sedentary behaviour on a selection of non-communicable diseases; and lifestyle interventions that can be used to reduce sedentary behaviour.

2.2 What is sedentary behaviour?

Sedentary behaviour has been used in many different contexts in literature and in lay terms. The term sedentary has its root in Latin, where 'sedere' means 'to sit' and has, therefore, broadly been defined as expending little energy in a sitting or lying position whilst awake (Wilmot et al., 2012). Energy expenditure for sedentary behaviour is commonly defined as ≤ 1.5 METs (Pate et al., 2008). This definition does not account for gender, body composition, or age, but has come to be used as the standard for describing sedentary behaviour. However, the range of definitions used for sedentary behaviour (Table 1.1) has led to ambiguity in the literature and in public health messaging. The Sedentary Behaviour Research Network was established in an attempt to bring consistency to the definition of sedentary behaviour. The network proposed the definition of sedentary behaviour as "any waking behaviour characterised by an energy expenditure ≤ 1.5 METs while in a sitting or reclining posture", and further proposed that this definition be adopted in all sedentary behaviour research and literature (Sedentary Behaviour Research Network et al., 2012).

Table 1.1 Commonly used definitions of sedentary behaviour

Definition	Reference
“A distinct class of behaviours (e.g., sitting, watching TV, driving) characterized by little physical movement and low energy expenditure (≤ 1.5 METs)”	(Tremblay et al., 2010)
“Activities that do not increase energy expenditure substantially above the resting level and includes activities such as sleeping, sitting, lying down, and watching television, and other forms of screen-based entertainment. Operationally, sedentary behaviour includes activities that involve energy expenditure at the level of 1.0-1.5 METs”	(Pate et al., 2008)
“any waking behaviour characterised by an energy expenditure ≤ 1.5 METs while in a sitting or reclining posture”	(Sedentary Behaviour Research Network et al., 2012)
“sitting and low levels of energy expenditure” “sitting during commuting, in the workplace, the domestic environment, and during leisure time”	(Owen, Healy, Matthews, & Dunstan, 2010)
“activities that use very little or no energy (e.g., sitting down, lying down, watching television or using a computer)”	(New Zealand Ministry of Health, 2016b)

Abbreviations: MET, metabolic equivalent unit; TV, television.

Historically, the distinction between sedentary behaviour and inactivity has also been inconsistent and confusing. Some population health surveys refer to inactivity as a failure to meet physical activity guidelines (Lee et al., 2012; World Health Organization, 2010), whereas others regard inactivity as <30 minutes per week of physical activity (New Zealand Ministry of Health, 2016b; Sedentary Behaviour Research Network et al., 2012). It is important to distinguish between sedentary behaviour and physical inactivity; the terms are associated with a potentially three fold difference in energy expenditure. Failure to meet physical activity guidelines and/or participating in <30 minutes of physical activity per week cannot infer that time is spent in sedentary behaviour. Non-sedentary behaviour, by definition, has a higher energy expenditure than sedentary behaviour and therefore could have a different effect on health outcomes.

As energy expenditure (often reported in METs) is not typically measured during day to day living, sedentary behaviour is most commonly estimated from activities carried out in a sitting or reclining position (e.g., watching television, using a computer) (Table 1.2). Mansoubi et al. (2015) measured the METs of participants performing activities in different body positions in order to determine whether the broad definition of ‘sitting or lying’ is appropriate in relation to sedentary behaviour. These authors found that 1.5 METs, as an upper limit for sedentary behaviour, is appropriate for distinguishing between most sitting and standing activities, although some sitting activities (e.g., sitting typing, sitting playing play station, and sitting playing Wii) require more than 1.5 METs (Mansoubi et al., 2015). Indeed, Mansoubi et al. (2015) found that a sitting activity such as typing had a MET value of 1.56, and therefore would be categorised as non-sedentary under current definitions. These findings suggest that studies assessing workplace sedentary behaviour should reconsider the methods used for measuring sedentary behaviour (e.g., use accelerometers to measure activity counts), or the definition of such behaviour.

Table 1.2 MET values for various sedentary behaviours

METs	Activity
1.0	Lying quietly watching TV
1.3	Lying quietly doing nothing
1.3	Sitting quietly
1.5-1.8	Sitting fidgeting (hands/feet)
1.3	Reclining
1.0	Sitting playing video games
1.5	Sitting using a computer
1.5	Sitting office work/desk work

Abbreviations: METs, metabolic equivalent units; TV, television.

Note. Data from Ainsworth et al., (2011).

2.3 How is sedentary behaviour measured?

Sedentary behaviour is typically assessed using either subjective or objective methods. Subjective methods are often reported by the participant in self-administered or interview-based questionnaires and activity diaries. Objective measures utilise wearable devices (Biddle et al., 2017;

Same et al., 2016; Young et al., 2016), such as accelerometers and other activity monitors worn on the wrist, hip or thigh (ActiGraph, 2018; Holtermann et al., 2017; PAL Technologies, 2018; Steeves et al., 2015). Self-report questionnaires help to provide context to the activities being performed by an individual (Young et al., 2016). Self-report assessments often use representative markers, such as time spent watching television, driving, or using a computer to extrapolate time spent in sedentary behaviour (Same et al., 2016). However, self-reported activity can be inaccurate, with over-reporting known to occur in overweight or obese populations (Prince et al., 2008), less physically active individuals, and in non-European New Zealanders (Moy et al., 2008). Objective assessment of sedentary behaviour uses wearable technologies with built-in inclinometers to assess body posture, and accelerometers to determine movement and/or lack of movement (Biddle et al., 2017). Objective measures of sedentary behaviour can provide a more precise and detailed picture of behaviour patterns than self-report methods (Young et al., 2016). Although wearable devices can measure time spent sitting, lying or standing still, most cannot distinguish between these activities (Holtermann et al., 2017). Direct observation is a further method of estimating sedentary behaviour but is typically only used in lab-based research settings. During direct observation a trained researcher observes the research participant performing various tasks in order to assess the intensity of each activity (Lyden, Petruski, Staudenmayer, & Freedson, 2014). Observation can take place in person or via video recording, however, this method can be time consuming and is impractical for multiple-participant studies under free-living conditions.

Sedentary behaviour may be carried out at work, home or school and for the purpose of working, learning, travel or leisure (Young et al., 2016). Device-based and self-report measures of sedentary behaviour are often used together to provide an overall understanding of the amount of time spent in sedentary behaviour as well as the task that is being achieved, and where and why it is occurring (Dempsey et al., 2015; Owen, 2012; Young et al., 2016). However, no standardised procedure for combining such data are readily available (Gibbs, Hergenroeder, Katzmarzyk, Lee, & Jakicic, 2015).

The development and availability of a standardised set of procedures for measuring and evaluating sedentary behaviour patterns would help build stronger evidence for scientific literature (Gibbs et al., 2015; Young et al., 2016) and allow more accurate comparison of studies on this topic.

2.3.1 Accelerometers

Accelerometers are commonly used to assess sedentary behaviour and physical activity under free-living conditions, or in the laboratory when used in conjunction with direct observation. Accelerometer data may be collected over a short period for the purpose of validation (Carr & Mahar, 2012; Kaminsky & Ozemek, 2012; Sasaki, John, & Freedson, 2011). However, it is more typically used over prolonged periods (days or weeks) to determine habitual levels of physical activity and sedentary behaviour or the efficacy of activity interventions (Craft et al., 2012; Edwardson et al., 2012; Froberg & Raustorp, 2014; Yang & Hsu, 2010). Accelerometers may be worn on the hip, thigh, wrist, or ankle, with placement often depending on the specific aim of a study (Yang & Hsu, 2010). Accelerometers for assessing physically active behaviour are most commonly attached to the hip because it is close to the body's centre of mass, is easily accessible, and is less restrictive than other positions on the body (Yang & Hsu, 2010). Positioning on the thigh can be used to accurately classify lying (93% accuracy), sitting (99% accuracy), and upright postures (98% accuracy) using the proprietary Actigraph software with 15 second epochs (Edwardson et al., 2016). Placement on the wrist can be used for measurement of sleep and movement during sleep, whereas placement on the ankle is useful for monitoring gait and step counts (Yang & Hsu, 2010). Commercially available accelerometers report a variety of parameters including METs, estimated energy expenditure, activity counts, activity intensity/duration, sedentary and upright time, and steps (Yang & Hsu, 2010). Activity counts and estimated energy expenditure can be used to determine intensity of activities (Wullems, Verschueren, Degens, Morse, & Onambele, 2017). Accelerometers derive activity counts by measuring the frequency and intensity of acceleration and deceleration, whereas inclinometers measure tilt angle and can therefore identify body posture

(Byrom, Stratton, Mc Carthy, & Muehlhausen, 2016). Sedentary behaviour is usually classified as <100 counts per minute and can also be estimated from inclinometer data (Freedson, Melanson, & Sirard, 1998; Pfister et al., 2017).

2.4 Prevalence of sedentary behaviour in New Zealand

In New Zealand specific measurement of sedentary behaviour is lacking. The annual New Zealand Health Survey (NZHS) focusses on meeting national physical activity guidelines (≥ 30 minutes of moderate-intensity physical activity on at least five days of the week; (New Zealand Ministry of Health, 2016a) and physical inactivity (<30 minutes per week of moderate-intensity physical activity; (New Zealand Ministry of Health, 2016a)), but does not report time spent in sedentary behaviours. However, the NZHS does indicate that New Zealand adults are becoming less active. There was a 3.4% increase between 2006/07 and 2016/17 in adults self-reporting they performed 'little to no physical activity' (New Zealand Ministry of Health, 2017). Indeed, in the 2015/16 NZHS 15% of adults performed less than 30 minutes of physical activity in the seven days prior to completing the survey, whilst 52% of all adults failed to meet the physical activity guidelines (New Zealand Ministry of Health, 2016a). Although these figures are alarming in themselves, physical inactivity is distinct from sedentary behaviour, and as a result, the NZHS does not provide insight into sedentary behaviours of the New Zealand population. However, reporting of inactivity may give some indication of the potential prevalence of sedentary behaviour.

Despite the short-comings of the NZHS in terms of sedentary behaviour reporting, sedentary behaviour may have been indirectly captured as part of the New Zealand Time Use Survey: 2009/10 (Statistics New Zealand, 2011). The New Zealand Time Use Survey reported time spent in both productive (i.e., paid and unpaid work, such as household and labour force activities) and leisure (including screen time, socialising and sports) activities. New Zealand adults spent >2 hours per day in two particular sedentary screen time behaviours: watching television and videos (Statistics New

Zealand, 2011). Although females increased the time spent watching television by 10 min·day⁻¹ (8% increase from 1998/99), there were no differences between females and males in the amount of time spent engaged in sports and exercise (Statistics New Zealand, 2011). Collectively, data from the New Zealand Time Use Survey and the NZHS suggest that there has likely been an increase in sedentary behaviour, in recent times. New Zealanders over the age of 12 years spent more than 80% of their leisure time in potentially sedentary activities; >4.5 hours each day were spent on television or video watching, socialising and conversation, and reading and writing (Statistics New Zealand, 2011). Although these behaviours are typically considered sedentary (Ainsworth et al., 2011), it is important to distinguish whether or not the context of these activities is truly sedentary behaviour. For instance, body position during socialising and the amount of movement occurring whilst playing computer and video games might affect the classification of these sedentary behaviours (Ainsworth et al., 2011).

2.4.1 Age

The amount of time spent participating in different activities varies largely by age group and life stage (New Zealand Ministry of Health, 2014). Contributing to this variation is level of commitments (or lack thereof) to work, school, child care, and household activities (Statistics New Zealand, 2011). Coupled parents in their prime working age (25-44 years) each spent an average of 4 hours and 20 minutes per day on household and child care duties and spent similar amounts of time in paid and un-paid work as middle-aged people (45-64 years) (Statistics New Zealand, 2011). Therefore, prime working aged people, likely have less time to spend in sedentary behaviours such as media and social entertainment than those in other groups (younger or older people) without the combined responsibility of young children and paid and un-paid work. This suggestion is supported by findings from the New Zealand Time Use Survey which show that prime working aged adults (25-44 years) spend the least amount of time on mass media and free time (Statistics New Zealand, 2011). Younger adults spend more time in potentially sedentary activities and also had decreased

participation rates in physical activity between 2006/07 and 2013/14 (from 56% to 51%) (New Zealand Ministry of Health, 2014). Young people spent more than double the amount of time (i.e., they spend 1 hour 15 minutes per day), than prime working age and middle aged people, on largely non-sedentary activities such as sports and hobbies (Statistics New Zealand, 2011). In contrast, older adults spent the majority of the day on potentially sedentary activities, such as mass media (almost 5 hours per day) compared to those aged 25-65 years (2.5 – 3 hours per day) (Statistics New Zealand, 2011). Surprisingly though, older adults have also increased participation rates in physical activity (from 34% to 42%) (New Zealand Ministry of Health, 2014). Although these findings could be indicative of increased sedentary behaviour in younger adults and decreased sedentary behaviour among older adults, it may not necessarily be the case; less physical activity cannot be directly extrapolated to an increase in sedentary behaviours.

2.4.2 Gender

Participation in physical activity is not consistent across genders in New Zealand. More women (76%) participate regularly (at least once per week) in sport and recreation activities compared to men (72%), but fewer women (45%) than men (51%) meet physical activity guidelines (New Zealand Ministry of Health, 2016a; Sport New Zealand, 2015). Participation in physical activity among New Zealand adults and between genders did not change significantly between 2006/07 and 2013/14 (New Zealand Ministry of Health, 2014). Amongst adults who do participate in physical activity, participation time was similar between males (2 hours 13 minutes) and females (2 hours 5 minutes) (Statistics New Zealand, 2011). Males spent the majority of their free time engaged in sports and hobbies and mass media (average 2 hours 22 minutes per day), whereas females spent more time on social entertainment, especially socialising with others (1 hours 16 minutes per day) (Statistics New Zealand, 2011). Within socialising and mass media entertainment activities (e.g., screen time such as television and computer) potential exists for these to be either sedentary or non-sedentary behaviours. Therefore, it is unclear in this circumstance whether time spent on mass media and

socialising should be considered sedentary non-sedentary behaviour. Other non-work activities that contribute to significant non-sedentary time are household work and home and garden maintenance. Females spent almost 4.5 hours on unpaid household work while men spent about 2.5 hours per day on home and garden maintenance (Statistics New Zealand, 2011).

2.5 Impact of sedentary behaviours on health outcomes

Large amounts of sedentary behaviour are associated with adverse health outcomes, which may be independent of the time spent in physical activity (Craft et al., 2012; de Rezende, Lopes, Rey-Lopez, Matsudo, & Luiz, 2014; Healy, Dunstan, Salmon, Cerin, et al., 2008; Healy, Dunstan, Salmon, Shaw, et al., 2008; Wilmot et al., 2012). Wilmot et al. (2012) found that the relative risk for T2DM and CVD was more than doubled when people spent large amounts of time being sedentary. However, the relationship between sedentary behaviour and negative health outcomes is made complex because it is dependent on the types of sedentary activities and the age group under investigation (de Rezende et al., 2014). For instance, strong evidence exists for the association between leisure time sedentary behaviour and obesity in children and adolescents but evidence is less clear in adults (de Rezende et al., 2014). In contrast, there is strong evidence in adults for an association between T2DM and leisure time television viewing (de Rezende et al., 2014), but little evidence for a relationship of T2DM in occupational sedentary behaviour (Stamatakis et al., 2017). To further complicate the issue of increased disease risk with sedentary behaviour, evidence supporting the association between negative health outcomes and occupational sitting specifically, is lacking. Some studies reported that sitting time at work was not associated with negative health outcomes (Picavet et al., 2016; Stamatakis et al., 2017; van Uffelen et al., 2010). For example, Picavet et al. (2016) found that workers with sedentary jobs did not have an increased risk of negative health outcomes over 15 years, compared to those with non-sedentary jobs. This lack of relationship could be attributed to computer work contributing to a large proportion of activity performed while sitting in a 'sedentary job'; Mansoubi et al. (2015) found that typing while sitting exceeded the ≤ 1.5 MET

threshold defining sedentary behaviour. Therefore, the small amount of increased energy expenditure associated with the seemingly sedentary activity of computer work may be sufficient to provide some degree of protection from chronic diseases such as T2DM and CVD (Hagger-Johnson, Gow, Burley, Greenwood, & Cade, 2016).

2.5.1 Obesity

Body mass index (BMI) is often used to classify individuals as overweight or obese, determined by dividing body weight in kilograms by height in metres squared. The New Zealand Ministry of Health (NZMOH) (New Zealand Ministry of Health, 2016a) defines obesity in adults (≥ 18 years) as a BMI of $\geq 30 \text{ kg}\cdot\text{m}^{-2}$. Overweight and obesity are major risk factors for disability, depression, T2DM, CVD, and mortality (Hruby & Hu, 2015). BMI classifications of weight status are consistent across all ages and genders but may correspond to different body fat percentages in some population groups (Sloan, 2016). For example, interpretation of health risks with different BMI's may be necessary when there are differences in the population such as high muscularity, tall stature ($>190 \text{ cm}$) and short stature ($<150 \text{ cm}$) (Sloan, 2016). Within New Zealand and around most of the world, the recommended BMI thresholds for healthy, overweight and obese are 20, 25 and $30 \text{ kg}\cdot\text{m}^{-2}$, respectively (New Zealand Guidelines Group, 2012; New Zealand Ministry of Health, 2016b; World Health Organisation, 2000).

2.5.1.1 Obesity prevalence in New Zealand

High BMI is the leading cause of health loss in New Zealand and was responsible for 9% of illness, disability, and early death 2015 (New Zealand Ministry of Health, 2016a). Overweight is a major contributing factor to T2DM, CVD and a variety of other non-communicable diseases, including osteoarthritis and sleep apnoea (New Zealand Ministry of Health, 2016a). Obesity prevalence among New Zealand adults was 32.2% in 2016/17; an increase from 27% over the previous 10 years (New Zealand Ministry of Health, 2017). Obesity is most common in middle age; 36% of 45-64 year old New Zealanders are classified as obese compared to only 28% of older adults (75 years and above)

and 11% of children aged 2-14 years (New Zealand Ministry of Health, 2017). Although the prevalence of obesity is slightly higher amongst women, there is no significant difference in prevalence of obesity between genders in New Zealand (New Zealand Ministry of Health, 2016a).

2.5.1.2 Associations between sedentary behaviour and obesity

Evidence for an association between time spent in sedentary behaviour and obesity in adults is unclear (Biddle et al., 2017; Keating et al., 2016; Pulsford, Stamatakis, Britton, Brunner, & Hillsdon, 2013; Van Dyck et al., 2015). Biddle et al. (2017) found that breaks in sedentary behaviour, rather than accumulated time spent in sedentary postures, had the strongest associations with weight status. These findings were supported by Healy et al. (2011) who reported that participants who took more breaks during sedentary bouts had a smaller waist circumference than those who took the least number of breaks. Chastin et al. (2015) also reported a negative association between measures of obesity (e.g., waist circumference and BMI) and number of breaks in sedentary time, independent of overall sedentary time. In a review of systematic reviews (Biddle et al., 2017), it was concluded that there may be a higher risk of adulthood obesity or high BMI when sedentary behaviour was excessive during adolescence and childhood. However, there is no evidence to suggest a causal link between sedentary behaviour and overweight/obesity in adults (Biddle et al., 2017). Nevertheless, Drenowatz et al. (2015) reported that overweight and obese adults expended a higher percentage of energy in sedentary and light activities and a significantly lower proportion of energy in moderate to vigorous physical activity compared to normal weight adults (Drenowatz et al., 2015). Healy et al. (2008) found a significant positive dose dependent association between the amount of time spent watching television and waist circumference. Television time was also negatively associated with systolic blood pressure, fasting and 2-h plasma glucose, triglycerides, and HDL-cholesterol. Another study found that the strength of the association between sedentary behaviour and BMI varied depending on the time spent participating in physical activity (Dunton, Berrigan, Ballard-Barbash, Graubard, & Atienza, 2009), suggesting that physical activity might

counteract some of the negative effects of excessive sedentary behaviour. The conflicting results indicate a lack of clear understanding of the relationship between sedentary behaviour and obesity in adults, but rather that a combination of genetic, behavioural, socioeconomic and environmental factors contribute to overweight and obesity (Hruby & Hu, 2015).

2.5.2 Metabolic disease

Metabolic disease is a disruption to the body's chemical processes that participate in energy metabolism (Miller-Keane & Marie T. O'Toole, 2003). Metabolic diseases are acquired when there is disease in an endocrine organ, such as the pancreas (Farlex Partner Medical Dictionary, 2012). Metabolic syndrome is an acquired metabolic disease, involving a cluster of CVD risk factors along with insulin resistance (DeFronzo & Ferrannini, 1991). Risk factors for metabolic syndrome include central obesity and insulin resistance (Grundy, Brewer, Cleeman, Smith, & Lenfant, 2004). T2DM is an acquired metabolic disease involving high blood sugar and insulin resistance. Risk factors for T2DM include obesity, physical inactivity, insulin resistance, hyperinsulinemia, high blood pressure, and high cholesterol (Fletcher, Gulanick, & Lamendola, 2002). The mechanisms involved in metabolic syndrome mean that non-communicable diseases such as T2DM and CVD are closely related through a positive feedback loop involving high cholesterol, high blood pressure, high insulin, and insulin resistance (Boehme, Esenwa, & Elkind, 2017; Daviglius & Stamler, 2001; DeFronzo & Ferrannini, 1991).

2.5.2.1 Metabolic disease prevalence in New Zealand

Risk factors for metabolic diseases include obesity, insulin resistance, high blood pressure, high cholesterol, and along with T2DM are very common in New Zealand, with 5.5% of the population diagnosed with diabetes (New Zealand Ministry of Health, 2014). Prevalence of high blood pressure is increasing in New Zealand with 16.3% of adults reporting high blood pressure, compared with 14% in 2006/07 (New Zealand Ministry of Health, 2017). During the 2016/17 NZHS, one in ten New

Zealand adults received treatment for high cholesterol (New Zealand Ministry of Health, 2017). There was a significant increase (3.2% increase) in the prevalence of high cholesterol, with an overall rate of 11.5% among New Zealand adults, between the 2006/07 and 2016/17 NZHS (New Zealand Ministry of Health, 2017)

2.5.2.2 Associations between sedentary behaviour and metabolic diseases

Strong evidence for an association between sedentary behaviour and metabolic diseases, such as T2DM and metabolic syndrome have been repeatedly reported (de Rezende et al., 2014; Edwardson et al., 2012; Ford, Kohl, Mokdad, & Ajani, 2005; Healy, Dunstan, Salmon, Shaw, et al., 2008; Healy et al., 2011; van Uffelen et al., 2010; Wilmot et al., 2012; Young et al., 2016). Individuals with high sedentary behaviour (<2 hours per week of activity ≥ 3 METs) were twice as likely to suffer T2DM than active individuals (≥ 22 hours per week of activities ≥ 3 METs) (Rana, Li, Manson, & Hu, 2007). Similarly, prolonged sitting time (including while watching television and when in automobiles) was related to compromised metabolic health (e.g., waist circumference, systolic blood pressure, triglycerides, HDL-cholesterol, 2-h plasma glucose, fasting plasma glucose, and fasting insulin) (Ford et al., 2005; Healy, Dunstan, Salmon, Shaw, et al., 2008; Healy et al., 2011) and increased the risk of premature mortality (Owen, 2012). Findings suggest that these associations could be attributed to a combination of decreased energy expenditure and increased energy intake, which is often paired with television watching (Ford et al., 2005). Decreased energy expenditure has an effect on energy balance, increasing body weight, blood pressure, triglyceride concentrations, blood glucose concentrations, and decreasing HDL-cholesterol (Ford et al., 2005). Since these factors all contribute to metabolic syndrome, increasing sedentary behaviour may increase the risk of metabolic syndrome (Ford et al., 2005). Healy et al. (2008; 2011) reported similar outcomes in Australian and North American adults, with high total sedentary time associated with a decrease in HDL-cholesterol, beta cell function, insulin sensitivity, and an increase in C-reactive protein, triglyceride

concentration, and waist circumference. In contrast, there is little evidence to suggest that occupational sitting time results in T2DM in the long term (13 years) (Stamatakis et al., 2017).

2.5.3 Cardiovascular disease

CVD is the collective term for a number of conditions related to the heart and blood vessels, including hypertension, coronary heart disease, and stroke (World Health Organisation, 2017, 2018). Hypertension is most commonly contributed to by one or more factors including high cholesterol and obesity (Andalib et al., 2012), excessive sodium intake (Savica, Bellinghieri, & Kopple, 2010), inadequate potassium intake (Mente et al., 2014), physical inactivity (Lesniak & Dubbert, 2001), and excess alcohol consumption (Klatsky, 2010). Coronary heart disease is a disease of the blood vessels that supply blood to the heart muscle and can lead to heart attack (World Health Organisation, 2017, 2018). Major risk factors for coronary heart disease include high cholesterol, high blood pressure, and smoking (Daviglius & Stamler, 2001). Stroke is caused by a disease of the blood vessels supplying blood to the brain, and is also known as cerebrovascular disease (World Health Organisation, 2017, 2018). Risk of stroke is increased by high blood pressure, high cholesterol, physical inactivity, and smoking (Boehme et al., 2017).

2.5.3.1 Cardiovascular disease prevalence in New Zealand

CVD is the leading cause of death in New Zealand, with 33% of deaths annually associated with the disease (New Zealand Ministry of Health, 2015b). In 2016/17, one in six adults (16.3%) received treatment for high blood pressure (New Zealand Ministry of Health, 2017), an increase of 2.3% from 2006/07 (New Zealand Ministry of Health, 2017). Coronary heart disease was the second most common cause of death in New Zealand in 2011 (New Zealand Ministry of Health, 2015b); one in twenty adults (4.6% of the population) self-reported a diagnosis of coronary heart disease (New Zealand Ministry of Health, 2015c). In 2015/16 1.5% of older reported having had a stroke in their life (New Zealand Ministry of Health, 2016a). As age is a non-modifiable risk factor for stroke, older

people are more likely to have had a stroke than younger people (New Zealand Ministry of Health, 2015b). Surprisingly, 64% of adults who reported having had a stroke were under the age of 75 years (New Zealand Ministry of Health, 2016a).

2.5.3.2 Associations between sedentary behaviour and cardiovascular diseases

Sedentary behaviour is strongly associated with increased CVD risk and has been reported as being independent of time spent in moderate to vigorous physical activity (Chomistek et al., 2013; de Rezende et al., 2014; Green et al., 2014; Healy, Dunstan, Salmon, Shaw, et al., 2008; Healy et al., 2011; Petersen et al., 2014; Proper, Singh, van Mechelen, & Chinapaw, 2011; van Uffelen et al., 2010; Wilmot et al., 2012; Young et al., 2016). Women meeting the physical activity guidelines had a higher risk of CVD if they also reported sitting for extended periods of time (i.e., ≥ 10 hour per day) compared to shorter periods (≤ 5 hours per day) (Chomistek et al., 2013). In a study of young adult women, time spent in sedentary behaviour was significantly associated with increased triglyceride concentration and lipid accumulation (Green et al., 2014). Clinically meaningful differences in triglyceride concentration and insulin resistance have been reported between adults spending the least versus the most amount of time in sedentary activities (Healy et al., 2011). Significant associations have also been reported between specifically television viewing time and high systolic blood pressure (Healy, Dunstan, Salmon, Shaw, et al., 2008). Conversely, a study investigating occupational activities found no association between occupational sitting time and hypertension or hypercholesterolemia (Picavet et al., 2016). A systematic review that also looked at occupational sitting and disease risk found conflicting results (van Uffelen et al., 2010). While four studies showed an increased risk of CVD with increased occupational sitting time, a further three studies reported no such association. One of the studies even showed that increased occupational physical activity was linked to a greater risk of CVD (van Uffelen et al., 2010). Some studies have reported that certain activities, such as sitting while typing, which is typically considered sedentary and is commonly associated with sedentary occupations, are not always within the 1.5 MET energy expenditure

threshold of sedentary behaviour (Mansoubi et al., 2015). This discrepancy might explain conflicting results between studies examining specific domains of sedentary behaviour.

2.6 Lifestyle interventions to decrease sedentary behaviour

Any effect on health cannot be attributed solely to reduced sedentary behaviour but is also affected by an increase in movement (Biddle et al., 2017). Thus, physical activity guidelines in New Zealand and many other countries recommend spending more time in active behaviour and less time in sedentary activities (Department of Health and Social Care UK, 2010; New Zealand Ministry of Health, 2015a; U.S. Department of Health and Human Services, 2018). As sedentary behaviour and physical inactivity are distinct from one another, many authors have suggested that even when physical activity guidelines are met, prolonged sitting still contributes to adverse health outcomes (de Rezende et al., 2016; Ford et al., 2005; Owen et al., 2010).

2.6.1 *Breaking up sedentary time*

Independent of time spent in sedentary activities, interrupting sedentary behaviour with short bouts of light physical activity results in positive changes to markers of disease risk (Chastin et al., 2015; Dunstan et al., 2012; Duvivier et al., 2013; Ford et al., 2005; Healy, Dunstan, Salmon, Cerin, et al., 2008; Healy et al., 2011; Owen et al., 2010; Peddie et al., 2013; Young et al., 2016). Specifically, disruptions to sedentary time have been associated with improvements in body composition (Chastin et al., 2015; Healy, Dunstan, Salmon, Cerin, et al., 2008; Healy et al., 2011), glucose and insulin concentrations (Chastin et al., 2015; Dunstan et al., 2012; Green et al., 2014; Healy, Dunstan, Salmon, Cerin, et al., 2008; Healy et al., 2011; Peddie et al., 2013; Young et al., 2016), triglycerides (Green et al., 2014; Healy, Dunstan, Salmon, Cerin, et al., 2008), and C-reactive protein (Healy et al., 2011). For example, breaking up nine hours of sitting time with 18 active breaks of 100 seconds (total 30 minutes; 5.5% of sitting time) resulted in reduced post prandial glucose and insulin concentrations (Peddie et al., 2013). Similar improvements to those markers were also seen when 5

hours of sitting was broken up with 14 active breaks of 120 seconds (total 28 minutes; 9.3% of sitting time) (Dunstan et al., 2012).

2.6.2 Reducing sedentary time

Such is the impact of sedentary behaviour on metabolic health that Ford et al. (2005) suggested that if adults reduced their screen time to <1 hour per day the prevalence of metabolic syndrome in the United States could be reduced by ~30-35%. Furthermore, Green et al. (2014) reported that cardiorespiratory fitness (VO_{2peak}) is an important factor in reducing the effect of sedentary behaviour on cardiometabolic risk, especially blood lipid concentrations and insulin resistance. Therefore, these authors suggested that interventions to reduce cardiometabolic disease risk should focus not only on decreasing sedentary behaviour and increasing physical activity but also on increasing VO_{2peak} through increased cardiorespiratory fitness. Green et al. (2014) also found that body composition could be an important factor contributing to insulin resistance in young women, a factor that is improved by reduced sedentary behaviour (Healy, Dunstan, Salmon, Cerin, et al., 2008) and increased physical activity (Dunton et al., 2009).

Since time per day is finite, a decrease in the amount of time spent in sedentary behaviour translates to a corresponding increase in an alternate activity (Biddle et al., 2017; Ekblom-Bak, 2016). For example, if a person reduced the time spent sitting relaxing or watching television, that time must be replaced by something else, such as standing or cooking. Substitution of sitting time for standing or light physical activity, such as walking or pedalling, markedly reduced insulin levels (Han et al., 2018), and also resulted in a reduction in C-peptide, triglycerides, total cholesterol, non-HDL-cholesterol, HOMA-IR, and apo B concentrations in adults (Duvivier et al., 2018; Duvivier et al., 2013) and young women (Green et al., 2014). These data suggest that in order to maintain good cardiometabolic health, sedentary time should be decreased whilst also increasing light physical activity.

For some activities, it is possible to perform the same tasks in a range of body positions (Biddle et al., 2017). For instance, computer work, speaking on the phone and watching television can all be done in either seated or standing positions, demonstrating that many common sedentary tasks may be undertaken in non-sedentary positions. The idea of performing traditionally sedentary tasks in non-sedentary positions or even light-intensity physical activity has already led to innovations such as standing and treadmill desks (Biddle et al., 2017). These simple substitutions in posture may be sufficient to have positive effects on health, independent of the amount of moderate to vigorous physical activity performed (Wilmot et al., 2012).

2.6.3 Fidgeting

Small movements of the hands and feet, commonly referred to as fidgeting, (Soanes & Stevenson, 2003) have been shown to increase energy expenditure (Hagger-Johnson et al., 2016), and therefore may reduce the risk of all-cause mortality associated with large amounts of sedentary behaviour (Dempsey et al., 2015; Hagger-Johnson et al., 2016). In a cohort study of women, there was a 30% increase in the risk of mortality in those who sat for ≥ 7 hours per day compared to those who sat for < 5 hours, but only among those who did not fidget (Hagger-Johnson et al., 2016). In those women who fidgeted there was no associated increase in mortality risk with longer periods of sitting (Hagger-Johnson et al., 2016). This result suggests that fidgeting, and its associated small increase in energy expenditure, could mitigate some of the negative consequences associated with increased sitting time. The evidence is supported by previous studies which have shown that occupational sedentary behaviour, which often includes sitting at a desk typing (similar to common fidgeting movements), is not associated with T2DM (Stamatidis et al., 2017), hypertension or hypercholesterolemia (Picavet et al., 2016). Increasing small movements or fidgeting behaviours could be used as a simple intervention for reducing the negative impact of sedentary behaviour on disease risk.

2.6.4 Public health initiatives

Although reducing sedentary behaviour likely means an increase in physical activity, it appears that interventions solely focusing on reducing sedentary time, are more effective than providing strategies which attempt to decrease sedentary time and increase physical activity simultaneously (Young et al., 2016). Initiatives that have focused on increasing population participation in physical activity during leisure time have had only modest successes (Heath et al., 2012). In contrast, there is consistent evidence to show interventions aimed at sedentary behaviour can reduce sedentary time at levels that are clinically meaningful (Prince, Saunders, Gresty, & Reid, 2014). In order to reduce premature mortality worldwide, it is important to promote active lifestyles by encouraging sustainable reductions in sitting time (de Rezende et al., 2016).

Australia and Canada have developed specific Sedentary Behaviour Guidelines (The Department of Health, 2017; Tremblay et al., 2016) which are distinct from the widely available physical activity guidelines set out in many countries (Department of Health and Social Care UK, 2010; New Zealand Ministry of Health, 2015a; U.S. Department of Health and Human Services, 2018; World Health Organisation, 2004). The Canadian guidelines from the Canadian Society for Exercise Physiology recommend limiting leisure time screen activities to ≤ 2 hours per day and restricting sedentary (motorised) transport, extended sitting, and time spent indoors (Tremblay et al., 2016). The Australian Sedentary Behaviour Guidelines (The Department of Health, 2017) and New Zealand Eating and Activity guidelines (New Zealand Ministry of Health, 2015a) recommend limiting time spent sitting each day and interrupting prolonged sitting as much as possible.

2.7 Summary

Sedentary behaviour is strongly and positively associated with non-communicable diseases (metabolic diseases and CVD) and other negative health consequences such as obesity. Rather than

targeting physical activity for public health initiatives, the interest in sedentary behaviour is increasing as a positive step to improving these negative health outcomes. There is growing evidence to support relationships between various sedentary behaviours (such as screen time during work and leisure) and disease outcomes or biochemical markers of disease. Sedentary behaviour in different contexts (i.e., television viewing during leisure and occupational sitting) often present different associations with risk of disease. However, there is no research investigating the different types of sedentary behaviours and associations with health outcomes in New Zealand women. It is important to understand disease risk associations with different postures of sedentary behaviour to establish specific sedentary behaviour guidelines and interventions to improve health outcomes. Objectively measured sedentary behaviour with precise postural classifications will help to accurately define different types of sedentary behaviour. This will allow for investigation of the association between different sedentary postures and anthropometric and metabolic markers of disease risk.

Chapter 3: Research Study Manuscript

3.1 Abstract

There is evidence to suggest that sedentary behaviour has a negative impact on the risk of some non-communicable diseases, however associations differ within different contexts (e.g., leisure time, occupational). The current study examined the association between different types of sedentary behaviour and disease risk, in women, using objectively measured sedentary data.

Methods: The study was conducted in two parts. A validation study ($n = 20$) used direct observation and objective measurement of common sedentary behaviours (e.g., reclining, sitting and sitting typing) to classify sedentary behaviour into four categories: lying down; sitting (non-active); sitting (active); standing. In a cross-sectional study of healthy women ($n = 348$, age = 16-45 years) accelerometer-derived sedentary behaviour classifications were correlated with body composition, metabolic, inflammatory and blood lipid variables, from the women's EXPLORE study.

Results: Participants spent an average of 7 hours 42 minutes per day in sedentary behaviour. Of the time spent sedentary, 58% was classified as non-active sitting and 26% as active sitting. Non-active sitting showed weak positive correlations with BMI ($r = 0.244$, $p \leq 0.001$), body fat percent ($r = 0.216$, $p \leq 0.001$), body mass ($r = 0.236$, $p \leq 0.001$), waist:hip ($r = 0.141$, $p = 0.009$), fat mass ($r = 0.241$, $p \leq 0.001$), insulin ($r = 0.160$, $p = 0.003$), leptin ($r = 0.237$, $p \leq 0.001$), systolic and diastolic blood pressure ($r = 0.137$, $p = 0.010$ and $r = 0.135$, $p = 0.011$), and weak negative correlations with HDL-cholesterol ($r = -0.117$, $p = 0.031$). Conversely, active sitting was weakly negatively correlated with BMI ($r = -0.300$, $p \leq 0.001$), body fat percent ($r = -0.249$, $p \leq 0.001$), body mass ($r = -0.305$, $p \leq 0.001$), waist:hip ($r = -0.164$, $p = 0.002$), fat mass ($r = -0.320$, $p \leq 0.001$), insulin ($r = -0.180$, $p = 0.001$), leptin ($r = -0.259$, $p \leq 0.001$), and weakly positively correlated with HDL-cholesterol ($r = 0.115$, $p = 0.035$).

Conclusion: The current study demonstrates a positive association between active sitting and reduced risk of disease. It provides a new focus for the development of public health initiatives and

sedentary behaviour guidelines by showing that different types of sedentary behaviours might have different effects on markers of disease risk.

3.2 Introduction

Large amounts of sedentary behaviour have recently been linked with adverse health outcomes, independent of time spent in physical activity (Craft et al., 2012; de Rezende et al., 2014; Ford et al., 2005; Healy, Dunstan, Salmon, Shaw, et al., 2008; Healy, Wijndaele, et al., 2008; Owen et al., 2010; Wilmot et al., 2012). It is estimated that adults spend between 8 and 11 hours (55-70%) of the waking day in sedentary behaviour (An et al., 2017; Dempsey et al., 2015; Gupta et al., 2016; Peterson et al., 2015). Increases in sedentary behaviour through automation of transport, communications, work place productivity, and entertainment (Dempsey et al., 2015) mirror the rise in obesity rates (Hruby & Hu, 2015; Lanningham-Foster, Nysse, & Levine, 2003). Other non-communicable diseases associated with sedentary behaviour, such as metabolic syndrome, T2DM and CVD (Chomistek et al., 2013; de Rezende et al., 2014; Edwardson et al., 2012; Ford et al., 2005; Healy, Dunstan, Salmon, Shaw, et al., 2008; Petersen et al., 2014; Proper et al., 2011; van Uffelen et al., 2010; Wilmot et al., 2012) have also concurrently risen, suggesting a possible link between sedentary behaviour and these diseases (Bhatnagar, Wickramasinghe, Wilkins, & Townsend, 2016; Garcia, Mulvagh, Merz, Buring, & Manson, 2016; Moore, Chaudhary, & Akinyemiju, 2017; Ranasinghe, Mathangasinghe, Jayawardena, Hills, & Misra, 2017).

Sedentary behaviour is often performed as occupational sitting (Gupta et al., 2016; Hagger-Johnson et al., 2016; Picavet et al., 2016; Pulsford et al., 2013; Stamatakis et al., 2017; van Uffelen et al., 2010) and during leisure time (e.g., television viewing) (Biswas et al., 2015; Healy, Dunstan, Salmon, Shaw, et al., 2008; Machado-Rodrigues et al., 2015; Matthews et al., 2012; Owen, 2012; Pulsford et al., 2013; Stamatakis, Hamer, & Dunstan, 2011; Stamatakis et al., 2017; Wijndaele et al., 2011). Despite strong evidence for associations between sedentary behaviour and disease risk, the associations in different contexts of sedentary behaviour (e.g., occupational or leisure time) are contrasting (Hagger-Johnson et al., 2016; Healy, Dunstan, Salmon, Shaw, et al., 2008; Owen et al., 2010; Picavet et al., 2016; van Uffelen et al., 2010). Leisure time sedentary behaviour is often

associated with increased risk of disease (Healy, Dunstan, Salmon, Shaw, et al., 2008; Owen et al., 2010), whereas little evidence exists for occupational sedentary behaviour (Picavet et al., 2016; van Uffelen et al., 2010). Contrasting associations between leisure and occupational sedentary behaviour may particularly relate to sitting, since different energy expenditure estimates have been reported between sitting typing and sitting watching television (Mansoubi et al., 2015). This difference indicates that different types of sedentary behaviours should be examined separately, in order to better understand associations between various sedentary behaviours and disease risk indicators.

The purpose of the current study was to examine the association between different types of sedentary behaviours and indicators of disease risk in a sample of New Zealand women using data from the women's EXPLORE study (Kruger et al., 2015). The women's EXPLORE study collected body composition, metabolic disease risk, inflammatory, and lifestyle data from New Zealand European, Māori, and Pacific women. Data was used to investigate predictors of body fat profiles in young New Zealand women (Kruger et al., 2015). For the current study, in order to examine different types of sedentary behaviour an algorithm was required to classify objectively measured sedentary postures (e.g., reclining, sitting, and sitting typing) into different sedentary behaviour categories (e.g., non-active sitting and active sitting). These categories were then used to examine the amount of time spent in the different sedentary behaviour categories and associations with body composition (indicating overweight and obesity) and markers of metabolic and cardiovascular diseases.

3.3 Methods

Data presented in this report were collected in two parts. A validation study ($n = 20$) was conducted to categorise posture and accelerometer counts, based on direct observation of various sedentary postures and activities. These categories were then applied to cross-sectional accelerometer data of New Zealand women ($n = 348$) to determine time spent in types of sedentary behaviour (i.e., lying,

non-active sitting, active sitting, and standing) and associations with disease risk indicators of body composition, metabolic and cardiovascular variables.

3.3.1 Validation study

3.3.1.1 Participants

Twenty women between the age of 16 and 45 years (28 ± 9 years), were recruited in Auckland, New Zealand to participate in the validation study. Participants were included if they were post-menarche but pre-menopausal and were excluded if they were pregnant, lactating or diagnosed with a metabolic disorder. Ethical approval was gained from Massey University Human Ethics Committee and has been notified as low risk (ethics notification no. 400001832) and each participant gave written informed consent prior to participation. Participants were weighed to the nearest 0.1 kg using a digital scale (Seca, Birmingham, UK), and had their height measured to the nearest 0.1 cm using a stadiometer (Seca, Birmingham, UK).

3.3.1.2 Activity measurement

A triaxial accelerometer (Actigraph wGT3X+, Pensacola, FL, USA) was used to collect accelerometer/inclinometer data. One accelerometer was fitted on the right hip (on the mid axillary line) of participants, using an adjustable elastic strap (Bassett et al., 2014; Edwardson et al., 2016; Steeves et al., 2015). The hip worn accelerometer was used to match the data collection protocol of the women's EXPLORE study. The researcher directly observed all postures and activities during validation. Accelerometer data were collected at a frequency of 100 Hz.

Participants followed a predetermined randomised sequence of body postures/activities, each of which was first demonstrated by the researcher. Participants were asked to maintain each posture/activity for five minutes. A one-minute transition period between each activity was allowed. Descriptions of the postures/activities can be found in Table 3.1.

Table 3.1 Description of postures and activities

Posture/Activity	Environment	Posture classification
Lying supine	Examination table	Lying
Lying supine, with knees bent	Examination table	Lying
Lying right lateral side	Examination table	Lying
Lying left lateral side	Examination table	Non-active sitting*
Reclining	Examination table	Non-active sitting
Sitting	Chair	Non-active sitting
Sitting, with right leg crossed over the left knee	Chair	Non-active sitting
Sitting, with left leg crossed over the right knee	Chair	Non-active sitting
Sitting	Stool	Active sitting
Sitting, typing on a keyboard	Chair and desk	Active sitting
Standing		Standing
Standing, fidgeting with paper		Standing

Objectively measured pre-determined postures/activities used for classification of sedentary behaviours into categories (lying, non-active sitting, active sitting, and standing).

*(Lying left lateral side classified as non-active sitting because the posture/activity could not be differentiated from other postures/activities within the non-active sitting group based on accelerometer data).

3.3.1.3 Data Analyses

Raw accelerometer data were downloaded in 60 second epochs using ActiLife software (version 6.10.4, Pensacola, FL, USA) and further analysed in Matlab (R2013A, MathWorks, Natick, MA, USA). No differences in the activity counts were seen between postures, so classification was performed using the inclination counts for lying, sitting, and standing. These inclination counts were compared to actual observation and a classification scheme was developed to identify four sedentary activity categories, which were labelled lying, non-active sitting, active sitting, and standing (Tables 3.1 and 3.2). No differences could be found between activities within each category. The varying postures within each classification (e.g., standing vs standing fidgeting within standing classification) did not differ in activity or inclinometer counts. Using this classification scheme, the classification matched the observation 84% of the minutes.

Table 3.2 Classification of sedentary posture categories

Category of posture	Inclinometer-Lying	Inclinometer-Sitting	Inclinometer-Standing
Lying (cpm)	≥10		
Non-active sitting (cpm)	<10		<10
Active sitting (cpm)	<10	<30	≥10
Standing (cpm)	<10	≥30	≥10

Abbreviations: cpm, counts per minute.

3.3.2 Cross-sectional study

Detailed methods for this cross-sectional study have previously been published (Kruger et al., 2015). In summary, objectively measured physical activity data, body composition data and markers of metabolic and cardiovascular health were collected as part of the women’s EXPLORE study. Ethical approval was gained from Massey University Human Ethics Committee: Southern A, Reference No.13/13. Written informed consent was gained from each participant prior to data collection.

3.3.2.1 Participants

Participants included 406 women aged 16–45 years who identified with either Māori, Pacific or New Zealand European ethnicities. Women were recruited in Auckland, New Zealand via media articles, advertising, flyers and posters in the local vicinity, as well as through social media, emailing lists from Massey University, and through face-to-face contact with community liaisons. Participants were included if they were post-menarche but pre-menopausal and were excluded if they were pregnant, lactating or diagnosed with a metabolic disorder; these criteria were assessed using a screening questionnaire.

3.3.2.2 Activity Measurement

A triaxial accelerometer (Actigraph wGT3X+, Pensacola, FL, USA) was used to collect accelerometer/inclinometer data at 100 Hz during physical activity, sedentary behaviour and sleep, over a period of seven consecutive days. The accelerometer was fitted to the participant’s right hip

on the mid axillary line, attached by an adjustable strap. Instructions were given to participants, directing them to wear the accelerometer at all times (excluding water-based activities). Sedentary behaviour was defined as activities with <100 accelerometer counts per minute (Freedson et al., 1998; Pfister et al., 2017). Participants were excluded from the current study if they did not meet the criteria for accelerometer wear time of ≥ 10 hours per day on ≥ 4 week or weekend days. Non-wear time was determined by ≥ 60 continuous minutes of 0 counts per minute with an allowance of 1-2 minutes of activity during that time. Valid data were received from 348 women; women with insufficient ($n = 34$) or no data ($n = 24$) were excluded.

3.3.2.3 Demographic, anthropometric and biomarker data

Demographic data were collected from participants via a questionnaire at the beginning of the study. Detailed methodology of body composition measurements was published by Kruger et al. (2015). Waist circumference was measured to the nearest 0.1 cm using a metal Lufkin tape measure. Height was measured using a Harpenden stadiometer, to the nearest 0.1 cm. Body mass and body composition (body fat percentage and fat mass (kg)) were measured using air displacement plethysmography (BodPod, 2007A, Life Measurement Inc, Concord, CA; manufacturer supplied software V4.2+). BMI ($\text{kg}\cdot\text{m}^{-2}$) was calculated using body mass and height.

Details of the full methodology used for metabolic testing is described elsewhere (O'Brien et al., 2017). Briefly, a fasting venous blood sample was taken from each participant in the morning to test metabolic, cardiovascular and inflammatory markers. Blood was drawn into ethylene diamine tetra-acetic acid tubes and an aliquot of whole blood was frozen at -80°C for later analysis of glycated haemoglobin (HbA1c). The remainder was centrifuged and used to measure serum insulin using immunoassay, and cholesterol, HDL-cholesterol, triglyceride, and glucose using automated Dimension Vista. Total cholesterol to HDL-cholesterol ratio and low-density lipoprotein (LDL) cholesterol were calculated. Plasma levels of interleukin-6 (IL-6), interleukin-10 (IL-10), tumour

necrosis factor alpha (TNF- α), ghrelin, and leptin were measured using Milliplex immunoassay kits (Millipore Corp., Billerica, MD, USA). Blood pressure was measured using an automated blood pressure monitor (Riester Ri Champion, Rudolf Riester GmbH, Jungingen, Germany).

3.3.2.4 Energy intake

Energy intake was used as a covariate for markers of overweight and obesity in the analysis. Participants completed an online food frequency questionnaire (Houston, 2014). Total energy intake was calculated using data from the questionnaire and analysed through FoodWorks dietary analysis software (FoodWorks Professional 7; Xyris Software, Australia; New Zealand Food Composition Database).

3.3.2.5 Statistical analysis

Data were downloaded at 60 second epochs using ActiLife software (version 6.7.1, Pensacola, FL, USA). Sedentary behaviour classification codes identified in the validation study were applied to accelerometer data on a minute by minute basis using Matlab (R2013A, MathWorks, Natick, MA, USA). Each minute was first classified as either sleep, non-wear, or awake using the method in Barreira et al. (2015). All awake minutes <100 counts per minute were classified as sedentary (Troiano et al., 2008) and were further sorted into categories of lying, non-active sitting, active sitting, or standing based on the cut offs obtained from the validation study. Following this classification, the data were sorted into individual days to find the total amount of sedentary time for each day, as well as the total amount of time for each of the four classifications of sedentary behaviour.

Statistical analyses were carried out using SPSS Statistics 22 for Windows (SPSS, Inc., Chicago, IL). A paired 2-tailed T-test was performed to analyse the differences between time spent in the different categories of sedentary behaviour. In order to understand the relationship between different types

of sedentary behaviour and disease risk indicators, bivariate correlations (Pearson's) were performed for sedentary categories and all body composition and biomarker variables.

Sedentary time (total and by sub-categories) was an average of the recorded sedentary time (min) per valid day for each classification. Data are presented as mean (\pm SD) and correlation coefficients (significance). Significance for statistical analysis was set at $p < 0.05$ for all variables.

3.4 Results

Participants in the current study were 348 women (Māori, $n = 68$; Pacific, $n = 65$; New Zealand European, $n = 215$) with an average age of 32.6 ± 8.5 years. BMI range was 18.7-49.1 $\text{kg}\cdot\text{m}^{-2}$ and prevalence of overweight was 54.6%. Further participant characteristics are presented in Table 3.3.

Results of the classification scheme applied to the accelerometer data are shown in Table 3.4. On average, participants spent 7 hours and 42 minutes (\pm 1 hour and 12 minutes) engaging in sedentary behaviour. Of this time, the majority was spent in the non-active sitting classification (58%), followed by active sitting (26%). The remainder of the sedentary time was spent lying (9%) or standing (7%). There was a significant difference ($p < 0.001$) in the amount of time spent in the four different types of sedentary behaviour.

Table 3.3 Participant anthropometric and biomarker characteristics

	Mean	SD
Total energy intake (kJ)	9686.5	3417.3
<i>Anthropometric variables</i>		
BMI (kg·m ⁻²)	27.0	5.7
Body mass (kg)	75.1	16.3
Fat mass (kg)	25.3	9.0
Body fat (%)	33.4	8.0
Waist:Hip	0.8	0.1
<i>Biomarker variables</i>		
Insulin (mmol·L ⁻¹)	11.7	8.3
Serum glucose (mmol·L ⁻¹)	4.7	0.4
HbA1c (mmol·mol ⁻¹)	28.6	3.7
CRP (nmol·L ⁻¹)	3.9	3.2
IL-6 (pg·ml ⁻¹)	2.4	1.8
IL-10 (pg·ml ⁻¹)	14.8	12.9
TNF-a (pg·ml ⁻¹)	6.7	2.5
Leptin (µg·ml ⁻¹)	101.1	7.0
Ghrelin (pg·ml ⁻¹)	48.0	39.9
Systolic blood pressure (mmHg)	116.3	10.0
Diastolic blood pressure (mmHg)	73.0	8.3
Cholesterol (mmol·L ⁻¹)	4.6	0.9
HDL-cholesterol (mmol·L ⁻¹)	1.6	0.4
Triglycerides (mmol·L ⁻¹)	1.0	0.7
TC:HDL	3.1	0.9
LDL-cholesterol (mmol·L ⁻¹)	2.6	0.8

Abbreviations: BMI, body mass index; HbA1c, glycated haemoglobin; CRP, C-reactive protein; IL-6, interleukin 6; IL-10, interleukin 10; TNF-a, tumour necrosis factor alpha; HDL, high density lipoprotein; TC:HDL, total cholesterol to high density lipoprotein ratio; LDL, low density lipoprotein.

Table 3.4 Time spent in different types of sedentary behaviour

	Mean	SD
<i>Accelerometer derived variables (min)</i>		
Total sedentary time	464.2	72.8
Lying time	43.4	31.1
Sitting time non-active	269.0	75.9
Sitting time active	120.9	63.1
Standing time	30.8	12.5

3.4.1 Total sedentary behaviour

There were no correlations between total sedentary behaviour and any body composition variables or markers of metabolic disease. Total sedentary behaviour time was positively correlated with systolic blood pressure ($r = 0.118$, $p = 0.028$), but with no other CVD markers (Table 3.5). There were no significant associations between total sedentary time or sedentary postures with inflammatory markers.

3.4.2 Lying down

An average of 43 minutes (± 31 minutes) per day was spent lying down (Table 3.4). Positive, but weak, correlations were observed between lying time and body composition variables ($r = 0.111$ - 0.252 , $p \leq 0.05$), systolic and diastolic blood pressure ($r = 0.137$, $p = 0.011$ and $r = 0.120$, $p = 0.025$), and triglyceride concentration ($r = 0.142$, $p = 0.009$). Correlations with lying time were also weakly positive for insulin and leptin ($r = 0.173$, $p = 0.001$, and $r = 0.185$, $p = 0.001$), and negative for ghrelin ($r = -0.66$, $p = 0.002$).

3.4.3 Non-active sitting

Participants spent 4 hours and 30 minutes (± 1 hour and 18 minutes) non-active sitting, per day (Table 3.4). Positive, but weak, correlations were observed between non-active sitting and body composition variables ($r = 0.141$ – 0.244 , $p \leq 0.05$), insulin ($r = 0.160$, $p = 0.003$) and leptin ($r = 0.237$, $p \leq 0.000$). Weak correlations with non-active sitting were also positive for systolic and diastolic blood pressure ($r = 0.137$, $p = 0.010$ and $r = 0.135$, $p = 0.011$) and negative for HDL-cholesterol ($r = -0.117$, $p = 0.031$) (Table 3.5).

Table 3.5 Pearson's correlations of sedentary behaviour with anthropometric variables and biomarkers

	Total SB	Lying	Non-active sitting	Active Sitting	Standing
Age (years)	-0.150[#]	-0.187[†]	0.015	-0.075	-0.120[*]
Total energy intake (kJ)	-0.006	0.167[†]	-0.111[*]	0.039	0.029
<i>Markers of overweight/obesity</i>					
BMI (kg·m ⁻²)	0.044	0.232[†]	0.244[†]	-0.300[†]	-0.285[†]
Body mass (kg)	0.043	0.252[†]	0.236[†]	-0.305[†]	-0.277[†]
Body fat (%)	0.007	0.111[*]	0.216[†]	-0.249[†]	-0.290[†]
Fat mass (kg)	0.015	0.245[†]	0.241[†]	-0.323[†]	-0.320[†]
Waist:Hip	-0.012	0.067	0.141[#]	-0.164[†]	-0.258[†]
<i>Markers of metabolic diseases</i>					
Insulin (mmol·L ⁻¹)	0.065	0.173[†]	0.160[†]	-0.180[†]	-0.124[*]
Serum glucose (mmol·L ⁻¹)	-0.051	-0.001	0.023	-0.072	-0.079
HbA1c (mmol·mol ⁻¹)	-0.017	-0.064	-0.020	0.034	0.010
CRP (nmol·L ⁻¹)	-0.016	0.072	0.003	-0.034	-0.120[*]
IL-6 (pg·ml ⁻¹)	0.077	0.058	0.058	0.005	-0.072
IL-10 (pg·ml ⁻¹)	-0.018	0.013	-0.065	0.051	-0.003
TNF-α (pg·ml ⁻¹)	-0.034	-0.013	-0.055	0.039	-0.019
Leptin (ng·ml ⁻¹)	0.058	0.185[†]	0.237[†]	-0.259[†]	-0.267[†]
Ghrelin (pg·ml ⁻¹)	-0.050	-0.166[†]	-0.036	0.061	0.037
<i>Markers of cardiovascular disease</i>					
Systolic blood pressure (mmHg)	0.118[*]	0.137[*]	0.137[*]	-0.089	-0.039
Diastolic blood pressure (mmHg)	0.091	0.120[*]	0.135[*]	-0.098	-0.093
Cholesterol (mmol·L ⁻¹)	0.016	-0.045	-0.008	0.052	-0.013
HDL-cholesterol (mmol·L ⁻¹)	-0.043	-0.105	-0.117[*]	0.115[*]	0.147[#]
Triglycerides (mmol·L ⁻¹)	-0.017	0.142[#]	-0.005	-0.054	-0.150[#]
TC:HDL	0.031	0.044	0.084	-0.058	-0.153[#]
LDL-cholesterol (mmol·L ⁻¹)	0.030	-0.022	0.033	0.013	-0.038

Values are Pearson correlation coefficients. Abbreviations: SB, sedentary behaviour; BMI, body mass index; HbA1c, glycated haemoglobin; CRP, C-reactive protein; IL-6, interleukin 6; IL-10, interleukin 10; TNF-α, tumour necrosis factor alpha; HDL, high density lipoprotein; TC:HDL, total cholesterol to high density lipoprotein ratio; LDL, low density lipoprotein.

Significant correlations are in bold: * ($p < 0.05$); # ($p < 0.01$); † ($p < 0.005$)

3.4.4 Active sitting

Of the total sedentary time, only 2 hours (± 1 hour) was spent active sitting (Table 3.4). Negative, but weak, correlations were observed between active sitting and body composition variables ($r = -0.164$ - -0.323 , $p \leq 0.002$), insulin ($r = -0.180$, $p = 0.001$) and leptin ($r = -0.259$, $p \leq 0.000$). Weak correlations with active sitting time were positive for HDL-cholesterol ($r = 0.115$, $p = 0.035$) (Table 3.5).

3.5 Discussion

In the current study, we developed a specific classification algorithm using the dataset from the validation section of the current study, which provides a valuable tool for classifying types of sedentary behaviour in future studies. The classification allowed identification of four categories of sedentary behaviours (within the definition of <100 counts per minute) based on differences in inclinometer data. The classification algorithm provided 84% agreement between observed behaviours and accelerometer data and is comparable in accuracy to previous studies (Kozey-Keadle, Libertine, Lyden, Staudenmayer, & Freedson, 2011; Peterson et al., 2015; Wullems et al., 2017). Categories were applied to cross-sectional accelerometer data from the women's EXPLORE study in order to understand the implications of different types of sedentary behaviours on disease risk in a sample of New Zealand women. Through bivariate correlations we identified that active sitting (within the limits of sedentary behaviour i.e., <100 counts per minute) was inversely associated with markers of overweight and obesity, metabolic disorders and CVD risk. To the author's knowledge, this is the first study to report objectively measured types of sedentary behaviour and the associated indicators of disease risk.

Total sedentary time in the current study was not associated with overweight/obesity or with any markers of metabolic or CVD risk, with the exception of a positive correlation with systolic blood pressure. Many previous studies investigating associations between sedentary behaviour and markers of disease have used total sitting time as a surrogate for total sedentary behaviour,

producing some conflicting results. A 2012 meta-analysis (Edwardson et al.) of 10 cross-sectional studies found an increased risk of metabolic disease with increased sitting time. Furthermore, a large prospective women's health study (Chomistek et al., 2013) found that prolonged sitting was positively correlated with risk of CVD. Other studies have also found a positive correlation between sitting time and risk of CVD (Biswas et al., 2015; Ford & Caspersen, 2012; Wijndaele et al., 2011). The Whitehall II study (Pulsford et al., 2013), although reporting no association between sitting time and obesity, did find that prior obesity was related specifically to time spent watching television, but not to other types of sitting. All of the studies described above used self-reported total sitting time to estimate total sedentary behaviour, whereas in the current study total sedentary behaviour was objectively measured, and included all sedentary behaviours. The previously reported effects of total sedentary behaviour on markers of disease risk are likely dependent on the specific type of sedentary behaviour that contributed most to total sedentary time, a factor that cannot be determined from most previous studies. Without knowledge of the specific sedentary behaviours being performed, the positive effects of one behaviour (e.g., active sitting) may counteract the negative effects associated with other behaviours (e.g., non-active sitting). However, by objectively measuring sedentary behaviour and using the classification of total sedentary time into different behaviour categories we were able to elucidate these independent associations.

Unlike total sedentary behaviour, the categories of sedentary behaviour presented in the current study had clearly differing associations with health and disease risk. The major finding was that active sitting was inversely associated with disease risk. Active sitting appears to be most representative of occupational sitting time (e.g., working on a computer at a desk and/or typing), as opposed to leisure time sitting behaviours, such as watching television. This difference is likely due to the active sitting classification category used in the current study, which included sitting typing and sitting on a stool, but not sitting still or reclining (more common when sitting watching television). The finding of a negative association between active sitting and markers of non-

communicable diseases is supported by a cohort study (Hagger-Johnson et al., 2016) which reported a lower risk of mortality in women who fidget while sitting compared to those who do not. However, in other studies no association between occupational sitting and markers of cardiometabolic health (Picavet et al., 2016) and obesity (Pulsford et al., 2013; Stamatakis et al., 2017) have been reported. Whilst five of ten cross-sectional studies in a systematic review showed a positive relationship between occupational sitting and BMI, a further four studies reported no such association and only one reported a negative association (van Uffelen et al., 2010). Gupta et al. (2016) used accelerometers to measure both occupational and leisure time sitting, and also found that long bouts of sitting at work, but not during leisure time, were positively correlated with obesity. The difference in results between Gupta et al. (2016) and the current study may be that the current study reports all sitting-active time in one category, whereas Gupta et al. (2016) split sitting time into sitting at work and during leisure time. Within the bounds of sedentary behaviour, a more active sedentary task (e.g., sitting typing) is associated with reduced disease risk relative to performing a less active sedentary task (e.g., television watching).

While active sitting had generally positive effects on indicators of health in the current study, non-active sitting was associated with an increase in disease risk. Although previous studies have not defined types of sedentary behaviour in the same way as the current study, non-active sitting can be considered most closely related to sitting watching television. Time spent watching television has been used in previous studies as a predictor of total sedentary behaviour during leisure time. The association between non-active sitting and unfavourable markers of disease risk is supported by numerous studies (Biswas et al., 2015; Healy, Dunstan, Salmon, Shaw, et al., 2008; Machado-Rodrigues et al., 2015; Matthews et al., 2012; Owen, 2012; Pulsford et al., 2013; Stamatakis et al., 2011; Stamatakis et al., 2017; Wijndaele et al., 2011). The AusDiab study in adults without clinically diagnosed T2DM or heart disease, reported a dose-response association between television viewing time and markers of T2DM and CVD in men, an association that was even stronger in women (Healy,

Dunstan, Salmon, Shaw, et al., 2008; Owen, 2012). Increased television viewing time has been associated in multiple studies with increased CVD risk (Biswas et al., 2015; Matthews et al., 2012; Stamatakis et al., 2011; Wijndaele et al., 2011) and with metabolic disease risk in young women (Machado-Rodrigues et al., 2015). Furthermore, individuals with prior obesity were found to spend more time watching television than those of normal weight (Pulsford et al., 2013). In contrast, in a large 13-year cohort study (Stamatakis et al., 2017) there was limited evidence to suggest an association between television viewing time and diabetes. Overall, increased television viewing time is associated with negative health implications in the majority of research, and strategies to reduce this inactive sitting behaviour present a simple target for public health messaging.

This study is unique in that sedentary behaviour has not previously been classified according to both posture and activity type using objectively measured data. Furthermore, the use of these classifications to establish associations between different types of sedentary behaviour and disease risk has also not previously been performed. However, the current study has a number of limitations that must be acknowledged. The objective data was not accompanied by subjective data to provide context to the various types of sedentary behaviours, however the use of categories to classify sedentary behaviours may negate the need for such contextual understanding. The study was conducted in New Zealand women between the ages of 16 and 45 years, so finding may not be generalisable to some other population groups. As with any cross-sectional data, which provides a snapshot of the population in time, causation cannot be determined.

The current study highlights an interesting association, where objectively measured sedentary behaviour, towards the upper end of the sedentary range, might have positive effects on markers of non-communicable disease risk. Therefore, it is important to study this area of sedentary behaviour and its outcomes, in more depth. Future research should focus on objective measures of different types of sedentary behaviours and the associated disease risks. Taking the current findings into

consideration, a strong public health message can be assembled stating that even within sedentary behaviour, behavioural changes can be made to potentially reduce the population risk of non-communicable diseases. Active sitting made up only 26% of total sedentary behaviour. Therefore, messages to reallocate sedentary time from 'inactive' to 'active' sedentary behaviours may contribute to combatting the increase in prevalence of non-communicable diseases associated with excessive sitting.

3.6 Conclusion

Non-communicable diseases are increasing in prevalence worldwide. Results from the current study suggest that active sitting (e.g., sitting typing) might be beneficially associated with disease risk. These findings provide a new focus for the development of public health initiatives in that, along with current physical activity guidelines, key sedentary behaviour guidelines should be strongly considered. Further investigation of objectively measured sedentary behaviour is needed to better understand the long-term effects of different types of sedentary behaviour on disease risk indicators and disease outcome in order to reduce the burden of disease associated with excessive inactive sedentary behaviours.

Chapter 4: Conclusion and Recommendations

Large amounts of sedentary behaviour, especially during leisure time, are strongly linked to a number of prevalent non-communicable diseases such as metabolic syndrome, T2DM and CVD (de Rezende et al., 2014; Edwardson et al., 2012; Ford et al., 2005; Healy, Dunstan, Salmon, Shaw, et al., 2008; Healy et al., 2011; Petersen et al., 2014; Proper et al., 2011; van Uffelen et al., 2010; Wilmot et al., 2012; Young et al., 2016). The associations with markers of these diseases are complicated by the type and amount of sedentary behaviour being performed (de Rezende et al., 2014). Previous research investigating associations between sedentary behaviour and disease risk has not identified different types of sedentary behaviours beyond simple classification as either occupational (Picavet et al., 2016; Stamatakis et al., 2017; van Uffelen et al., 2010) or leisure time sitting. Furthermore, leisure time sedentary behaviour is often predicted by time spent watching television (Foley, Maddison, Jiang, Olds, & Ridley, 2011; Healy, Dunstan, Salmon, Shaw, et al., 2008; Machado-Rodrigues et al., 2015; Wijndaele et al., 2011). However, reported associations between occupational and leisure time sedentary behaviour, with disease risk, are conflicting (Hagger-Johnson et al., 2016; Healy, Dunstan, Salmon, Shaw, et al., 2008; Owen et al., 2010; Picavet et al., 2016; van Uffelen et al., 2010). Therefore, it is important to understand the different types of sedentary behaviour and their impacts on incident disease or disease risk. A clear understanding of the effects of different sedentary behaviours on markers of disease is needed in order to generate meaningful guidelines for sedentary behaviour. Such guidelines, to be used in conjunction with already accepted guidelines on physical activity (Department of Health and Social Care UK, 2010; New Zealand Ministry of Health, 2015a; U.S. Department of Health and Human Services, 2018) might be effective in reducing the prevalence and burden of non-communicable diseases, such as metabolic syndrome, T2DM and CVD, on modern society.

The current study was conducted in two parts. Firstly, a validation study was used to classify different sedentary postures/activities into categories using accelerometer counts and inclinometer data. Secondly, cross-sectional data were used to describe the relationship between different categories of sedentary behaviour and indicators of disease risk. Objectives of the validation study were to: 1) apply a classification algorithm to raw accelerometer data to differentiate between the various body postures during sedentary behaviours; and 2) to compare direct observation of predetermined activities and body postures to accelerometer data in order to calculate percentage agreement. Objectives for the cross-sectional part of the current study were to calculate the proportion of time spent in different sedentary postures and relate it to markers associated with disease risk.

A list of sedentary postures/activities which are common in a free-living environment was compiled. Activities included reclining, sitting with one leg crossed over the other at the knee, and sitting typing. The sedentary postures/activities were used in the validation study and were categorised into four different types of sedentary behaviour based on inclinometer data: lying; non-active sitting; active sitting; and standing. No standard list of sedentary postures/activities exists for validating objectively measured sedentary behaviour. Until a robust list is made available, studies validating accelerometers for use in measurement of sedentary behaviour will likely each have to compile their own list of sedentary postures, possibly compromising comparability between studies. The categories used for types of sedentary behaviours were chosen because they represented different contexts of sedentary behaviour. For example, active sitting included sitting typing, representative of computer work and often carried out during occupational sitting. Whereas non-active sitting represents sitting behaviours involving less movement and are often carried out during leisure time (e.g., sitting or reclining whilst watching television). Active sitting and non-active sitting were chosen as distinct sedentary behaviour categories because occupational sitting is not associated with the adverse disease risks reported for leisure time sedentary behaviour (Hagger-

Johnson et al., 2016; Healy, Dunstan, Salmon, Shaw, et al., 2008; Owen et al., 2010; Picavet et al., 2016; van Uffelen et al., 2010). In addition, it has been found that sitting typing, commonly found in occupational sedentary behaviour, exceeds 1.5 METs (part of the definition of sedentary behaviour) in many people (Mansoubi et al., 2015). Therefore, sitting typing was included in the active sitting category of sedentary behaviour enabling examination of the relationship between a more active type of sedentary behaviour and indicators of disease risk.

In the validation section of the current study a classification algorithm was developed and used to categorise sedentary postures/activities into sedentary behaviour categories. The algorithm is a valuable tool which can be used in future studies for classifying different types of sedentary behaviour, an area of sedentary behaviour which has not been explored before. Previous studies have used accelerometer validation in order to distinguish between sedentary behaviours, non-sedentary behaviours and intensities of physical activity (Peterson et al., 2015; Pfister et al., 2017; Wullems et al., 2017) rather than between types of sedentary behaviour, as was done in the current study. This is the first study to classify sedentary postures/activities into types of sedentary behaviour beyond simply sitting, lying or standing (Lyden, John, Dall, & Granat, 2016; Tigbe, Granat, Sattar & Lean, 2017). Even though we have classified sedentary behaviour in a novel way, the accuracy of the classification algorithm was still 84% for lying down, non-active sitting, active sitting, standing, and total sedentary behaviour. Other studies have used accelerometers and inclinometers to distinguish merely between sedentary and non-sedentary activities, reporting >90% accuracy for accelerometer measures (Kozey-Keadle et al., 2011; Peterson et al., 2015; Wullems et al., 2017) and >70% accuracy for inclinometer measures (Peterson et al., 2015). However, different sedentary behaviours are more difficult to classify, so the accuracy achieved in the current algorithm with a combination of accelerometer and inclinometer data indicates its valuable potential for the classification of sedentary behaviours.

Participants spent almost 8 hours in sedentary behaviour each day, which is similar to previous studies (An et al., 2017; Dempsey et al., 2015; Gupta et al., 2016; Peterson et al., 2015). More than half of the time spent being sedentary was classified as non-active sitting, which was associated with unfavorable outcomes of overweight and obesity, some indicators of metabolic diseases, and blood pressure and HDL-cholesterol. Less than one quarter of sedentary time was classified as active sitting, which was associated with favourable outcomes of overweight and obesity, some metabolic indicators, and HDL-cholesterol. An increase in the proportion of time spent in active sedentary behaviour is likely to decrease risk of disease in comparison to non-active sedentary behaviour. The implications of this finding could be used to encourage the development of sedentary behaviour guidelines which supplement the current physical activity guidelines. Public health initiatives which have attempted to promote increased physical activity and reduced sedentary behaviour concurrently, have not been as effective as those focussing on promotion of changing one behaviour alone (Young et al., 2016). Specific sedentary behaviour guidelines could be useful for encouraging a change in the amount of time spent in sedentary behaviour and/or in the type of sedentary behaviour being performed.

Sedentary behaviour is typically assessed using either subjective or objective methods. Whilst subjective assessment of sedentary behaviour is prone to bias, especially in overweight/obese (Prince et al., 2008) and less physically active (Moy et al., 2008) individuals, it provides context to behaviours. On the other hand, objective measures provide a precise and detailed picture of behaviour patterns (Young et al., 2016) but no understanding of the types of sedentary behaviours being performed. In the current study a classification algorithm was developed to examine the relationships between different types of sedentary behaviours and indicators of disease risk using only objective sedentary behaviour data. Classifying different types of sedentary behaviours into categories in this way eliminated the need for subjective data to enable understanding of context. Categories (e.g., active sitting) rather than contexts (e.g. leisure time) of sedentary behaviours may

effectively inform specific targeting of sedentary behaviours in public health initiatives and sedentary behaviour guidelines.

Most longitudinal studies use questionnaires to measure sedentary behaviour (Hagger-Johnson et al., 2016; Matthews et al., 2012; Nguyen, Bauman, & Ding, 2017; Petersen et al., 2014; Picavet et al., 2016; Pulsford et al., 2013; Stamatakis et al., 2017; Wijndaele et al., 2011), and as a result, there is a lack of longitudinal research in which sedentary behaviour has been objectively measured (Gibbs et al., 2015). Future research into the long-term health outcomes of different types of sedentary behaviour might benefit from using objectively measured data and applying algorithms, as was conducted cross-sectionally in the current study. Investigating different types of sedentary behaviours in this way would be valuable in understanding the varying associations of disease risk between occupational and leisure time sedentary behaviour and to provide recommendations on strategies to reduce such risk.

The current study revealed that sedentary behaviours are not equally associated with markers of disease risk and adds valuable new evidence to existing knowledge in this field. In daily living, only a quarter of sedentary time was allocated to the type of sedentary behaviour (i.e., active sitting) that was positively associated with markers of health. Therefore, substantial scope exists to encourage change in the most widely performed sedentary behaviour (sitting), from non-active to active sitting. Furthermore, objectively measuring different sedentary behaviours will provide a more accurate understanding of the effects of sedentary behaviour type on markers of non-communicable diseases. This study has provided a sound foundation for further investigation into different types of objectively measured sedentary behaviour and their effects on long-term health.

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