Exploring physical activity profiles of Māori, Pacific and European women from Aotearoa New Zealand: Implications for body composition and metabolic health

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Abstract

Background

Regular physical activity provides extensive health benefits, and is a key modifiable risk factor for chronic disease.

Aims and objectives

The research aim was to robustly explore the physical activity profiles of Māori, Pacific and European women aged 16-45 years, living in New Zealand, to understand ethnic differences in their physical activity profiles and its consequences on body composition and metabolic health markers. Objectives were to: investigate the challenges of collecting hip-worn accelerometer data; determine ethnic differences in physical activity levels, and associated disease risk of being overweight-obese; investigate whether substituting sedentary behaviour with equal time in physical activity can predict improved health markers; examine recreational physical activity preferences to make ethnic-specific suggestions for meeting physical activity guidelines.

Methods

Participants were 406 healthy premenopausal Māori, Pacific and European women aged 16-45 years, stratified by body composition profile and ethnicity. Physical activity data were collected using hip-worn accelerometers and Recent Physical Activity Questionnaire. Body composition was assessed using anthropometry, air displacement plethysmography and dual-energy x-ray absorptiometry. Metabolic biomarkers were measured from venous blood samples.

Results

Accelerometer wear compliance was 86%, but discomfort (67%) and embarrassment (45%) hindered wear. European women (92.7%) returned more valid data than Māori (82.1%) or Pacific (73.0%, $p < 0.04$) women. More overweight-obese European (67%) than Māori (49%) or Pacific (32%, $p < 0.001$) women achieved physical activity guidelines. Achieving guidelines was strongly associated for Māori, inversely with total and regional fat percentages and clustered cardiometabolic risk score ($p < 0.01$) and positively with body lean percentage ($p = 0.21$), and for European women inversely with regional fat percentages and positively with body lean percentage ($p \leq 0.036$). Substituting sedentary time with moderate-vigorous physical activity predicted improvements ($p < 0.05$) in total (14.8%) and android (12.5%) fat percentages, BMI

(15.3%) and insulin (42.2%) for overweight-obese Māori women, and waist-to-hip ratio (6.4%) among Pacific women. Recreational physical activity preferences varied by ethnicity, possibly due to cultural/ethnic factors. Suggestions to increase physical activity were: family/whanau-based team activities for Māori women; community/church-linked games and fitness sessions for Pacific women; adding variety to existing activities for European women.

Conclusions

Ethnicity played a major role in: collecting data; amounts/types of physical activity performed; implications of physical activity on health markers. Tailoring physical activity recommendations for specific ethnic groups could have major positive health implications for New Zealand women.

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ANOVA	Analysis of variance
BF%	Body fat percentage
BMI	Body mass index
BP	Blood pressure
CCMR	Clustered cardiometabolic risk
Chol:HDL	Cholesterol to HDL-c ratio
cpm	Counts per minute
CVD	Cardiovascular disease
DALY	Disability adjusted life years
DXA	Dual-energy X-ray absorptiometry
EDTA	Ethylene diamine tetraacetic acid
EXPLORE	Examining Predictors Linking Obesity Related Elements
HbA1c	Glycosylated haemoglobin
HDL-c	High-density lipoprotein cholesterol
HH	High BMI, high BF%
HIIT	High intensity intermittent training
HOMA-IR	Homeostatic Model Assessment of Insulin Resistance
HR	Heart rate
ICC	Interclass correlation coefficient
IPAQ	International Physical Activity Questionnaire
ISAK	International Society for the Advancement of Kinanthropometry
LDL-c	Low-density lipoprotein cholesterol

ISCOLE	International Study of Childhood Obesity, Lifestyle and the Environment
MEMS	Microelectro-mechanical systems
MET	Metabolic equivalent of task
MVPA	Moderate-vigorous physical activity
MVPA10	Moderate-vigorous physical activity in bouts of 10 or more minutes
NH	Normal BMI, high BF%
NHANES	National Health and Nutrition Examination Survey
NN	Normal BMI, normal BF%
NZE	New Zealand European
NZPAQ	New Zealand Physical Activity Questionnaire
OECD	Organisation for Economic Co-operation and Development
PA	Physical activity
PAQ	Physical activity questionnaire
RPAQ	Recent Physical Activity Questionnaire
RPE	Rating of Perceived Exertion
RR	Risk ratio
SD	Standard deviation
SE	Standard error
SPSS	Statistical Package for the Social Sciences
USA	United States of America
VO_2	Volume of oxygen
WC	Waist circumference
WHO	World Health Organisation
WHR	Waist-to-hip ratio

Chapter 1 Introduction

Physical activity is one of the most modifiable lifestyle factors for chronic disease risk and long-term health, and is a key element in healthy weight management (World Health Organization, 2010). Conversely, physical inactivity is estimated to cause approximately 5.3 million deaths annually worldwide (Lee *et al.*, 2012), and is equivalent to smoking and obesity in terms of health risk (Lee *et al.*, 2012). Physical activity refers to *any bodily movement produced by skeletal muscle that results in energy expenditure* (Caspersen *et al.*, 1985) and can be incidental (e.g. walking between offices) or intentional (e.g. going for a run), whilst inactivity generally relates to failure to meet physical activity guidelines (World Health Organization, 2010).

Despite overwhelming evidence for the benefits of physical activity, well over half the adult population in many countries, including Australia, New Zealand, USA and Canada, currently fail to meet basic physical activity guidelines (≥150 min/week moderate intensity aerobic exercise) recommended for health (Brown *et al.*, 2012; Australian Bureau of Statistics, 2013; Centers for Disease Control and Prevention, 2014; Ministry of Health, 2016). Furthermore, in almost all countries, fewer women than men are physically active (World Health Organization, 2016). Indeed, fewer women (45%) than men (51%) in New Zealand are physically active across all age and ethnic groups (Ministry of Health, 2016). Physical activity participation also varies between age groups; however, activity levels are consistent across the majority of ethnic groups within New Zealand (Ministry of Health, 2015a). Regardless of age, gender or ethnicity, levels of physical activity are declining worldwide in both developed and developing countries (Australian Bureau of Statistics, 2013; Centers for Disease Control and Prevention, 2014; Statistics Canada, 2014; Centers for Disease Control and Prevention, 2015; Ministry of Health, 2015d, World Health Organization, 2016), and thus increasing otherwise preventable risk for developing many chronic diseases.

In line with declining levels of physical activity, obesity prevalence has been increasing worldwide over the past three decades (Ng *et al.*, 2014; World Health Organization, 2015). New Zealand has one of the highest rates of obesity of any country (Ng *et al.*, 2014; OECD, 2015), with almost one third (30.7%) of all adults and 32.0% of women being classified as obese (body mass index (BMI) ≥30 kg/m^2) (Ministry of Health, 2015a). In total, 61.5% of New Zealand women have a BMI above the healthy range (i.e. they are overweight (BMI 25.0-29.9 kg/m^2) or obese) (Ministry of Health, 2015a), placing a large portion of the adult female population at substantially increased risk of obesity-related diseases and associated complications (De Lorenzo *et al.*, 2013; World Health Organization, 2015). Yet obesity prevalence is not uniform across the New Zealand population, with large disparities between ethnicities (Ministry of Health, 2016). Pacific adults, and Pacific women in particular, have the highest obesity prevalence of all population groups in New Zealand: 69.5% of Pacific women are obese, with a further 19.1% classified as overweight (Ministry of Health, 2015a). Obesity prevalence among Māori (47.6%) and New Zealand European (30.6%) women is also higher than among their male counterparts (45.4% and 27.7% respectively; 62.4% in Pacific men) (Ministry of Health, 2015a).

Obesity status is commonly classified according to BMI (World Health Organization, 2006), a power-index used to assess weight relative to height (Blackburn and Jacobs, 2014). However, excess fat mass (De Lorenzo *et al.*, 2013), and the location and distribution of said fat mass, have important negative health consequences in relation to disease risk, regardless of BMI (Bastien *et al.*, 2014). For example, excess fat mass in the android region poses greater risk to metabolic health (e.g. type 2 diabetes risk) than an equal amount of fat in the gynoid region (Bastien *et al.*, 2014). Furthermore, excessive fat mass in relation to lean mass may be hidden when BMI is within the healthy range (De Lorenzo *et al.*, 2006), yet result in similar metabolic disease risk to that experienced by individuals with equivalent levels of visible body fat (Marques-Vidal *et al.*, 2010; Romero-Corral *et al.*, 2010; Olafsdottir *et al.*, 2016).

Body composition, especially excess fat mass and body fat percentages, are known to improve with physical activity (World Health Organization, 2010; Rosenkilde *et al.*, 2012; Donnelly *et al.*, 2013; Hazell *et al.*, 2014; Weiss *et al.*, 2016). Intervention studies have shown that aerobic and intermittent exercise reduce fat mass and increase lean mass in a range of populations, including both normal weight and obese women (Rosenkilde *et al.*, 2012; Donnelly *et al.*, 2013; Hazell *et al.*, 2014; Weiss *et al.*, 2016; Kleist *et al.*, 2017). Such changes in body composition may have widespread implications on disease risk factors and metabolic health (Weiss *et al.*, 2016; Chung *et al.*, 2017; Kleist *et al.*, 2017). Yet, physical activity also independently and substantially reduces the risk of the three major non-communicable diseases (cardiovascular disease, type 2 diabetes, many cancers) (Sattelmair *et al.*, 2011; Lee *et al.*, 2012; Aune *et al.*, 2015), and moderates markers in the causal pathways of these diseases (Jorge *et al.*, 2011; Korshoj *et al.*, 2016; Weiss *et al.*, 2016; Tudor-Locke *et al.*, 2017). Indeed, a 2011 meta-analysis (Sattelmair *et al.*, 2011) showed that women meeting basic physical activity guidelines had 14% lower risk of coronary heart disease than inactive women. Furthermore, biomarkers associated with cardiovascular disease (e.g. BMI, waist-to-hip ratio, high-density lipoprotein cholesterol (HDL-c), low-density lipoprotein cholesterol (LDL-c), triglycerides) were greatly improved following aerobic and intermittent exercise interventions among overweight-obese and inactive women (Jorge *et al.*, 2011; Donnelly *et al.*, 2013; Hazell *et al.*, 2014; Share *et al.*, 2015; Korshoj *et al.*, 2016; Weiss *et al.*, 2016). Results from a recent meta-analysis (Cloostermans *et al.*, 2015) investigating type 2 diabetes risk showed that regular physical activity of any type or volume substantially attenuates risk of the disease in most populations. In fact, women meeting aerobic and resistance components of physical activity guidelines were at 33% lower risk of type 2 diabetes than inactive women (Grontved *et al.*, 2014). Markers of type 2 diabetes risk (e.g. glycosylated haemoglobin (HbA1c), fasting glucose, insulin, BMI, waist circumference) are inversely associated with, and improved by, all forms of exercise in a range of populations (Ross *et al.*, 2004; Lee *et al.*, 2005; Tjønna *et al.*, 2008; Trapp *et al.*, 2008; Balducci *et al.*, 2010; Jorge *et al.*, 2011; Share *et al.*, 2015; Weiss *et al.*, 2016).

Evidence-based physical activity guidelines initially set by the World Health Organization (WHO) (World Health Organization, 2010) have been adopted in many countries (U.S. Department of Health and Human Services, 2008; Bull & the Expert Working Groups, 2010; Australian Government Department of Health, 2014; Ministry of Health, 2015c; Rütten *et al.*, 2016) and are aimed at promoting health through physical activity participation. However, leisure-time for physical activity participation is limited for most individuals, so finding effective and preferred activities for specific population groups is important to maximise physical activity participation and its associated benefits (World Health Organization, 2007). Given the vast range of recreational physical activity choices available, physical activity profiles, including activities that are most appropriate or preferred by individuals, might differ between populations and ethnicities (Lee and Im, 2010). For example, certain religious protocols may disallow sport participation on Sunday (World Health Organization, 2007; Gordon *et al.*, 2013), and cultural values may influence preferences for recreational activities, such as those involving traditional dance or group fitness sessions focussing on family involvement (World Health Organization, 2007; Schluter *et al.*, 2011; Gordon *et al.*, 2013).

In order to understand physical activity profiles, including preferred activities and rates of participation, good quality physical activity data are required (Dishman *et al.*, 2001; Hallal *et al.*, 2012). A range of tools, both objective and subjective, are available to obtain such data (Steene-Johannessen *et al.*, 2016). Accelerometers may be worn to capture normal daily activities of free-living individuals over multiple days (Westerterp, 2009), and provide objective data regarding intensity, timing and duration of physical activities (Matthews *et al.*, 2012; Tudor-Locke *et al.*, 2012; Pedisic and Bauman, 2015). On the other hand, subjective measures, such as physical activity questionnaires, are effective in assessing the specific types of activity or the domain in which activities are performed (e.g. occupation, home) (MRC Epidemiology Unit, 2006; IPAQ, 2010; van Poppel *et al.*, 2010). Combined, objective and subjective methods provide valuable and detailed data to establish physical activity profiles of a population on which to base population-specific recommendations for physical activity based health improvement (Haskell, 2012; Steene-Johannessen *et al.*, 2016).

While the benefits of physical activity are well reported, few data are available on this topic in a specifically New Zealand context, and in particular, among New Zealand women. Some portions of the New Zealand population are particularly vulnerable and are at substantially increased risk of chronic diseases which are mediated by physical activity, yet objectively measured physical activity data among New Zealand women is lacking, especially regarding its effects on disease risk and obesity prevalence. For instance, Pacific women are at 3.5 times greater risk of type 2 diabetes than non-Pacific women (Ministry of Health, 2015b), whereas Māori women are 2.3 times more likely to die from cardiovascular disease and even more likely (2.5 times) to die from ischemic heart disease specifically, than non-Māori women (Ministry of Health, 2015e). Despite the wide ethnic disparities in obesity prevalence and chronic disease risk (especially cardiovascular disease and type 2 diabetes), obesity and disease risk have not been investigated collectively in New Zealand women of different ethnicities in relation to physical activity. To address the paucity of New Zealand data, this research project was designed to robustly describe and examine the complex relationships between physical activity, body composition and metabolic health markers among New Zealand women of different ethnicities.

1.1 Study aims and objectives

The aim of this thesis was to robustly explore the physical activity profiles of Māori, Pacific and European women aged 16-45 years living in New Zealand, in order to understand ethnic differences in the physical activity profiles of these women, and to explore the consequences of physical activity on their body composition and markers of metabolic health.

The objectives of this research were to:

- Investigate the challenges associated with collecting objectively-measured physical activity data from New Zealand women of different ethnicities using hip-worn accelerometers.
- Determine the physical activity levels of overweight-obese New Zealand women, and examine ethnic differences in body composition and metabolic health markers and their associations with physical activity.
- Investigate whether substituting sedentary behaviour with equal time in more physically active behaviours can predict improvements in the body composition and metabolic health markers of New Zealand women.
- Examine the recreational physical activity preferences of New Zealand women of different ethnicities to make ethnic-specific suggestions for meeting physical activity guidelines.

1.2 Structure of the thesis

This thesis begins with a review of the literature (Chapter 2), which presents the health benefits of physical activity, along with important information on levels of physical activity worldwide and in New Zealand, the impact of physical activity on long-term health, and concludes with a review of physical activity assessment.

The literature review is followed by four manuscripts that individually address each objective of this doctoral research. Since each manuscript is presented in a form suitable for publication, there may be a small amount of repetition throughout the thesis. The first manuscript (Chapter 3) will draw on data from all participants who received accelerometers, in conjunction with data obtained from a sub-sampled semi-structured telephone interview, to explore the challenges of collecting physical activity data via hip-worn accelerometry. Chapter 4 will examine ethnic-specific relationships between levels of physical activity, body composition and metabolic health markers among all overweight-obese women. This chapter is followed by an investigation into the predicted changes in body composition and metabolic health markers from substituting sedentary behaviour with equal time in more physically active behaviours using an isotemporal substitution paradigm and will analyse all valid accelerometry data (Chapter 5). The final manuscript (Chapter 6) will use data taken from a Recent Physical Activity Questionnaire to examine the recreational physical activity preferences of the study cohort, with evidence-based, ethnic-specific suggestions for meeting physical activity guidelines. The thesis concludes with a discussion amalgamating the main results of the various analyses presented in the thesis, alongside the methodological strengths and limitations of the studies, before presenting recommendations for use of the findings and future research.

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Chapter 2 Literature review

2.1 Introduction

Physical activity is one of the key modifiable risk factors for many chronic diseases and for healthy body weight management. Extensive experimental and prospective literature supports the role of physical activity in disease prevention and health maintenance across a range of populations and settings. The benefits of physical activity on the major non-communicable diseases and weight management, along with levels of physical activity in relation to guidelines, particularly in New Zealand, will be reviewed.

Obesity has reached epidemic proportions in many countries worldwide and is of serious public health consequence. Understanding obesity status in terms of makeup (e.g. body composition) and prevalence in different populations is an important step in alleviating the burden obesity poses on society. Obesity prevalence and ethnic and gender disparities will be addressed, both internationally and particularly in the New Zealand context.

Various methods and technologies are available to assess physical activity in both intervention and epidemiological settings. Physical activity trends in New Zealand are monitored annually through subjective interviews as part of a national health survey. However, there is little objective evidence of physical activity among New Zealand adults, and even less focussing on the impact of physical activity on health outcomes. Physical activity assessment methods and subsequent data analysis will be reviewed, and the advantages and limitations of different methods will be discussed.

In New Zealand, and many other countries, physical activity levels are declining amid gender and ethnic disparities in rising obesity prevalence and susceptibility to certain non-communicable diseases. Within New Zealand though, there is a paucity of research linking these factors in women, especially in relation to ethnicity. Hence, this review will consider all of these aspects, in the context of women from three major New Zealand ethnic groups.

2.2 Definitions and terminology in physical activity

2.2.1 Physical activity, inactivity and sedentary behaviour

The presence or absence of physical activity, and the relative intensities such activities represent, have various definitions within the fields of physical activity and exercise. The terms physical activity and exercise are often used interchangeably across a range of settings, whilst sedentary behaviour and physical inactivity are often considered one in the same. Yet these four terms all have quite distinct meanings.

The distinction between the terms physical activity and exercise is relatively clear, despite the two definitions sharing four out of six defining elements (Caspersen *et al.*, 1985). Both activities (a) produce body movement via skeletal muscle that (b) results in energy expenditure on (c) a continuum from low to high, and are (d) positively (physical activity) or very positively (exercise) correlated with physical fitness (Caspersen *et al.*, 1985). Exercise though, is also (e) planned, structured and repetitive, (f) with the aim of improving some aspect of physical fitness (Caspersen *et al.*, 1985) (Table 2.1). Physical activity on the other hand, includes all exercise as well as incidental activities of daily living (Caspersen *et al.*, 1985).

Table 2.1. Commonly used definitions of physical behaviours

Classification	Definition
Exercise	Planned, structured, repetitive physical activity carried out with the intention of improving or maintaining at least one aspect of physical fitness (Caspersen *et al.*, 1985).
Physical activity	Any bodily movement produced by skeletal muscle that results in energy expenditure (Caspersen *et al.*, 1985).
Physical inactivity	Less than 30 min per week of physical activity of at least moderate (brisk walking or greater) intensity (Ministry of Health, 2015f),
	Performing some physical activity, but insufficient to meet physical activity guidelines (World Health Organization, 2010; Sedentary Behaviour Research Network, 2012).
Sedentary	Sleeping, sitting or lying activities that do not substantially increase energy expenditure above resting levels; 1.0-1.5 metabolic equivalents (Pate *et al.*, 2008),
	Waking activities performed whilst sitting, reclining or lying, with energy expenditure ≤1.5 metabolic equivalents (Sedentary Behaviour Research Network, 2012),
	Excessive daily sitting (Ekblom-Bak *et al.*, 2016a).

Terminology relating to sedentary behaviour and physical inactivity is also inconsistent and is even more confusing (Table 2.1). Sedentary behaviour has historically referred to the absence of moderate or vigorous activity, especially in sport and exercise literature (Sedentary Behaviour Research Network, 2012). In health settings though, sedentary behaviour has had various definitions including low level activity with energy expenditure only marginally above resting (Pate *et al.*, 2008), or activity equivalent to sleeping, sitting, lying or non-upright activities (Tremblay *et al.*, 2017), among others (Ekblom-Bak *et al.*, 2016a).

Some population health surveys refer to inactivity as being a failure to meet physical activity guidelines (World Health Organization, 2010; Lee *et al.*, 2012), whereas others regard inactivity as <30 min/week of physical activity (Ministry of Health, 2015f). A confusing reference to *inactivity* was included in the 2008 Physical Activity Guidelines for Americans (U.S. Department of Health and Human Services, 2008) and reflected neither of these definitions. The guidelines recommend that *inactivity* should be avoided and replaced with *activity* whenever possible. A statement with similar intent is included in several other physical activity guidelines, but the word *inactivity* is instead replaced with *sedentary*, i.e. *sedentary* time should be limited or replaced with other behaviours (Department of Health, 2011; Garber *et al.*, 2011; Australian Government Department of Health, 2014; Ministry of Health, 2015d). In a further display of contradictory terminology, a study investigating patterns of physical activity and inactivity define the latter as periods of <100 accelerometer counts per minute (cpm) (Hagstromer *et al.*, 2007) - the threshold commonly used to quantify sedentary behaviour (Matthews *et al.*, 2008; Tudor-Locke *et al.*, 2012). In fact, in that study, examples of inactivity included sitting and lying, behaviours typically described as sedentary behaviour (Hagstromer *et al.*, 2007; Ainsworth, 2011). A further published definition of sedentary behaviour is that of excessive daily sitting (Ekblom-Bak *et al.*, 2016a).

In response to the ambiguity surrounding terminology, an international collaboration of sedentary behaviour researchers and health professionals (Sedentary Behaviour Research Network) was established specifically to find consensus on definitions (Sedentary Behaviour Research Network, 2012; Tremblay *et al.*, 2017). The group recommended that journal editors adopt and enforce the proposed definitions of sedentary behaviour and inactivity in order to bring consistency to the literature (Sedentary Behaviour Research Network, 2012). These definitions are (Sedentary Behaviour Research Network, 2012; Tremblay *et al.*, 2017):

- Physical inactivity - a level of physical activity insufficient to meet current physical activity guidelines;
- Sedentary behaviour - waking behaviour of ≤1.5 metabolic equivalents whilst in a sitting, reclining or lying posture.

Publication of and adherence to these recommendations is encouraging, however care must still be taken when interpreting statements regarding physical inactivity and sedentary behaviour, to ensure the intended definitions of these terms are apparent and understood. Throughout this review (unless otherwise stated), the above definitions of sedentary behaviour and physical inactivity will be followed.

2.2.2 Levels of physical activity

Levels of physical activity are typically categorised in absolute terms according to estimated energy expenditure, expressed as metabolic equivalents (METs) and defined as the ratio of the work metabolic rate to a standard resting metabolic rate of 1.0 kcal/kg/h (Ainsworth *et al.*, 2000). One MET is considered the resting metabolic rate or the energy cost of a person at rest (Ainsworth *et al.*, 2000). Physical activity intensity can also be expressed in relative terms such as perceived exertion (e.g. Borg's Rating of Perceived Exertion (RPE) scale (Borg, 1970; Norton *et al.*, 2010)). Common classifications of physical activity intensity are sedentary, light, moderate, vigorous, and moderate-to-vigorous combined (MVPA) (Table 2.2). It is interesting to note though, that the well-established definition of sedentary behaviour (<100 accelerometer cpm) which has become somewhat of a norm for healthy adults, is arbitrary, and not based on any scientific evidence (Matthews *et al.*, 2008; Kozey-Keadle *et al.*, 2011).

Table 2.2. Classification of physical activity intensities

PA intensity	METs	RPE	Description	Examples of activities
Sedentary	≤1.5	<8	Activities with energy requirement little greater than resting.	Sitting, reclining or lying whilst watching television, reading, commuting.
Light	1.6–2.9	8-10	Activities that do not cause a noticeable increase in heart rate.	Washing dishes, playing piano, light walking.
Moderate	3.0–5.9	11-13	Activities that require increased effort, but during which a conversation can still be maintained.	Brisk walking, playing tennis, swimming.
Vigorous	≥6.0	≥14	Activities in which increased breathing means a normal conversation cannot be maintained.	Shovelling, martial arts, running.
Vigorous is sometimes further segregated into (Norton *et al.*, 2010):				
Vigorous	6.0–8.9	14–16	Activities in which increased breathing means a normal conversation cannot be maintained.	Shovelling, martial arts, running.
High	≥9.0	≥17	An intensity that cannot usually be sustained for >~10 min.	Exercising at an intensity nearing maximal effort.

Abbreviations: PA, physical activity; METs, metabolic equivalent of tasks (Ainsworth *et al.*, 2011); RPE, rating of perceived exertion (Borg's scale 6-20) (Borg, 1970).

2.2.3 Physical activity guidelines

In response to growing concerns over declining physical activity levels, and compelling evidence for the benefits of a physically active lifestyle, many countries and international health communities have adopted evidence-based guidelines for physical activity with the purpose of improving long term health outcomes (World Health Organization, 2010). The first physical activity recommendations came in 1978 from the American College of Sports Medicine (American College of Sports Medicine, 1978). However, these early guidelines were focussed on improving physical performance, rather than on fitness for health *per se* (American College of Sports Medicine, 1978). Not until 1990 were guidelines published for physical activity which focussed on health related outcomes (American College of Sports Medicine, 1990). In 2004, the WHO's World Health Assembly issued a mandate urging Member States to develop national action plans aimed at increasing their nations' levels of physical activity. The WHO Global Recommendations on Physical Activity for Health (World Health Organization, 2010) was published in 2010 as a guide for the prevention of non-communicable diseases through physical activity. Renewed calls to reduce physical inactivity came from the United Nations in 2011, followed in 2013, by an agreement from WHO Member States to a 10% reduction in physical inactivity by 2025 (World Health Organization, 2006). Scientific knowledge on the benefits of physical activity continues to evolve, hence physical activity guidelines are periodically revised and updated in accordance with newly available supporting scientific evidence.

Current physical activity guidelines are similar across many countries including New Zealand, Australia, United Kingdom, Canada, USA and Germany, and reflect those of the WHO (Haskell *et al.*, 2007; U.S. Department of Health and Human Services, 2008; World Health Organization, 2010; Department of Health, 2011; Australian Government Department of Health, 2014; Ministry of Health, 2015d; Rütten *et al.*, 2016). Most guidelines recommend both aerobic and resistance exercise, but the levels and intensities vary to meet the needs of specific populations (Table 2.3). For healthy adults, the recommended basic guideline is for ≥150 min/week moderate intensity aerobic exercise (≥3 METs), accumulated in bouts of 10 or more minutes (World Health Organization, 2010). This level of activity is sufficient to improve cardiorespiratory and muscular fitness, reduce the risk of non-communicable diseases and premature death, and prevent weight gain in most individuals (World Health Organization, 2010; Department of Health, 2011; Australian Government Department of Health, 2014; Ministry of Health, 2015d). Additional health benefits might be gained by increasing aerobic exercise time (≥300 min/week moderate intensity) or intensity (≥150 min/week vigorous intensity) to meet advanced guidelines (World Health Organization, 2010). In recognition of the negative health consequences of sedentary behaviour, guidelines from New Zealand and some other countries (e.g. Australia, United Kingdom) include advice to sit less and move more, and to break up periods of prolonged sitting (Department of Health, 2011; Australian Government Department of Health, 2014; Ministry of Health, 2015d). Outside of the formal physical activity guidelines, a longstanding step-based target of 10,000 steps daily acts as a surrogate for meeting physical activity guidelines (Tudor-Locke and Bassett, 2004; Tudor-Locke *et al.*, 2008). The American College of Sports Medicine even use this metric in material promoting walking as a means of meeting physical activity guidelines (American College of Sports Medicine, 2011). Less than 5,000 steps has been used as an index for sedentary behaviour (Tudor-Locke *et al.*, 2013), although this classification might be more appropriately termed, inactive behaviour (Tremblay *et al.*, 2017).

In addition to physical activity guidelines for healthy adults, guidelines have also been tailored to meet the needs of specific population groups. For instance, recommendations for older adults include flexibility and balance sessions in addition to the basic adult guidelines (Table 2.3). These additional exercises are intended to reduce risk of falls and to maintain range of motion and quality of life (World Health Organization, 2010). For type 2 diabetic populations, a combination of resistance and aerobic exercise is recommended (Table 2.3) to assist with weight loss, increase lean muscle mass and improve glycaemic control (Sigal *et al.*, 2006). Some authors even suggest moderate physical activity of as much as 210 min/week for those with diabetes (Hordern *et al.*, 2012). Individuals with type 2 diabetes are advised to undertake aerobic exercise at least every second day, as the positive acute effects of exercise on insulin persist for ~48 h post exercise (Colberg *et al.*, 2010; Hordern *et al.*, 2012). For all populations though, it is advised that some exercise is better than none (Ministry of Health, 2015d), as even physical activity well below recommended guideline levels infer some degree of positive health benefits for most people (Sattelmair *et al.*, 2011).

Table 2.3. Physical activity guidelines

Population	Exercise type	Volume/Frequency	References
Healthy adults (basic guidelines)	Moderate intensity aerobic exercise (bouts of ≥10 min),	≥150 min/week	(Haskell *et al.*, 2007; U.S. Department of Health and Human Services, 2008; World Health Organization, 2010; Department of Health, 2011; Australian Government Department of Health, 2014; Ministry of Health, 2015d, Rütten *et al.*, 2016)
	OR vigorous intensity aerobic exercise (bouts of ≥10 min),	≥75 min/week	
	PLUS resistance exercise (major muscle groups).	≥2 day/week	
Older adults	Healthy adult basic guidelines,		(Nelson *et al.*, 2007; World Health Organization, 2010; Ministry of Health, 2015d; Rütten *et al.*, 2016)
	PLUS balance and flexibility exercises.	≥3 day/week	
Diabetics (type 2)	Moderate intensity aerobic exercise (bouts of ≥10 min),	≥150 min/week (at least every second day)	(American College of Sports Medicine and the American Diabetes Association, 2010; Hordern *et al.*, 2012; Ministry of Health, 2015d)
	OR vigorous intensity aerobic exercise (bouts of ≥10 min),	≥75 min/week (at least every second day)	
	PLUS resistance exercise - major muscle groups (2-4 sets, 8-10 reps)	≥2 non-consecutive days/week	
Everyone	Sit less and move more. Break up periods of prolonged sitting.	As much as possible, daily	(World Health Organization, 2010; Australian Government Department of Health, 2014; Ministry of Health, 2015d; Rütten *et al.*, 2016)
Most healthy adults	Stepping	10,000 steps daily	(Tudor-Locke and Bassett, 2004; Tudor-Locke *et al.*, 2008; American College of Sports Medicine, 2011)

2.3 The population under investigation

2.3.1 The setting: Aotearoa New Zealand

New Zealand (officially known as Aotearoa New Zealand) is a South Pacific island nation of 4.8 million people (51.3% female) (Statistics New Zealand, 2014b; Statistics New Zealand, 2017). Māori, the indigenous people of New Zealand, are thought to have arrived in Aotearoa from East Polynesia some 800 years ago (Wilson, 2005), whilst arrival of the first European settlers occurred as recently as the early 19th century (Phillips, 2005a). Since the arrival of these early immigrants, immigration has played an important role in population growth in New Zealand, with periods of high immigration at different times from Britain, the Pacific Islands and Asia (Phillips, 2005b). As a result, the New Zealand population consists of people from a wide range of cultural and ethnic backgrounds (Table 2.4). People of European decent make up the vast majority of the population (63%), while Māori are the second most populous group (13%). Strong immigration from the Pacific Islands occurred during the 1950s and 60s and then again in the 1980s (Phillips, 2005b). Coupled with high fertility rates among Pacific women (2.7 live births per woman (Statistics New Zealand, 2013)), the population of New Zealanders of Pacific Island origin increased from a mere 3600 in 1951 to 295,944 (6%) in 2013 (Phillips, 2005b; Statistics New Zealand, 2014b). A recent major influx of Asian immigrants saw this group increase by 25% between 2006 and 2013 to stand at 10% of the total population (Statistics New Zealand, 2014b). Almost one third of the New Zealand population resides in the country's largest city, Auckland. This city has a unique demographic, being home to the largest populations of both Māori (9%) and Pacific (13%) people in any single city worldwide (Statistics New Zealand, 2014a).

Table 2.4. Ethnic makeup of the New Zealand population, results from the 2013 Census

Ethnicity	Number	% of total population[a]
European	2,969,391	63.4
Māori	598,602	12.8
Pacific	295,944	6.3
Asian	471,708	10.1
Middle Eastern, Latin American, African	46,953	1.0
Other	67,752	1.4
Total people (stating at least one ethnicity)[b]	*4,011,399*	
Not elsewhere included [c]	230,649	4.9
Total people	**4,242,048**	**100.0**

Adapted from Statistics New Zealand 2013 Census (Statistics New Zealand, 2014b). [a] Column does not total 100% as some individuals identify with more than one ethnicity, so are included multiple times; [b] Total number of people who stated at least one ethnicity; [c] No ethnicity stated.
Note: Includes all people who stated being of each ethnic group, whether as their only ethnic group or as one of several. Where a person reported more than one ethnic group, they have been counted in each applicable group.

2.3.2 Women versus men

Men and women have numerous biological and physiological differences. Throughout reproductive life, women maintain a greater percentage of body fat than men, yet accumulation of adipose tissue typically differs between genders (Wiklund *et al.*, 2008). Whereas women predominantly accumulate fat in the gynoid region (i.e. around the hips and thighs), abdominal (android) fat accumulation is more common, and dangerous, in men (Wiklund *et al.*, 2008). Furthermore, there is evidence that the specific location of adipose storage sites differentially affects insulin sensitivity and serum lipids in men and women (Masharani *et al.*, 2009). Total and central adiposity was associated with lower insulin sensitivity and increased cardiovascular disease risk in men but not in women (Wiklund *et al.*, 2008; Masharani *et al.*, 2009). In contrast, fat mass (total and central) predicted less favourable lipid profiles in women, but not in men (Masharani *et al.*, 2009).

Aside from the obvious physical differences between men and women, some of the more subtle physiological and endocrine differences can lead to sex disparities in metabolic and other health risk factors (Huxley, 2007; Peters *et al.*, 2014; Appelman *et al.*, 2015). For females, disorders associated with pregnancy (e.g. gestational diabetes) and female endocrine disorders (e.g. polycystic ovary syndrome) are associated with higher incidence of cardiovascular disease (Appelman *et al.*, 2015). Mortality from cardiovascular disease though, and from coronary heart disease and stroke specifically, is substantially higher in men than women (Mozaffarian *et al.*, 2015). However, cardiovascular disease risk factors (e.g. migraine, smoking, type 2 diabetes) are more potent for at-risk women than they are for men of equal risk profile (Huxley *et al.*, 2006; Peters *et al.*, 2014; Appelman *et al.*, 2015). For example, women with type 2 diabetes are at significantly greater risk of cardiovascular disease (46% for coronary heart disease (Huxley *et al.*, 2006) and 27% for stroke (Peters *et al.*, 2014)) than similarly diagnosed men (Huxley *et al.*, 2006; Peters *et al.*). Conversely, without diabetes, incidents of stroke are similar between men and women, while coronary heart disease is higher (7.6%) in men than women (5.0%) (Mozaffarian *et al.*, 2015).

Even substrate metabolism has been shown to have sex specific differences (Varlamov *et al.*, 2015). Rather than oxidise circulating free-fatty acids, women tend to store them (especially subcutaneously), whereas the opposite seems to occur in men (Varlamov *et al.*, 2015). During exercise however, lipid oxidation is higher, and carbohydrate oxidation and muscle glycogen depletion lower, among women than men (Tarnopolsky, 2008), suggesting that exercise might be a more effective weight (especially fat) loss strategy for women. Interestingly though, when men were administered oestrogen, fat and carbohydrate oxidation during exercise reflected that seen in women, suggesting that at least some of the sex-differences in substrate utilisation might be due to the effect of female oestrogens (Tarnopolsky, 2008).

Gender differences also exist with regards to physical activity; men are typically more physically active and less physically inactive than women (Hallal *et al.*, 2012; Ng and Popkin, 2012; World Health Organization, 2015a). Despite this disparity, there has been an historic paucity of female-specific physical activity research. In fact, the seminal physical activity studies such as the Harvard alumni study (Paffenbarger *et al.*, 1978) and London Transport workers study (Morris *et al.*, 1953) were conducted exclusively in men; a trend that continued for many years. Nevertheless, the described sex discrepancies in disease risk, body composition and substrate utilisation demonstrate that direct translation of research findings between the sexes is not always valid (Franconi *et al.*, 2015; Maas and Leiner, 2016). In fact, a call was made for sex-specific investigations in both humans and animals, even in pre-clinical and cell trials (Clayton and Collins, 2014). Bearing in mind that all aforementioned factors for sex and gender disparity are closely related, investigating these relationships in a sex-specific manner is of great importance in the advancement of health-related research.

2.3.3 Age

Countless physical changes occur throughout the lifespan. Physical activity is known to decline throughout adolescence and into adulthood (Jasik and Lustig, 2008), and continues throughout middle and older age (Yang *et al.*, 2017). In a longitudinal study of children followed from birth, MVPA among girls fell steadily from 47 min/day at age nine years to 18 min/day at age 15 years (Nader *et al.*, 2008); this decrease in physical activity was associated with a 26% increase in BMI over the same period and was strongest at the upper end of the BMI distribution (Mitchell *et al.*, 2013). Reduced physical activity and increased body weight with aging are also reported among women across the lifespan (Yang *et al.*, 2017). Fat mass is known to increase progressively from maturity to menopause, with an even greater increase in fat mass (especially abdominally) (Franklin *et al.*, 2009) and a concomitant reduction in lean mass occurring with sarcopenia following menopause and into older age (St-Onge, 2005). The period following physical maturation until prior to menopause (52.5 years) (or perimenopause, 47.5 years) likely provides a relatively stable biological and physiological platform in healthy, normally menstruating women (Gold *et al.*, 2013) on which to assess the effects of physical activity on body composition and metabolic risk factors.

2.4 Physical activity

Despite overwhelming evidence for the health benefits of physical activity, participation rates are declining worldwide, and are below those recommended for health in substantial portions of the population (Ng and Popkin, 2012). In some countries the decline might be partly attributable to reduced occupational physical activity resulting from mechanisation, and movement away from traditional farming-based economies into those centred around manufacturing and other urbanised industries (Hallal *et al.*, 2012; Ng and Popkin, 2012). It is not surprising that Brazil and China, with their rapidly developing economies and subsequently reduced occupational physical activity (Ng and Popkin, 2012), are experiencing the fastest rates of physical activity decline (Ng and Popkin, 2012). Total physical activity in Brazil fell by 50% in just six years (2002-2008), while in China, a fall of 47% occurred between 1991 and 2009 (Ng and Popkin, 2012).

2.4.1 Global differences in reporting physical activity prevalence against guidelines

In 2015, an estimated 31% of adults worldwide were insufficiently active for health, defined as failing to meet basic WHO adult physical activity guidelines (World Health Organization, 2006). While this is indeed a concerning statistic, reporting of physical activity relative to guidelines can be ambiguous. Adult prevalence of meeting physical activity guidelines in the United States (21%) (Centers for Disease Control and Prevention, 2015) and Canada (22%) (Statistics Canada, 2014b) is reported against all components of the guidelines, including both aerobic and resistance exercise. In contrast, compliance in Australia (43%) (Australian Bureau of Statistics, 2013), England (60%) (Townsend *et al.*, 2015), Scotland (62%) (Townsend *et al.*, 2015) and New Zealand (47%) (Ministry of Health, 2016d) represents only the aerobic exercise component of the guidelines. Adding to the ambiguity, some national statistics report objectively measured (i.e. accelerometer, pedometers) data (e.g. Australia, Canada) (Australian Bureau of Statistics, 2013; Statistics Canada, 2014a), whilst statistics from other nations are questionnaire based (e.g. New Zealand, United Kingdom) (Ministry of Health, 2015c; Townsend *et al.*, 2015). Furthermore, the National Health and Nutrition Examination Survey (NHANES), assesses physical activity using accelerometers in some years, but via questionnaires in others (Centers for Disease Control and Prevention, 2017). Regardless of the reporting criteria though, the prevalence of regular physical activity is declining across almost all countries, ethnicities, genders and age groups (Australian Bureau of Statistics, 2013; Centers for Disease Control and Prevention, 2014c; Statistics Canada, 2014b, Centers for Disease Control and Prevention, 2015; Ministry of Health, 2015f; World Health Organization, 2016).

2.4.1 Physical activity in New Zealand

Population prevalence of physical activity and inactivity in New Zealand is reported annually as part of the New Zealand Health Survey. This survey monitors trends in self-assessed health and health impacting behaviour in the New Zealand population through an interview-based questionnaire (Ministry of Health, 2015c). In the survey, regular physical activity reflects the New Zealand physical activity guidelines (Ministry of Health, 2015d) and is defined as ≥30 min/day brisk walking or other moderate intensity physical activity (or 15 min vigorous physical activity) accumulated in ≥10 min bouts on ≥5 days each week (Ministry of Health, 2016b). Contrary to the definitions proposed by the Sedentary Behaviour Research Network (Tremblay *et al.*, 2017), physical inactivity describes little or no physical activity, and is defined as accumulating <30 min/week of moderate intensity physical activity (Ministry of Health, 2016b).

Levels of physical activity in New Zealand have been declining at a rate of around 1% per year since prior to the early 1990s; currently, 47% of the adult population regularly participate in physical activity (Ministry of Health, 2016d). As in most countries, rates of physical activity are higher among men (51%) than women (45%) (Ministry of Health, 2016d). At the same time that physical activity is declining, physical inactivity amongst New Zealand adults is rising, increasing from 10.0% to 14.3% in just eight years to 2015 (Ministry of Health, 2016d). In 2016, 13% of New Zealand men and 18% of women were physically inactive (Ministry of Health, 2016d).

2.4.1.1 Demographic differences in physical activity in New Zealand

Despite falling rates of physical activity, the prevalence of regular physical activity participation is similar (47-54%) across all age groups (except those aged >75 years) of New Zealand adults (Ministry of Health, 2015a). However, participation among 15-17 year olds has fallen faster than in other age groups in recent years (59% in 2006/07, 50% in 2014/15) (Ministry of Health, 2008b; Ministry of Health, 2015a). In contrast, the 45-54 year age group has consistently been some of the most active adults in New Zealand (~54%) (Ministry of Health, 2015a), whilst also being the least inactive group (9%) (Ministry of Health, 2015a). The cause of these statistics is not known, but could be attributed to increased discretionary time through reduced family responsibilities, greater financial freedom to pursue leisure time activities, or the realisation of the health benefits of physical activity. Rates of inactivity also show little variation (~13% prevalence) across age groups, up to age 65 years (Ministry of Health, 2015a).

Physical activity levels are known to vary by ethnicity in some countries (Centers for Disease Control and Prevention, 2014c), including New Zealand (Ministry of Health, 2016d) (Table 2.5). Asian adults (especially women) continue to be the least active ethnic group and remain 25% less likely than non-Asians to meet physical activity guidelines (Ministry of Health, 2016d); well over half (55%) of Asian adults fail to meet physical activity guidelines (Ministry of Health, 2016d). Rates of physical activity among Pacific adults had been trending downward prior to 2014/15 when a sharp (21%) increase on the previous year occurred (Ministry of Health, 2015f). In the same year, Pacific men were reported as being the most active group (64%) in New Zealand; an increase of over 12% from the previous year. The reasons behind these dramatic increases remain unexplained and should be interpreted with caution until further surveys confirm whether these increases are a continuing trend (Ministry of Health, 2015f).

Table 2.5. Prevalence of regular physical activity and physical inactivity in the New Zealand adult population (2014/15)

	Total %	Men %	Women %
Regularly physically active [a]			
Māori	53.1	59.9	46.9
Pacific	54.3	63.5	46.2
Asian[c]	44.5	48.8	40.3
European/Other[d]	51.7	56.0	47.7
Total	**50.7**	**55.2**	**46.5**
Physically inactive [b]			
Māori	16.8	12.4	20.8
Pacific	16.3	12.7	19.5
Asian[c]	16.0	14.3	17.7
European/Other[d]	13.5	11.2	15.7
Total	**14.3**	**12.0**	**16.5**

Unadjusted prevalence of regular physical activity in adult population aged ≥15 years (Ministry of Health, 2015f).

Notes: [a] Regular physical activity is defined as meeting the basic physical activity guidelines for aerobic activity (≥30 min/day of moderate intensity physical activity on ≥5 days in the previous week) (Ministry of Health, 2016d); [b] Physical inactivity is defined as performing <30 min physical activity during the previous week (Ministry of Health, 2015a); [c] Individuals who identify as descending from any area of Asia, including South Asian (e.g. India); [d] Other includes all individuals not identifying as European, Māori, Pacific or Asian.

Rates of physical inactivity are similar across most ethnic groups in New Zealand, although European/Other adults have been the least inactive group (~13%) for a number of years (Ministry of Health, 2015a) (Table 2.5). Inactivity among Māori adults almost doubled over an eight year period, increasing from 9% in 2007 to 17% in 2015 (Ministry of Health, 2008b; Ministry of Health, 2015f); this rapid increase is concerning and warrants further investigation.

2.4.1.2 Physical activity profile of New Zealand women

Despite 76% of New Zealand women reporting participation in some form of recreational or sporting activity at least once in any given week (Sport New Zealand, 2015), less than half (47%) of New Zealand women met national physical activity guidelines in 2015 (Ministry of Health, 2016d). These women who did meet the guidelines likely comprised some of the 38% of all women who report participating in recreational or sporting activities on most days of the week (Sport New Zealand, 2015).

Walking is by far the most popular recreational physical activity across all groups of New Zealand women (Sport New Zealand, 2015). When walking is excluded from analyses, women participating in a recreational or sporting activity at least weekly fall from 76% to 49%, highlighting the high prevalence of walking as a recreational pursuit (Sport New Zealand, 2015). Other recreational activities with high female participation include swimming (33%), equipment-based exercise (22%) and cycling (including mountain biking) (22%); however, participation in any of these activities is less than half that of walking (72%) (Sport New Zealand, 2015). Women have a stronger tendency toward recreational activities (e.g. walking, attending exercise classes) rather than to sport *per se*, however netball is the number one participation sport among women (8%). In line with the high prevalence of walking, New Zealand women tend toward casual participation (either alone or with others) in recreational and sporting activities rather than competitive events and races (Sport New Zealand, 2015).

Understanding the incentives and barriers to physical activity, and the recreational activity preferences in different sectors of the population is important in order to effectively promote physical activity participation in specific groups (Ministry of Health, 2003). New Zealand women are motivated to exercise primarily for health and fitness benefits, and simple enjoyment (Sport New Zealand, 2015). However, incentives to exercise do seem to vary by ethnicity. Non-Pacific New Zealand women consider proximity to exercise amenities and other environmental factors (e.g. accessibility to exercise sessions), along with additional time (e.g. opportunity to exercise during work time) and free gym memberships as incentives to exercise

(Sport New Zealand, 2015). In contrast, Pacific mothers report child care, social support and encouragement as incentives to becoming or remaining physically active (Schluter *et al.*, 2011). The greatest barrier to physical activity among New Zealand women is lack of time, particularly due to family responsibilities (Sullivan *et al.*, 2003; Schluter *et al.*, 2011; Sport New Zealand, 2015). Cost, discouragement or lack of encouragement from others, and child care issues are also barriers that prevent or deter New Zealand women from increasing their levels of physical activity (Sullivan *et al.*, 2003; Schluter *et al.*, 2011; Tava'e and Nosa, 2012; Sport New Zealand, 2015). Cultural ties and social acceptability of physical activity might also be a barrier to participation in some cultures (World Health Organization, 2007). For example, participation in traditional activities (e.g. traditional games at cultural gatherings) may be viewed more favourably than fitness-oriented activities such as running; cultural or religious protocols might inhibit female or Sunday participation in sport or physical activity (World Health Organization, 2007; Gordon *et al.*, 2013). Furthermore, the vital role that Pacific women play in the stability of the family and in the wider community has also been suggested as a reason for low participation in physical activity among some Pacific women (Koloto and Sharma, 2006).

2.5 Overweight and obesity as a health risk factor

Obesity has reached epidemic proportions in many parts of the world. The prevalence of overweight and obesity (BMI ≥25 kg/m^2) in adults is estimated at 2.1 billion worldwide (37% males, 38% females; 2013 figures), representing a rise of 28% over the last three decades (Ng *et al.*, 2014). Obesity and excess body fatness are associated with a range of negative health consequences and have been found to substantially increase the risk of the major non-communicable diseases including ischemic heart disease, stroke, many cancers and type 2 diabetes (World Health Organization, 2015b). In 2015, overweight and obesity accounted for an estimated 4 million deaths globally, equating to 7.1% of deaths from all causes (The GBD 2015 Obesity Collaborators, 2017). Of all global deaths related to high BMI, almost 70% were from cardiovascular disease alone (The GBD 2015 Obesity Collaborators, 2017).

2.5.1 Etiology of obesity

Obesity arises as a consequence of how the body regulates energy intake, energy expenditure and energy storage, and reflects a state of positive energy balance (Hall *et al.*, 2011; Blundell *et al.*, 2015; Hopkins and Blundell, 2016). Known contributors include imbalances in pathways of glucose and lipid metabolism that occur as a consequence of variations in diet quantity and quality, sedentary lifestyle, physical inactivity and genetic predisposition (Blundell *et al.*, 2015). A vicious cycle follows (Maffetone *et al.*, 2017), involving a state of excessive insulin secretion and a series of metabolic responses that produce systemic insulin resistance (Gregor and Hotamisligil, 2011; Park *et al.*, 2014). Insulin insensitivity is accompanied by increased oxidative stress, leptin secretion, and inflammation, a decreased ability to metabolise lipid and a default to storing energy as adipose tissue (Gregor and Hotamisligil, 2011; Park *et al.*, 2014).

2.5.2 Obesity in New Zealand

New Zealand is the third most obese nation in the OECD (Organisation for Economic Co-operation and Development) (OECD, 2015). Almost two-thirds of New Zealand adults are classified as having an unhealthily high BMI (≥25 kg/m^2) and an estimated 1.1 million of those are obese (BMI ≥30.0 kg/m^2) (Ministry of Health, 2015a). Obesity now ranks ahead of tobacco, and second only to diet, as a risk factor for health loss (i.e. disability adjusted life years (DALY)) among New Zealanders (Ministry of Health, 2016a). Obesity adds substantially to socio-economic burden (Ng *et al.*, 2014), costing an estimated $849m in 2006 when accounting for both health care and costs attributable to lost productivity and short-term absenteeism (Lal *et al.*, 2012). Projected out to current population levels and obesity prevalence, obesity might cost around $1b annually in today's terms.

Alarmingly, only 33.1% of New Zealand adults are within the healthy BMI range (18.5-24.9 kg/m^2) (Ministry of Health, 2015f). A further 34.9% of New Zealand adults are overweight, and 30.7% are obese (Ministry of Health, 2015f). Possibly even more alarming is the 5.3% of adults (males 3.6%, females 7.0%) who are morbidly obese (BMI >40 kg/m^2), an increase of 18% from the previous year alone (Ministry of Health, 2015a). Overweight and obesity prevalence is rising for almost all age, sex and ethnic groups of the New Zealand population (Ministry of Health, 2015f) and is higher among women than men in all age and ethnic groups, except Asian (Ministry of Health, 2015a).

Over the last three decades, the BMI of New Zealand women has increased at a rate (1.2 kg/m^2 per decade) and to a level (28.1 kg/m^2) that is second only to the USA among high income countries (Finucane *et al.*, 2011). Currently, 61.5% of New Zealand women are either overweight or obese (Ministry of Health, 2015a) (Table 2.6), putting a large portion of the New Zealand female population at significant health risk from obesity-related diseases and complications (De Lorenzo *et al.*, 2013; World Health Organization, 2015b). Obesity prevalence is highest among Pacific women (69.5%), whilst 47.6% of Māori and 30.6% of European women are obese; obesity among Asian women is a mere 9.2% (Ministry of Health, 2015a) (Table 2.6).

Table 2.6. Percentage of New Zealand women in weight categories by ethnicity (2014/15)

	Healthy range	Overweight	Obese			
			Class I	Class II	Class III	Total obese
BMI (kg/m^2)	18.5-24.9	25.0-29.9	30.0-34.9	35.0-39.9	≥40.0	≥30.0
Ethnicity (%)						
Māori	24.9	26.2	21.7	13.4	12.5	47.6
Pacific	11.1	19.1	24.4	20.8	24.2	69.5
Asian[a]	58.5	27.9	4.9	2.5	1.9	9.2
European/Other	36.8	30.8	17.5	7.2	5.9	30.6
Total	**36.6**	**29.5**	**16.8**	**8.2**	**7.0**	**32.0**

Adapted from National Health Survey 2014/15 (Ministry of Health, 2015a).
Abbreviations: BMI, body mass index; Note: [a] Individuals who identify as descending from any area of Asia, including South Asian (e.g. India).

2.5.3 Classification of obesity

Body mass index is a widely used indicator of body mass-related health status and quantifies the relationship between body mass and height in a power-type index (Blackburn and Jacobs, 2014); body mass (kg) is divided by the square of height (m) to give BMI in kg/m^2 (Table 2.7). Originally referred to as the Quetelet Index (Blackburn and Jacobs, 2014), BMI is used extensively by clinicians, epidemiologists and many others to categorise weight status and obesity-related disease risk (World Health Organization, 2006; Ministry of Health, 2008a).

Table 2.7. Classifications of obesity

Classification	BMI (kg/m^2)	BF% (%)	Risk of BMI-related health conditions
Underweight	<18.5	<18.0	Low risk
Normal range	18.5-24.9	18.0-29.9	Average risk
Overweight	25.0-29.9	30.0-35.0	Increased risk
Obese	≥30.0	>35.0	Substantially increased risk
Obese I	30.0-34.9		Moderate risk
Obese II	35.0-39.9		Severe risk
Obese III	≥40.0		Very severe risk

Abbreviations: BMI, body mass index; BF%, body fat percentage.
(World Health Organization, 2006; Ministry of Health, 2008a; De Lorenzo *et al.*, 2013; Oliveros *et al.*, 2014)

BMI does not distinguish body fatness or its distribution, nor does it discriminate lean muscle mass from other body mass (Deurenberg, 2001; Okorodudu *et al.*, 2010); for these reasons the appropriateness of BMI as a diagnostic tool for obesity, especially at the individual level, has been questioned (Bosy-Westphal *et al.*, 2005; Romero-Corral *et al.*, 2008; Okorodudu *et al.*, 2010; Phillips *et al.*, 2013). In a large cross-sectional study of Italian adults, 73% of women were classified as obese by BF% (>35% BF), while a mere 32% were regarded as obese when using BMI (≥30 kg/m^2) (De Lorenzo *et al.*, 2013). Similarly, a meta-analysis and analysis of NHANES data found that over half of people with excess body fat were not identified as obese at a BMI cut-off of ≥30 kg/m^2 (Romero-Corral *et al.*, 2008; Okorodudu *et al.*, 2010).

A healthy BMI with excess body fatness or low lean mass (i.e. normal-weight obese) can mask potential metabolic disease risk (Romero-Corral *et al.*, 2010; Gomez-Ambrosi *et al.*, 2012) and go unnoticed in routine health screenings and subsequent diagnoses such as type 2 diabetes (Romero-Corral *et al.*, 2010; Oliveros *et al.*, 2014). Indeed, normal-weight obese women had similar lipoprotein ratios and oxidative stress levels as overweight-obese women (De Lorenzo *et al.*, 2006) and a higher prevalence of metabolic syndrome, cardiovascular disease and dyslipidemia compared to women with normal BF% (Romero-Corral *et al.*, 2010). Similarly, 21.4% of New Zealand European women sampled had normal BMI but high BF% (≥30%) and elevated leptin and insulin concentrations (Kruger *et al.*, 2010). These studies highlight limitations in the diagnostic performance of BMI to identify obesity via adiposity at the individual level, and particularly in the intermediate range (BMI 25-30 kg/m^2; r = 0.32, p = 0.0001) (Romero-Corral *et al.*, 2008; Okorodudu *et al.*, 2010). However, BMI is not intended to measure individual level body fatness *per se*, but rather to predict body mass-related metabolic risk at the population level (Bosy-Westphal *et al.*, 2005). At the population level, BMI has been reported as a positive predictor for diagnosing obesity, with excellent specificity in both sexes when BMI is ≥30 kg/m^2, and has excellent correlation with BF% (r = 0.87, p = 0.0001) in women of all ages and body composition profiles (Romero-Corral *et al.*, 2008).

BMI has not been validated beyond the mainly Caucasian populations on which it was developed, and therefore does not differentiate ethnic background (Blackburn and Jacobs, 2014). Hence, the appropriateness of standardised BMI cut-off points across different ethnicities has been questioned (Deurenberg, 2001). Differences in BF% and visceral fat but not in BMI or waist circumference were reported among African-American, Hispanic and Caucasian women (Carroll *et al.*, 2008; Camhi *et al.*, 2011). Similarly, at any given BMI, BF% was higher among New Zealand European compared to Māori or Pacific adolescents (Sluyter *et al.*, 2011) and adults (Swinburn *et al.*, 1999; Rush *et al.*, 2007; Rush *et al.*, 2009). Ethnic-specific BMI cut-offs were suggested for obesity assessment in these populations (Swinburn *et al.*, 1999) and demonstrated using a reference BMI of 30 kg/m^2, equating to 43% body fat, in European women (Rush *et al.*, 2009). Body fat of 43% corresponded to a BMI of 33 kg/m^2 in Māori, 35 kg/m^2 in Pacific and only 26 kg/m^2 in Asian Indians, essentially over- or under-estimating obesity in these groups (Rush *et al.*, 2009). However, separate BMI cut-offs for Māori and Europeans were refuted with evidence that metabolic risk (e.g. insulin sensitivity, metabolic syndrome) was similar across ethnicities at any given BMI, regardless of differences in BF% (Taylor *et al.*, 2010).

The national nutrition and health surveys of 1997 and 2002/03 adopted ethnic-specific BMI cut-offs based on the recommendations of Swinburn *et al.* (1998), raising cut-offs for Māori and Pacific adults (overweight, ≥27.0 kg/m^2; obese ≥32.0 kg/m^2), but retaining WHO classifications for European adults (i.e. overweight, ≥25.0 kg/m^2; obese ≥30.0 kg/m^2) (World Health Organization, 2006). Following subsequent evidence and recommendations to the contrary (Taylor *et al.*, 2010), the 2008 and subsequent national health surveys reverted to, and still retain, the WHO's single set of BMI cut-offs for all ethnic groups (World Health

Organization, 2006; Ministry of Health, 2008a). Indeed, BMI remains the best and simplest method for speedy and cost effective assessment of body mass-related metabolic risk, especially in the epidemiological context (Okorodudu *et al.*, 2010).

2.6 Health indicators associated with physical activity

Physical activity substantially reduces the risk of many chronic diseases including the three major non-communicable diseases (i.e. cardiovascular disease, type 2 diabetes, some cancers), and is one of the most modifiable risk factors in the causal pathways of these diseases (World Health Organization, 2010; Sattelmair *et al.*, 2011; Aune *et al.*, 2015). Experimental and epidemiological studies similarly confirm an inverse relationship between physical activity and these areas of major health concern (Brown *et al.*, 2007; Sattelmair *et al.*, 2011; Goncalves *et al.*, 2014; Aune *et al.*, 2015). In contrast, physical inactivity causes approximately 5.3 million deaths annually worldwide and is responsible for 6-10% of the burden from the three major non-communicable diseases (Lee *et al.*, 2012). Such alarming statistics have identified physical inactivity as an important health risk factor, similar globally in its level of mortality to smoking (Lee *et al.*, 2012). Globally and in Australasia, physical inactivity is the fourth ranked risk factor for disease burden (Lee *et al.*, 2012), and in New Zealand alone, accounts for 12.7% of all-cause mortality (Lee *et al.*, 2012) and 3% of all health loss (i.e. DALYs) (Ministry of Health, 2016a).

Before presenting evidence for the protective effects of physical activity on two of the major non-communicable diseases (cardiovascular disease and type 2 diabetes), a number of metabolic biomarkers important in the development of these diseases will be discussed.

2.6.1 Biomarkers of diseases moderated by physical activity

Elevated HbA1c (glycosylated haemoglobin), fasting glucose and insulin are important indicators of metabolic dysfunction (Tsoukas *et al.*, 2013), and are key risk factors for the development of type 2 diabetes; characterised by increased insulin production and resistance, and altered glucose uptake (Martin *et al.*, 1992; Gregor and Hotamisligil, 2011; McArdle *et al.*, 2013). Fasting glucose is a marker of acutely circulating concentrations of glucose, whereas HbA1c indicates blood glucose profile over a preceding month (Tsoukas *et al.*, 2013).

Lipid biomarkers are associated with many disease states including cardiovascular disease and type 2 diabetes, and are known to improve with increased physical activity. LDL-c is a key component in the development of atherosclerosis and also contributes to vascular inflammation (Badimon and Vilahur, 2012), both major risk factors for cardiovascular disease. On the other hand, HDL-c has a protective effect against atherosclerosis and cardiovascular disease risk (Badimon and Vilahur, 2012), and is inversely associated with coronary heart disease morbidity and mortality (Grundy *et al.*, 2002). Triglycerides are an important risk marker for cardiovascular disease (Miller *et al.*, 2011), and high triglyceride concentrations occur in conjunction with obesity and insulin resistance (Miller *et al.*, 2011). Combined, elevated LDL-c and triglyceride concentrations, and low HDL-c are associated with obesity and insulin resistance, and are contributors to metabolic syndrome (Grundy *et al.*, 2002).

2.6.2 Cardiovascular disease

Cardiovascular disease accounts for 33% of deaths annually in New Zealand (Ministry of Health, 2015e), and including type 2 diabetes (since most diabetes-related health loss is vascular in nature (Ministry of Health, 2016a)), is the cause of 17% of health loss in the total New Zealand population. Coronary heart disease specifically, ranks second behind back disorders for health loss among New Zealand women (Ministry of Health, 2016a). Furthermore, Māori women are two-thirds more likely to suffer stroke (Ministry of Health, 2015b), and twice as likely to die from ischemic heart disease as non-Māori women (Ministry of Health, 2016c).

Physical activity provides substantial protection against cardiovascular disease in a negative, dose-dependent manner (Oguma and Shinoda-Tagawa, 2004; Warburton *et al.*, 2006; Sattelmair *et al.*, 2011). Analysis of 33 prospective cohort studies found that women meeting basic physical activity guidelines had 14% lower risk of coronary heart disease than those not meeting the same guidelines (Sattelmair *et al.*, 2011). Even greater protection (20%) was afforded to those meeting advanced guidelines (>300 min/week moderate intensity exercise) (Sattelmair *et al.*, 2011). However, women performing frequent strenuous exercise were at higher risk of some cardiovascular diseases (e.g. coronary heart disease, stroke) than those performing strenuous exercise less frequently or frequent exercise at only moderate intensity (Armstrong *et al.*, 2015). The physiological burden (e.g. acute vascular responses such as reduced flow-mediated dilation and increased oxidative stress) caused by very intense physical exertion (Wilson et al., 2015) may explain the slightly increased risk among these very active women. Nevertheless, women exercising at any frequency or intensity are still at lower risk of cardiovascular disease than habitually inactive women (Ferreira *et al.*, 2003; Oguma and Shinoda-Tagawa, 2004; Sattelmair *et al.*, 2011; Armstrong *et al.*, 2015). Supporting these findings is extensive experimental data (Table 2.8) from aerobic and high-intensity intermittent exercise training interventions in which many markers of cardiovascular disease risk (e.g. BMI, waist-to-hip ratio, HDL-c, LDL-c, triglycerides) were significantly improved with physical activity among overweight-obese and inactive women (Jorge *et al.*, 2011; Donnelly *et al.*, 2013; Hazell *et al.*, 2014; Share *et al.*, 2015; Korshoj *et al.*, 2016; Weiss *et al.*, 2016). Furthermore, arterial stiffness, one of the major risk factor for cardiovascular disease, was inversely and independently associated with cardiovascular fitness and daily physical activity in both men and women (Ferreira *et al.*, 2003).

Table 2.8. Exercise intervention studies investigating metabolic and body composition outcomes associated with physical activity

Reference	Population characteristics	Intervention details	Intervention compared to baseline within groups (no symbol indicates p = 0.05, *indicates p < 0.001)	
King et al. (2008)	35 sedentary, overweight-obese adults (25 female); age 39.6 y; BMI 31.8 kg/m^2	12 week, 5 day/week. Aerobic training, 500 kcal/session.	Body mass*	-3.7 kg
			Fat mass*	-3.7 kg
Tjonna et al. (2008)	30 adults with metabolic syndrome (15 female); age 52.3 y; BMI 30.4 kg/m^2	16 week, 3 day/week. High intensity interval training (HIIT): 40 min/session. Continuous moderate aerobic training: 47 min/session.	HIIT:	
			Body mass	-2.3 kg
			BMI	-0.7 kg/m^2
			Waist circumference	-5.0 cm
			Systolic BP	-9 mmHg
			Mean arterial BP	-6 mmHg
			HOMA-IR	15.0%
			HDL-c	0.15 mmol/L
			VO_{2max}	12.3 ml/kg/min
			Continuous:	
			Body mass	-3.6 kg
			BMI	-1.2 kg/m^2
			Waist circumference	-6.0 cm
			Systolic BP	-10 mmHg
Trapp et al. (2008)	45 normal weight women; age 18-30 y; BMI 23.2 kg/m^2	15 week, 3 day/week. HIIT: 20 min/session. Steady state aerobic: 40 min/session.	HIIT:	
			Fasting insulin	-6.0 µlU/ml
			Body mass	-1.5 kg
			Fat mass	-2.5 kg
			BF%	-2.7%
			VO_{2peak}*	7.6 ml/kg/min
			Steady state:	
			VO_{2peak}	6.0 ml/kg/min

Reference	Population characteristics	Intervention details	Intervention compared to baseline within groups (no symbol indicates *p* = 0.05, *indicates *p* < 0.001)	
Tjønna *et al.*(2009)	56 overweight-obese adolescents (28 girls); age 14.0 y; BMI 33.2 kg/m^2	HIIT: 3 month, 2 day/week, 40 min, with 12 month followup. Advice: 12 month exercise, dietary, psychological advice.	HIIT (at 12 mth followup):	
			BMI*	-1.8 kg/m^2
			Waist circumference	-5.2 cm
			BF%*	-2.0%
			Systolic BP*	-7.9 mmHg
			Diastolic BP	-4.9 mmHg
			Mean arterial BP*	-6.2 mmHg
			VO_{2max}	3.7 ml/kg/min
			Advice:	
			Systolic BP*	5.2 mmHg
Balducci *et al.* (2010)	82 adult patients with type 2 diabetes and metabolic syndrome, without CVD (34 female); age 40-75 y; BMI 27-40 kg/m^2	12 months training. Low: structured counselling to perform low intensity aerobic exercise. High: 2 day/week, 60 min supervised aerobic exercise @ 70-80% HR_{max}. Aerobic + resistance: 2 day/week, 40 min as per High plus 20 min resistance exercise	Low:	
			HbA1c	-0.45%
			High:	
			HbA1c*	-0.95%
			HOMA-IR	-0.85
			Waist circumference	-2.2 cm
			VO_{2max}*	6.5 ml/kg/min
			HDL-c	3.5 mg/dl
			Aerobic + resistance:	
			HbA1c*	-1.09%
			HOMA-IR*	-1.86
			VO_{2max}*	6.5 ml/kg/min
			HDL-c*	44.2 mg/dl
			Body mass	0.6 kg
			Waist circumference *	5.0 cm

Reference	Population characteristics	Intervention details	Intervention compared to baseline within groups (no symbol indicates p = 0.05, *indicates p < 0.001)	
Jorge *et al.* (2011)	48 overweight-obese type 2 diabetic adults (30 female); age 53.9 y; BMI 25-40 kg/m^2	12 week, 3 day/week, 60 min supervised exercise. Aerobic, Resistance, or Aerobic + resistance training	Aerobic:	
			Systolic BP	-10.0 mmHg
			Diastolic BP	-8.9 mmHg
			Fasting plasma glucose	-19.8 mg/dl
			Postprandial plasma glucose	-40.67 mg/dl
			Total cholesterol	-18.31 mg/dl
			HDL-c	-3.04 mg/dl
			Triglycerides	-14.25 mg/dl
			VO_{2max}	3.23 ml/kg/min
			Resistance:	
			Systolic BP	-10.0 mmHg
			Diastolic BP	-2.5 mmHg
			Fasting plasma glucose	-28.1 mg/dl
			Postprandial plasma glucose	-11.1 mg/dl
			Total cholesterol	-11.4 mg/dl
			HDL-c	-4.63 mg/dl
			Triglycerides	-81.8 mg/dl
			Aerobic + resistance:	
			Systolic BP	-3.8 mmHg
			Diastolic BP	-7.5 mmHg
			Fasting plasma glucose	-12.6 mg/dl
			Postprandial plasma glucose	-20.2 mg/dl
			Total cholesterol	-26.1 mg/dl
			Triglycerides	-26.1 mg/dl

Reference	Population characteristics	Intervention details	Intervention compared to baseline within groups (no symbol indicates p = 0.05, *indicates p < 0.001)	
Rosenkilde *et al.* (2012)	61 healthy, inactive, overweight males; age 29.0 y; BMI 27.9 kg/m^2	13 week aerobic training, 3 day/week >70 HR_{max}, 3 day/week self-paced. Moderate: 300 kcal/session. High: 600 kcal/session.	Moderate:	
			VO_{2max}	7.7 ml/kg/min
			Body mass	-3.6 kg
			Fat mass	-4.0 kg
			High:	
			VO_{2max}	7.0 ml/kg/min
			Body mass	-2.7 kg
			Fat mass	-3.8 kg
Donnelly *et al.* (2013)	100 healthy overweight-obese adults (46 females); age 18-30 y; BMI 25-40 kg/m^2	10 month supervised exercise 5 day/week, ~70% HR_{max}. Moderate: 400 kcal/session. High: 600 kcal/session.	Moderate:	
			Body mass	-3.9 kg
			Fat mass	-3.5 kg
			BF%	-2.9%
			VO_{2max}	18.3 ml/kg/min
			High:	
			Body mass	5.2 kg
			Fat mass	-5.2 kg
			BF%	-4.4%
			VO_{2max}	20.0 ml/kg/min
Hazell *et al.* (2014)	15 recreationally active females; age 22.9 y	6 week, 3 day/week HITT training.	Fat mass	-1.2 kg
			Waist circumference	-2.8 cm
			VO_{2max},	4.0 ml/kg/min
			Fat free mass	0.6 kg

Reference	Population characteristics	Intervention details	Intervention compared to baseline within groups (no symbol indicates p = 0.05, *indicates p < 0.001)	
Skrypnik *et al.* (2015)	44 abdominally obese females; age 18-65 y; BMI ≥30 kg/m^2; WC >80 cm	3 month, 3 day/week, 45 min. Aerobic: 50-80% HR_{max}. Aerobic + resistance: 20 min resistance, plus 25 min aerobic @ 50-80% HR_{max}.	Aerobic:	
			Body mass*	-2.2 kg
			BMI*	-0.9 kg/m^2
			Waist circumference*	-5.3 cm
			Waist-to-hip ratio	-0.02
			BF%*	-2.0%
			Fat mass*	-2.8 kg
			Systolic BP	-6.7 mmHg
			Diastolic BP	-5.5 mmHg
			VO_{2peak}*	-3.1 ml/kg/min
			Aerobic + resistance:	
			Body mass	-2.7 kg
			BMI*	-1.0 kg/m^2
			Waist circumference*	-7.7 cm
			Waist-to-hip ratio	-0.04
			BF%*	-2.0%
			Fat mass*	-2.7 kg
			Systolic BP	-8.9 mmHg
			Diastolic BP	-4.0 mmHg
			Lean mass*	0.8 kg
			Fat free mass*	0.7 kg
			VO_{2peak}*	3.8 ml/kg/min
Korshoj *et al.* (2016)	116 cleaning staff (88 females); age 45.3 y; BMI 26.7 kg/m^2	12 month, 2 day/week, 30 min group aerobic exercise sessions ≥60% HR_{max}.	VO_{2max}	4.0 ml/kg/min
			Waist circumference	-2.9 cm
			Diastolic BP	-4.3 mmHg
			LDL-c	-0.9 mmol/L

Reference	Population characteristics	Intervention details	Intervention compared to baseline within groups (no symbol indicates $p = 0.05$, *indicates $p < 0.001$)	
Weiss *et al.* (2016)	52 inactive overweight adults (39 postmenopausal females); age 45-65 y; BMI 25.0–29.9 kg/m^2	12-14 week weight loss with 20% energy deficit/week. Energy restriction: energy restriction only. Aerobic: moderate to high aerobic exercise only. Energy restriction + aerobic: energy restriction plus aerobic exercise.	Energy restriction:	
			Body mass*	-5.4 kg
			BMI*	-1.9 kg/m^2
			Waist circumference*	-6.9 cm
			Fat mass*	-4.1 kg
			Fat free mass*	-1.1 kg
			Trunk fat mass*	-2.4 kg
			Trunk fat% *	-3.7%
			Aerobic:	
			Body mass*	-5.6 kg
			BMI*	-2.0 kg/m^2
			Waist circumference*	-9.8 cm
			Fat mass*	-4.9 kg
			Fat free mass*	-0.2 kg
			BF%	-4.0%
			Trunk fat mass*	-2.9 kg
			Trunk fat%*	-4.8%
			VO_{2max}*	5.3 ml/kg/min
			Energy + aerobic:	
			Body mass*	-6.1 kg
			BMI*	-2.1 kg/m^2
			Waist circumference*	-6.5 cm
			Fat mass*	-5.0 kg
			Fat free mass*	-0.8 kg
			Trunk fat mass*	-3.0 kg
			Trunk fat%*	-4.7%
			VO_{2max}*	2.6 ml/kg/min

Reference	Population characteristics	Intervention details	Intervention compared to baseline within groups (no symbol indicates p = 0.05, *indicates p < 0.001)	
Kleist *et al.* (2017)	82 adults (46 females); age 39.4 y; BMI 31.9 kg/m^2	12 week weight loss. Energy restriction: -500 to -800 kcal/day. Energy restriction + aerobic: Energy restriction plus 3 h/week brisk walking	Energy restriction:	
			Body mass*	-7.0 kg
			BMI	-2.3 kg/m^2
			Waist circumference*	-7.2 cm
			Fat mass*	-4.8 kg
			Fat free mass	-2.2 kg
			Systolic BP*	-4.8 mmHg
			Diastolic BP*	-4.5 mmHg
			LDL-c	-0.29 mmol/L
			Energy + aerobic:	
			Body mass*	-8.8 kg
			BMI	-2.8 kg/m^2
			Waist circumference*	-7.1 cm
			Fat mass*	-6.4 kg
			Fat free mass*	-2.4 kg
			Diastolic BP*	-5.7 mmHg
			Triglycerides*	-0.56 mmol/L
			Total cholesterol	-0.51 mmol/L
			LDL-c*	-0.38 mmol/L
			Insulin	-14.5 pmol/L
			HOMA-IR	-0.6

Abbreviations and symbols: BMI, body mass index; HIIT, high intensity interval training; BP, blood pressure; HOMA-IR, homeostasis assessment model of insulin resistance; HDL-c, high-density lipoprotein cholesterol; VO_2, volume of oxygen; BF%, body fat percentage; HR, heart rate; CVD, cardiovascular disease; HbA1c, glycosylated haemoglobin; WC, waist circumference; LDL-c, low-density lipoprotein cholesterol.

2.6.3 Type 2 diabetes mellitus

Almost 6% of New Zealand women are currently diagnosed with type 2 diabetes. Pacific women though, are 3.5 times more likely to have type 2 diabetes (14.8% prevalence) than non-Pacific women (Ministry of Health, 2015b), placing them at substantially increased risk of the complications of the disease. The impact of physical inactivity on these high rates of type 2 diabetes is especially concerning, as type 2 diabetes is both a major contributor to cardiovascular disease risk and an independent health burden (Peters *et al.*, 2014).

Strong evidence exists in most populations that regular physical activity of any form or volume substantially attenuates type 2 diabetes risk (Cloostermans *et al.*, 2015), with a progressive decline in risk with increasing exercise exposure (Grontved *et al.*, 2014; Aune *et al.*, 2015; Cloostermans *et al.*, 2015). Aerobic, resistance and conditioning exercises have all been inversely associated with the risk of developing type 2 diabetes (Henson *et al.*, 2013; Grontved *et al.*, 2014; Aune *et al.*, 2015). The individual risk factors of type 2 diabetes, including elevated HbA1c, fasting glucose and insulin, as well as high BMI and waist circumference are also inversely associated, and improved, with all forms of exercise (Ross *et al.*, 2004; Lee *et al.*, 2005; Tjønna *et al.*, 2008; Trapp *et al.*, 2008; Balducci *et al.*, 2010; Jorge *et al.*, 2011; Share *et al.*, 2015; Weiss *et al.*, 2016) (Table 2.8). Women fulfilling physical activity guidelines with a combination of resistance and aerobic training reduced their risk of type 2 diabetes by 33% relative to inactive women (Grontved *et al.*, 2014). Intensity of exercise also seems to influence the degree to which physical activity protects against type 2 diabetes; for example, vigorous exercise reduced risk to a greater extent (-39%) than walking (-15%) (Aune *et al.*, 2015). In fact, regardless of whether physical activity participation has been habitually high (risk ratio (RR) 0.59), recently increased (RR 0.64) (Aune *et al.*, 2015), or even only slightly increased (RR 0.90) (Ekelund *et al.*, 2012), the risk of developing type 2 diabetes is significantly reduced. Furthermore, the protective effects of physical activity on type 2 diabetes risk has been reported in both men and women and across most body fat profiles (Jeon *et al.*, 2007; Ekelund *et al.*, 2012; Grontved *et al.*, 2014; Aune *et al.*, 2015). Body composition changes (especially reduced adiposity and increased lean mass) from habitual exercise may account for 20-30% of the association between physical activity and type 2 diabetes risk reduction, and are independent of the other metabolic factors that are improved with physical activity (Aune *et al.*, 2015). Improved body composition likely increases mitochondrial function in contracting skeletal muscle, improving insulin sensitivity and glucose homeostasis (Table 2.8) and consequently, reducing type 2 diabetes risk (Ross *et al.*, 2004; Hawley and Lessard, 2008; Trapp *et al.*, 2008).

Evidence suggests that even levels of physical activity well below physical activity guidelines have conferred greater protection against the three major non-communicable diseases than no exercise at all (Oguma and Shinoda-Tagawa, 2004; Sattelmair *et al.*, 2011; Boyle *et al.*, 2012; Goncalves *et al.*, 2014; Aune *et al.*, 2015). These findings support physical activity guidelines recommending that even some exercise is better than none (Ministry of Health, 2015d).

2.6.4 Weight status

Beyond reducing disease mortality risk, physical activity contributes to maintaining healthy body weight, reducing fat mass and increasing lean muscle mass (Table 2.8), all of which have their own positive health implications. For example, fat loss (total, abdominal and abdominal subcutaneous fat) among obese women following a 14-week aerobic exercise programme was significantly greater than dietary-induced weight loss of equivalent energy deficit (Ross *et al.*, 2004). Even without energy deficit, significant reductions in adiposity were observed following the exercise training protocol (Ross *et al.*, 2004). Improved body composition (BMI, body mass, fat-free mass, fat mass, BF%) has also been reported among normal-weight, over-weight and obese women following both aerobic and high-intensity intermittent training (Table 2.8) (Ross *et al.*, 2004; Trapp *et al.*, 2008; Tjønna *et al.*, 2009; Rosenkilde *et al.*, 2012; Donnelly *et al.*, 2013; Hazell *et al.*, 2014; Share *et al.*, 2015; Weiss *et al.*, 2016). Even greater improvements have been reported in initially inactive women compared to those who were already recreationally active (Trapp *et al.*, 2008; Hazell *et al.*, 2014). Improved body composition resulting from exercise has widespread implications on risk factors associated with the major non-communicable diseases and farther reaching effects than simple reductions in body mass (Table 2.8).

2.7 Measurement of physical activity

Research linking physical activity to health outcomes began during the 1950s with the investigations by Morris and colleagues (Morris *et al.*, 1953). This seminal work examined company and medical records of transport workers to infer links between occupational physical activity and incidence of coronary heart disease among workers (Morris *et al.*, 1953). Not surprisingly, workers in more active occupations (e.g. bus conductors) had lower incidents of coronary heart disease than those with more sedentary jobs such as bus drivers and secretarial staff (Morris *et al.*, 1953). Since this early work, many studies have been conducted using a range of subjective (e.g. questionnaires, activity diaries) and objective (e.g. pedometers, accelerometers) methods to collect physical activity data, in order to better understand the health implications of physical activity.

Population level assessment of physical activity is important in monitoring trends in physical activity behaviours and has traditionally been characterised using self-report questionnaires (Health and Social Care Information Centre, 2015; Ministry of Health, 2015f). More recently, the increasing practicality and economic viability of accelerometers for population-based studies has led to their utilisation in some national surveys (e.g. Canada (Statistics Canada, 2014a), USA (Centers for Disease Control and Prevention, 2014b)). Accelerometer-based assessment of physical activity provides data on the intensity, duration, timing and frequency of activity undertaken during a specified time period (Troiano *et al.*, 2014), without the need for participant recall, as is relied upon with subjective methods (Shephard, 2003; Haskell, 2012). Objective data though, does lack context and specific activity details that can be obtained through subjective methods (Matthews *et al.*, 2012).

Population-based studies in the United States (Centers for Disease Control and Prevention, 2014a) and Canada (Statistics Canada, 2014a) collect vast amounts of health-related data. In these studies, both objective (e.g. accelerometer, spirometry) and subjective (e.g. dietary questionnaires) data are collected, relating to a wide range of health concerns including physical activity, diabetes, infectious diseases and nutrition (Centers for Disease Control and Prevention, 2014c; Statistics Canada, 2014a). These data have contributed to the development and implementation of physical activity guidelines (U.S. Department of Health and Human Services, 2008), paediatric growth charts (Kuczmarski *et al.*, 2002), and health promotion and disease prevention objectives (National Center for Health Statistics, 2010), among numerous other health related initiatives (Centers for Disease Control and Prevention, 2014c).

The New Zealand Health Survey is an annual, subjective assessment of physical in/activity, nutrition and self-reported health status (Ministry of Health, 2015f). Whilst these annual surveys are invaluable for tracking subjectively assessed activity levels and associated trends, detailed data on timing and intensity of physical activity in New Zealand adults (especially women) is lacking. Few studies have objectively measured physical activity in New Zealand adults, especially with a focus on health outcomes. Pedometers and accelerometers have been used in New Zealand to assess occupational differences in physical activity (Schofield *et al.*, 2005) and to validate physical activity questionnaires (Mackay *et al.*, 2007); however these data were not used to specifically relate physical activity to health outcomes. More recently, accelerometers were used to investigate interactions between numerous aspects of built environments (e.g. footpaths, street layout, parks) and levels of physical activity and measure of obesity (Witten *et al.*, 2008; Witten *et al.*, 2012; Oliver *et al.*, 2015). However, gaps exist in the understanding of how all components of physical activity among New Zealand women impact indicators of long term health. Given that over a half of the female adult population are insufficiently active to be regarded as having an active lifestyle, gaining this understanding through objective physical activity assessment is of significant public health importance (Ministry of Health, 2015f).

2.7.1 Subjective methods

Until the early 2000s, the only cost-effective alternative to direct observation for assessment of habitual physical activity were subjective methods, predominantly in the form of self-report interviews, questionnaires and diaries (Dishman *et al.*, 2001). Physical activity diaries document activities during a period of time, rather than retrospectively as with questionnaires, and provide information that is difficult to obtain other than by direct observation (Dishman *et al.*, 2001). When completed judiciously, diaries provide detailed information on the type, frequency, and duration of activities. However, diaries are also highly burdensome on participants, particularly when required to account for regular time blocks (e.g. 15 min periods) (Dishman *et al.*, 2001). As well, the mere act of recording physical activity might subconsciously motivate individuals to increase physical activity participation during the assessment period (Dishman *et al.*, 2001). An alternative to physical activity diaries are retrospective physical activity questionnaires (PAQs). Such questionnaires can be self-administered or via interview, and are a convenient and unobtrusive instrument to assess physical activity levels of individuals or large populations (van Poppel *et al.*, 2010; Steene-Johannessen *et al.*, 2016). Their speed of administration, relative low cost and minimal participant burden, make PAQs a feasible assessment option, especially in the epidemiological setting (Dishman *et al.*, 2001). A wide range of PAQs are publically available, covering different assessment periods (e.g. 24-h recall, past month, lifetime) and activity domains (e.g. work, home, leisure) (Johnson-Kozlow *et al.*, 2006; MRC Epidemiology Unit, 2006; Maddison *et al.*, 2007; IPAQ, 2010; van Poppel *et al.*, 2010). Many are tailored to specific populations (e.g. obese, elderly) or outcomes (e.g. bone health, work place physical activity) (Dolan *et al.*, 2006; MRC Epidemiology Unit, 2006; Forsen *et al.*, 2010; IPAQ, 2010; van Poppel *et al.*, 2010).

Numerous validity and reliability studies have been conducted, validating specific PAQs against objective measures such as doubly labelled water or accelerometry (Prince *et al.*, 2008; Boon *et al.*, 2010; van Poppel *et al.*, 2010; Helmerhorst *et al.*, 2012; Cerin *et al.*, 2016). Results from such studies reveal that very few PAQs score well on both reliability and validity (van Poppel *et al.*, 2010; Helmerhorst *et al.*, 2012). Most PAQs do seem to have acceptable reliability, although validity is often only moderate, at best (van Poppel *et al.*, 2010; Helmerhorst *et al.*, 2012). Due to the highly variable nature of physical activity among free-living individuals, valid assessment via self-report remains extremely difficult (Helmerhorst *et al.*, 2012). Choosing the most appropriate PAQ for an intended research setting should consider the questionnaire validity and reliability in the particular setting (including population) along with the physical activity outcomes of interest (van Poppel *et al.*, 2010). When using PAQs to compare physical activity against guidelines, questions on the frequency and duration of physical activity in all domains (i.e. transportation, work, home, leisure) should be included to uphold content validity (van Poppel *et al.*, 2010).

The International Physical Activity Questionnaire (IPAQ) (in its numerous long and short forms), is the most commonly used and validated in the literature (Hagstromer *et al.*, 2006; van Poppel *et al.*, 2010; Silsbury *et al.*, 2015) and has been cited in hundreds of publications (Rosenberg *et al.*, 2008; Forsen *et al.*, 2010; IPAQ, 2010; Harrison *et al.*, 2011; Adams *et al.*, 2013; Cerin *et al.*, 2016; Steene-Johannessen *et al.*, 2016). The IPAQ has been translated into 22 languages, and exists in 38 different forms (i.e. long v short, telephone v self-administered, different languages), some with cultural-specific adaptations (IPAQ, 2010). The IPAQ-long version is a 31-item assessment of physical activity, covering the previous seven days (or a usual week) in all domains (leisure, transport, occupation, home and sedentary) (Craig *et al.*, 2003). The long version is intended for research use, particularly in domain-specific investigations of physical activity (Cerin *et al.*, 2016). In comparison, the short form IPAQ contains just nine items and also covers the previous seven days (IPAQ, 2010). The IPAQ-short assesses time in different activity intensities and in sedentary behaviour, and is recommended for prevalence and surveillance studies (Craig *et al.*, 2003). Validation studies across many countries have reported the IPAQ as having sufficient validity (r = 0.33-0.39) and reliability (interclass correlation coefficient (ICC) = 0.87-0.90) (Craig *et al.*, 2003; Hagstromer *et al.*, 2006; Boon *et al.*, 2010; Helmerhorst *et al.*, 2012). Given the multitude of different versions of the IPAQ, wide variations in results have been reported (van Poppel *et al.*, 2010; Helmerhorst *et al.*, 2012; Cerin *et al.*, 2016), but overall IPAQs tend to overestimate moderate, vigorous and total physical activity time, and underestimate sedentary time (Hagstromer *et al.*, 2006; Boon *et al.*, 2010; Helmerhorst *et al.*, 2012; Cerin *et al.*, 2016). However, the IPAQ-S7S was reported to have excellent reliability, correlated moderately with accelerometry, and was recommended as the most appropriate of all PAQs for clinical and research settings (Silsbury *et al.*, 2015).

The New Zealand Physical Activity Questionnaire (NZPAQ) was developed for use in the annual New Zealand Health Survey (Moy *et al.*, 2008; Boon *et al.*, 2010) as a modified version of the IPAQ (both long and short versions) to increase its relevance to New Zealand populations and culture (Maddison *et al.*, 2007; Moy *et al.*, 2008). The NZPAQ-long differs from the IPAQ-long in that it gathers information using a retrospective 7-day diary covering the various lifestyle domains (Moy *et al.*, 2008; Boon *et al.*, 2010). Validation of the NZPAQ-short against doubly labelled water showed significant systemic underestimation (-59%) of total energy expenditure (r = 0.38) starting at 1,000 kJ (Maddison *et al.*, 2007). In contrast, the NZPAQ-long overestimated total physical activity by 165% (r = 0.32) against accelerometry (Boon *et al.*, 2010) and by 134% (r = 0.25) against heart rate monitors (Moy *et al.*, 2008), but has been useful in monitoring trends in overall physical activity participation of the population.

The Recent Physical Activity Questionnaire (RPAQ) is an 11-item questionnaire developed as part of the European Prospective Investigation into Cancer and Nutrition Study (MRC Epidemiology Unit, 2006). The questionnaire covers the previous month in four lifestyle domains (work, transportation, leisure, home) and contains a list of 35 groups of leisure time activities against which the frequency and duration of participant engagement are recorded (MRC Epidemiology Unit, 2006). The RPAQ has been reported as a valid instrument for ranking individuals' total and physical activity energy expenditure and time spent in sedentary and in vigorous physical activity (Besson *et al.*, 2010). Significant correlations have also been reported with estimates of total (r = 0.67, p < 0.0001) and physical activity (r = 0.39, p < 0.0001) energy expenditure against doubly labelled water and of time spent in vigorous physical activity (r = 0.70, p < 0.0001) against a combination of heart rate and accelerometry (Besson *et al.*, 2010). The RPAQ has shown good reliability for physical activity energy expenditure (ICC = 0.76) and across activity intensities except transport (ICC 0.74-0.86; transport 0.32, $p = 0.0001$) (Besson *et al.*, 2010).

A limitation of any questionnaire is the susceptibility for reporting bias, either intentional (e.g. social desirability bias) or accidental (e.g. cognitive limitations, memory), and PAQs are no exception (Adams *et al.*, 2005; Prince *et al.*, 2008). The degree to which such bias might influence outcomes has been related to specific populations. For instance, over-reporting of physical activity has been associated with overweight-obese populations (Prince *et al.*, 2008), less active individuals (Moy *et al.*, 2008) and non-European New Zealanders (Moy *et al.*, 2008). Potential also exists for over-reporting when warm up/down periods are mistakenly included in total activity duration (Dyrstad *et al.*, 2014), or misreporting when memorable activities (e.g. strenuous workouts) are accurately reported whereas less memorable activities (e.g. light, incidental activities) might be omitted (Dyrstad *et al.*, 2014). Many PAQs, including those mentioned above, also have a tendency to underestimate physical activity energy expenditure with increasing volumes of activity (Besson *et al.*, 2010; van Poppel *et al.*, 2010) and with timeframes >7 days (Neilson *et al.*, 2008). The focus of PAQs varies widely, as does the application. For instance, the RPAQ elicits frequency and duration of individual leisure-time activities (e.g. cycling, swimming, martial arts) across 35 activity groups whereas the IPAQ does not (Craig *et al.*, 2003; MRC Epidemiology Unit, 2006). On the other hand, the IPAQ covers housework and child care activities, which is absent from the RPAQ (Craig *et al.*, 2003; MRC Epidemiology Unit, 2006).

Notwithstanding the inherent inaccuracies and imprecision of participant recall and reporting bias (Adams *et al.*, 2005; Prince *et al.*, 2008; Dyrstad *et al.*, 2014), few accurate and reliable alternatives to PAQs were available prior to the early 2000s for collecting physical activity data from free-living individuals (Montoye *et al.*, 1983; Dishman *et al.*, 2001; Troiano *et al.*, 2014). Despite the now widespread use of accelerometers for physical activity assessment, PAQs provide complimentary data, often adding context to objective data, and detail of specific activities performed (Helmerhorst *et al.*, 2012; Howitt *et al.*, 2016). PAQs also remain a valuable tool in monitoring the effectiveness of large-scale physical activity interventions and for tracking physical activity trends at a population level (Helmerhorst *et al.*, 2012).

2.7.2 Objective methods

Advances in technology have seen increasing use of objective methods (e.g. accelerometers, pedometers, consumer wearable devices) to assess normal physical activity of free-living individuals (Troiano *et al.*, 2014). The most widely used of these devices for research purposes, is the accelerometer (Chen *et al.*, 2012), however, pedometers and consumer wearables do have application.

2.7.2.1 Pedometers

Pedometers are an accurate, cost-effective and simple device to objectively measure walking and other ambulatory activities. Historically, pedometers have simply been step counters, giving no indication of exercise intensity (Abel *et al.*, 2011). Nonetheless, this step data has been valuable as a basic assessment of physical activity, for establishing trends in step-determined levels of physical activity, and in monitoring activity against the 10,000 steps/day recommendation (Tudor-Locke and Bassett, 2004; Tudor-Locke *et al.*, 2008). Some modern devices can now also assess sedentary behaviour (periods of no step counts) and step rate (cadence) (Abel *et al.*, 2011). This new measure, cadence, has recently been used to indicate activity intensity (Tudor-Locke *et al.*, 2017). A cadence of ~100 steps/min has been consistently found to represent walking of moderate intensity (Abel *et al.*, 2011; Tudor-Locke *et al.*, 2017) and could serve as a surrogate for assessing activity of moderate intensity (Tudor-Locke *et al.*, 2017). Due to the simplicity of these devices, pedometer-derived data (i.e. steps per day) are easily translatable between studies (Bassett *et al.*, 2010) and have been widely used in longitudinal training studies (Leung *et al.*, 2012; Gell and Wadsworth, 2015) and in epidemiology (Bassett *et al.*, 2010; Colpani *et al.*, 2013; Tudor-Locke *et al.*, 2017).

2.7.2.2 Consumer wearables

The term *wearables*, refers to consumable wearable activity monitors. Wearable devices, also known as fitness or activity trackers, have undergone an explosion in popularity in recent years, with over 400 different models on the market in late-2016 (Easton, 2017; Wright *et al.*, 2017). Although not yet of research quality, technology is advancing rapidly and these devices hold great potential for the future. These devices, and their associated apps, provide a vast array of information, including daily steps, sleep hours and quality, predicted VO_2max, change in elevation indicating stair climbing, and nutritional advice (Easton, 2017). Some wearables use feedback and behavioural change techniques (e.g. goalsetting and review) to motivate and encourage increased physical activity (Wright *et al.*, 2017). Web-based fitness communities such as MyFitnessPal and Fitocracy or device-specific apps (e.g. Fitbit) enable social interactions among users to create competition, compare results, and track progress for increased physical activity and healthy lifestyles (Wright *et al.*, 2017). Although only a few devices have been validated against criterion measures (Evenson *et al.*, 2015), wearables do hold potential for research use, especially given the large volumes of ecological data that are collected and transferred continuously (or periodically) to websites or smartphone apps (Wright *et al.*, 2017). In time, once validity and reliability of devices are established, the availability of these large datasets to researchers poses the potential to vastly increase understanding of numerous aspects of physical activity on physiological and health-related outcomes (Evenson *et al.*, 2015; Wright *et al.*, 2017).

2.7.2.3 Accelerometers

Technology

Portable accelerometers were first used to measure physical activity in the early 1980s by capturing accelerations resulting from human movement (Montoye *et al.*, 1983). These large, cumbersome devices, were heavy (~400 g), and their uniaxial technology enabled measurement only in the vertical plane (Montoye *et al.*, 1983). Early accelerometers employed bimorph piezo-electric technology, using crystalline structures on a weighted cantilevered beam to yield electrical signals proportional to the observed acceleration (Troiano *et al.*, 2014). Although this technology provided effective measurement of human movement, devices were costly to manufacture, impractical to wear for prolonged periods and required regular field calibration (Miller, 2013). Outputs from these early accelerometers were alternating current, so detected only transient dynamic accelerations indicating motion, with no capability to acquire data during periods of no activity (Troiano *et al.*, 2014).

Subsequent advances in technology resulted in the widespread use of microelectromechanical systems, utilising capacitive transducers and piezo-resistive technology. Over time, devices have become smaller, lighter and relatively less expensive, with improved reliability, increased battery and memory capacity, and higher-frequency sampling rates (Chen *et al.*, 2012; Plasqui *et al.*, 2013; Troiano *et al.*, 2014). The development of triaxial and omni-directional technology meant that in addition to movement in the vertical plane, data also became available in multiple planes, including antero-posterior and medio-lateral (Chen and Bassett, 2005; John and Freedson, 2012). Additional sensors such as pedometers and inclinometers (to determine posture) were later added to some devices (e.g. Actigraph GT3X+; Actigraph Corporation, Pensacola, FL), increasing the extent and scope of data collection (Sasaki *et al.*, 2011). Newer technology also enabled capture of both static (direct current) and dynamic (alternating current) accelerations (Chen *et al.*, 2012; John and Freedson, 2012; Plasqui *et al.*, 2013), to detect both active and passive behaviour (John and Freedson, 2012). These updated accelerometers not only provided dynamic accelerations indicating activity, but also static accelerations reflecting positional changes, which, if translated to posture, can differentiate between different types of sedentary behaviour (e.g. sitting v lying) (Chen *et al.*, 2012; Plasqui *et al.*, 2013; Troiano *et al.*, 2014). More recently, physiological sensors such as skin temperature, heart rate and galvanic skin response sensors have been incorporated into some devices (e.g. SenseWear Armband; BodyMedia, Inc., Pittsburgh, PA). This additional information provides even greater context to the data, enabling a more comprehensive understanding of physical activity (Chen *et al.*, 2012), and the potential for more indepth analysis of data (Troiano *et al.*, 2014). Technological advances have led to the now widespread use of accelerometers in population-based studies to provide relatively unobtrusive, objective and accurate assessment of normal daily activities from free-living individuals over multiple days (Westerterp, 2009).

Considerations when assessing physical activity using accelerometers

Non-wear time

Accelerometer wear compliance is an ongoing challenge in physical activity surveillance, interventions and epidemiological studies (Hagstromer *et al.*, 2007; Troiano *et al.*, 2008; Oliver *et al.*, 2009; Loprinzi *et al.*, 2012). In most study protocols, participants are instructed to remove accelerometers for activities such as showering and swimming (Choi *et al.*, 2012; Van Der Berg *et al.*, 2017), whilst many also require devices to be removed for sleeping (Matthews *et al.*, 2012; Tudor-Locke *et al.*, 2012; Pedisic and Bauman, 2015). Water-based activities, and those performed during other periods when the device is not worn (e.g. not replaced after showering) are classified as non-wear time and must be categorised separately from periods of zero activity counts (i.e. sedentary time) during actual wear time (Choi *et al.*, 2012). Various algorithms are available to identify and exclude non-wear and sleep time from data (Sirard *et al.*, 2011; Choi *et al.*, 2012). Results from a systematic review (Tudor-Locke *et al.*, 2012) show the most common definition of non-wear time is ≥60 consecutive minutes of 0 cpm, sometimes with allowance for short interruptions (1-2 min) of low level non-zero counts (e.g. device being moved on dresser) (Troiano *et al.*, 2008; Choi *et al.*, 2012; Tudor-Locke *et al.*, 2012). After removal of non-wear periods, the remaining time is regarded as wear time (Tudor-Locke *et al.*, 2012).

Valid wear time

Once total wear time is established, valid wear time must be determined. The number of hours per day and total days of wear determines whether the wear time is regarded as valid (Matthews *et al.*, 2012). In a 2012 systematic review of accelerometer-based studies, a valid day was defined as ≥10 hours of waking wear in 49 of 54 studies (Tudor-Locke *et al.*, 2012). The consistency in this definition is likely partially due to its use in NHANES algorithms and analysis (Tudor-Locke *et al.*, 2012). With decreasing wear-time, all other measured physical activity categories (e.g. moderate) also decrease to some extent, but the most pronounced decreases are reportedly in sedentary time (Masse *et al.*, 2005; Tudor-Locke *et al.*, 2011; Tudor-Locke *et al.*, 2012; Winkler *et al.*, 2012).

The number of valid days required for inclusion in analysis is somewhat variable, and can depend on specific research questions (Matthews *et al.*, 2012). For instance, a greater number of days are required to assess patterns of low-level activity or sedentary behaviour than are required for assessing active behaviour (Matthews *et al.*, 2002). In normally active adult populations, a minimum of four days (usually over a seven-day period) is most common and is considered to be a reliable estimate of habitual physical activity (Trost *et al.*, 2005; Matthews *et al.*, 2012; Tudor-Locke *et al.*, 2012; Pedisic and Bauman, 2015). Some protocols require the four days to include at least one weekend day to account for possible variations in activity patterns between week and weekend days (Trost *et al.*, 2005). When insufficient valid days are identified in data, some researchers require participants to re-wear accelerometers on the particular days of the week for which data were missing (Buman *et al.*, 2010; Candelaria *et al.*, 2012; Matthews *et al.*, 2012; Green *et al.*, 2014).

A 24-hour wear protocol was proposed to eliminate the need for defining wear-time criteria (Matthews *et al.*, 2012) and to improve compliance (Katzmarzyk *et al.*, 2013; Troiano *et al.*, 2014; Huberty *et al.*, 2015; Tudor-Locke *et al.*, 2015). Indeed, a 24-h wear protocol was implemented in the 2011/12 NHANES cycle, increasing compliance from 40-70% (≥6 days with ≥10 h/day) with variations across age groups, to 70-80% (≥6 days with ≥18 h/day) across all age groups (Troiano *et al.*, 2014). A 24-h hip-worn protocol was also employed to increase compliance in a 12-country International Study of Childhood Obesity, Lifestyle and the Environment (ISCOLE) study of children's physical activity behaviours (Katzmarzyk *et al.*, 2013). As many newer devices are now waterproof, the likelihood of obtaining continuous wear increases. Nevertheless, participants are unlikely to wear a device for entire 24-h periods over multiple days, so the need for at least some criteria of wear-time likely persists; the ISCOLE study used the common ≥10 h/day criteria (Katzmarzyk *et al.*, 2013). Moreover, some newer devices are equipped with sensors to detect skin contact (e.g. SenseWear Armband; BodyMedia, Inc., Pittsburgh, PA), making wear compliance and valid wear time easier to determine (Bodymedia, 2013).

Accelerometer placement

Early portable accelerometers were traditionally worn on the hip, since this is close to the centre of the body, and these large devices were most sensitive to vertical movement (Chen and Bassett, 2005). Modern devices, though, are worn at a range of body locations including wrist, ankle, arm and thigh (Pollard and Guell, 2012; Bodymedia, Huberty *et al.*, 2015; Actigraph LLC, 2016). Optimal placement of devices is often dictated by the primary purpose for data collection and the behavioural characteristics of interest (Trost *et al.*, 2005; Chen *et al.*, 2012). For example, Actigraph GT3X devices are typically worn on the hip for physical activity assessment, but on the wrist in sleep studies (Huberty *et al.*, 2015). The thigh mounted activPAL (PAL Technologies Ltd, Glasgow, Scotland) is designed to distinguish postural differences such as sitting and standing, and are used predominantly in studies of sedentary behaviour (Kozey-Keadle *et al.*, 2011; Healy *et al.*, 2015). Wear location somewhat determines attachment method; whilst many devices are attached to a buckled elastic belt (e.g. Actigraph GT3X+), some are attached directly onto the skin with adhesive pads (e.g. activPAL; PAL Technologies, Ltd., Glasgow, Scotland) (Matthews *et al.*, 2012). Some recent devices are even designed to be carried in the pocket of everyday pants to reduce participant burden and inconvenience (e.g. SitFIT; PAL Technologies, Ltd., Glasgow, Scotland).

Commonly used accelerometers

ActivPAL3 and Actigraph GT3X are the most widely used accelerometers currently on the market. The Actigraph GT3X+ (and its predecessors 7164 and GT1M) has been extensively used in small and large physical activity research studies (Buman *et al.*, 2010; Lyden *et al.*, 2012; Henson *et al.*, 2013; Hamer *et al.*, 2014; Barreira *et al.*, 2015; Bellettiere *et al.*, 2015), surveillance settings (Chen *et al.*, 2012; Cain *et al.*, 2013; Hänggi *et al.*, 2013), and in all rounds of NHANES in which physical activity has been objectively measured (Troiano *et al.*, 2008; Tudor-Locke *et al.*, 2010; Troiano *et al.*, 2014). In contrast, the ActivPAL3 (PAL Technologies Ltd, Glasgow, UK) is designed for sedentary research in which the impact of different types of sedentary behaviour (e.g. sitting v lying) are investigated in relation to health outcomes (Kozey-Keadle *et al.*, 2011; Lyden *et al.*, 2012; Healy *et al.*, 2015). Characteristics of these and other commonly used accelerometers are presented in Table 2.9.

Table 2.9. Characteristics and specifications of commonly used accelerometers.

	ActiGraph GT3X+	ActivPAL3	GENEActiv	Actical
Placement	Waist, ankle (PA); wrist (sleep)	Thigh	Wrist	Wrist, waist, ankle
Attachment	Elastic belt (waist), strap (wrist, ankle)	Adhesive pad	Strap	Belt clip (waist), strap (wrist, ankle)
Size (mm)	45 x 33 x 15	35 x 53 x 7	43 x 40 x 13	29 x 37 x 11
Weight (g)	19	15	16	16
Technology	MEMS capacitance transducer	MEMS capacitance transducer	MEMS	Bimorph piezo-electric system
Axes	Tri-axial	Tri-axial	Tri-axial	Omni-directional
Acceleration range (G)	±6	±2	±8	±2
Sampling frequency (Hz)	30-100	20–80	10–100	32
Memory	512 MB	16 MB	512 MB	32 MB
Waterproof	Yes	Yes	Yes	Yes
Measurement capacity	31 days @ 30 Hz; 11.5 days @ 100 Hz	14 days @ 20 Hz	45 days @ 10 Hz; 7 days at @ 100 Hz	Not stated
Inclinometer	Yes	Yes	No	No
Body temperature sensor	No	No	Yes (near, not direct skin contact)	No
Pedometer	Yes	Yes	No	Yes

Abbreviations: PA, physical activity; MEMS, microelectro-mechanical systems.

Data processing and analysis

The effectiveness of accelerometers to convey all aspects of physical activity has historically been limited by the accuracy of data processing methods (Lyden *et al.*, 2011; Bassett *et al.*, 2012; Freedson *et al.*, 2012). Until relatively recently, output of raw acceleration signals were unavailable (Chen *et al.*, 2012; Troiano *et al.*, 2014). Instead, proprietary software used algorithms to transform acceleration signals into 'counts' (the product of the acceleration amplitude and frequency) for a given time window (Chen and Bassett, 2005). The algorithms behind the proprietary software were seldom available to users who were often unaware of the filtering, amplification and sampling frequency applied to their data (Chen and Bassett, 2005). As a consequence, direct comparison of data from different devices was often not possible even if data were collected simultaneously (Troiano *et al.*, 2014). Data were further processed using algorithms to apply *cut-points* (intensity thresholds) to output data as time-per-day spent at different physical activity intensities (e.g. sedentary, moderate) (Freedson *et al.*, 1998; Troiano *et al.*, 2008; Staudenmayer *et al.*, 2012; Troiano *et al.*, 2014). These algorithms were generally developed using linear regression models to determine a line of best fit representing the relationship between accelerometer counts and the energy cost of specific lab-based tasks (Montoye *et al.*, 1983; Troiano *et al.*, 2014).

The assignment of physical activity intensities using cut-point algorithms is still frequently used, but has inherent limitations. Accelerometers were traditionally designed to primarily measure locomotive activities, so many devices do not adequately detect upper body movement (Montoye *et al.*, 1983; Lyden *et al.*, 2011; Lee and Shiroma, 2014). Accelerometers also do not accurately detect stationary activities such as weight training or non-ambulatory activities such as cycling and rowing (Montoye *et al.*, 1983; Herman *et al.*, 2014; Troiano *et al.*, 2014). In fact, hip-worn accelerometers underestimated cycling energy expenditure by 73% compared to walking (Herman *et al.*, 2014). Cut-points and METs represent absolute intensities, and therefore do not account for the functional capacities of different individuals (Norton *et al.*, 2010). Furthermore, accelerometer data evaluated using cut-points may yield similar energy expenditure estimates for activities performed under very different conditions and with vastly different energy costs (Pober *et al.*, 2006). Acceleration signals generated whilst walking in soft sand carrying a child (~7 METs) would appear quite similar to those recorded whilst walking on a firm level surface with no load (3 METs), despite substantially different energy costs (Pober *et al.*, 2006; Troiano *et al.*, 2008; Ainsworth *et al.*, 2011; Lyden *et al.*, 2011; Lee and Shiroma, 2014).

Advances in technology, and pressure from the research community, have led to now readily available raw acceleration signal data (Troiano *et al.*, 2014). Researchers are now able to analyse and reanalyse data using algorithms of their choice (Troiano *et al.*, 2014). Data can be compared across devices and studies, and even combined with other study data, greatly extending the scope of data use and analysis. Data from some large studies (e.g. NHANES, Nurses' Health Study, Womens' Health Initiative) are now available in open source repositories for use by all researchers. Furthermore, analytic techniques such as pattern recognition and machine learning algorithms can take advantage of a much wider array of data to identify specific activities (Pober *et al.*, 2006). All of these factors greatly extend the capacity to manipulate and analyse data.

Analysis using a range of models and algorithms are increasingly utilised in physical activity research, improving interpretation of accelerometer data to more specifically address relevant research questions (Lyden *et al.*, 2014; Ellingson *et al.*, 2016; Kerr *et al.*, 2017). Pattern recognition and behaviour-based machine learning algorithms enable researchers to predict activity type, duration and intensity (Pober *et al.*, 2006) and differentiate between activities. In contrast, isotemporal substitution analysis (Mekary *et al.*, 2009) and compositional data analysis (Chastin *et al.*, 2015) enable researchers to predict the impact of one behaviour on health-related outcomes and other behaviours, whilst bearing in mind that total time per day is finite (i.e. 24 hours).

Machine learning models are developed to recognise patterns in accelerometer signals of specific, known activities (Lyden *et al.*, 2014). Algorithms are then taught to recognise the signal sequences of the known task and those known to precede and succeed it (Pober *et al.*, 2006), enabling the specific activities to be identified and differentiated from others (Pober *et al.*, 2006; Ellis *et al.*, 2014; Kerr *et al.*, 2017). For example, the transition from sitting to standing and then walking has a unique combination of acceleration signals and postural outputs (Bassett *et al.*, 2012; Lyden *et al.*, 2014). Machine learning algorithms were used to predict transportation mode (including riding in a vehicle, walking and cycling) with 90% accuracy (Ellis *et al.*, 2014) and estimate activity status (e.g. sedentary, light physical activity) and duration from data collected in participants' natural environments using both accelerometers and direct observation (Lyden *et al.*, 2014). Under free-living conditions, normal daily activities comprise a range of activity types, intensities and combinations which vary in different populations and environments (e.g. elderly in a retirement village v adolescents attending school) (Butte *et al.*, 2010; Bellettiere *et al.*, 2015). A current limitation of machine learning models is that the population-specific nature of algorithms which cannot be used to predict activities performed by populations (e.g. children v elderly) or environments (e.g. residential care patients v athletes) different to those on which they were developed. To increase the practical application and widespread use of such models, algorithms must be developed and validated on diverse populations over a wide variety of activities (Ellis *et al.*, 2014).

Isotemporal substitution analysis originated in nutrition research to theoretically manipulate nutrient composition in diet (Willett *et al.*, 1997). In physical activity research, total daily time (or accelerometer wear time) is held constant, whilst time is substituted between activities of different intensity or duration, such as substituting 30 min/day of sedentary behaviour with 30 min/day of MVPA (Mekary *et al.*, 2009; Buman *et al.*, 2014; Ekblom-Bak *et al.*, 2016a;

Matthews *et al.*, 2016). Linear regression models are used to predict associated changes in outcome variables (e.g. body composition variable, disease risk markers) when these periods of time are substituted between activities (Mekary *et al.*, 2009; Buman *et al.*, 2014; Healy *et al.*, 2015). Reallocating time from sedentary to MVPA predicted improvements in metabolic risk markers including HbA1c, triglycerides, fasting insulin, HOMA-IR and BMI (Hamer *et al.*, 2014; Ekblom-Bak *et al.*, 2016b) and reduced mortality (Matthews *et al.*, 2016). This technique could also be used to guide physical activity recommendations after evaluating particular exercise regimes (e.g. intensity or duration) most beneficial to changes in metabolic or other variables in specific populations (Buman *et al.*, 2014; Healy *et al.*, 2015; Ekblom-Bak *et al.*, 2016a; Van Der Berg *et al.*, 2017).

Compositional data analysis is used to predict outcomes by considering the composition of all behaviours over an entire day, and acknowledges the co-dependence of time spent in one behaviour on all other behaviours (Dumuid *et al.,* 2017; Chastin *et al.*, 2015). For instance, the effect on outcomes of reallocating 30 min/day from sedentary to moderate physical activity would differ depending on the composition of the remaining day, i.e. how much time was already spent in sedentary behaviour and moderate physical activity, as well as that spent in each of sleep, light and vigorous physical activity (Dumuid *et al.,* 2017; Chastin *et al.*, 2015). This analysis was used to demonstrate the negative effects of sedentary behaviour and light physical activity on metabolic and obesity markers, whilst showing that MVPA had a positive effect (Chastin *et al.*, 2015). Looking more deeply, the negative relationship was higher in the direction of sedentary behaviour than it was for light physical activity, suggesting that when MVPA was not being performed, light physical activity was less detrimental to health than sedentary behaviour (Chastin *et al.*, 2015).

Limitations of accelerometer data and data processing

Despite advances in technology and the ongoing development of new data processing methods, many study outcomes continue to rely on traditional analytic approaches, such as cut-points and linear regression models, for estimating energy expenditure and time spent at different intensities of physical activity (Lyden *et al.*, 2014; Troiano *et al.*, 2014; Pedisic and Bauman, 2015). This persistence with older methods of data analysis is understandable, since many large studies utilise older accelerometer models, not capable of collecting data for more contemporary analyses (Troiano *et al.*, 2014). Furthermore, to preserve comparability with previous study outcomes, consistent methods of analysis must be maintained (Pedisic and Bauman, 2015). Although newer analytic approaches have distinct advantages over traditional methods (Freedson *et al.*, 2012), predominantly only the well-established physical activity research groups have the capacity in terms of both funding and skills (e.g. coding) to develop new algorithms (Lyden *et al.*, 2014; Kozey Keadle, 2017). Therefore, until algorithms are developed and validated on diverse populations and ranges of activities, and made available through open sources (Freedson *et al.*, 2012), older, cut-point style approaches will likely persist among many researchers (Intille *et al.*, 2012), potentially limiting the depth of analysis available.

No single method of assessing physical activity is ideal in every setting, and often the most appropriate method/s will depend on the specific research question or population under investigation. Some objective measures may not appropriately distinguish between physical activity and non-physical activity energy expenditure. For example, doubly labelled water is the gold standard for energy expenditure, but physical activity energy expenditure cannot be separated from resting energy expenditure or thermic effect of food (Pedisic and Bauman, 2015). Likewise, accelerometry does not adequately capture water-based activities such as swimming (due to removal of devices), or non-ambulatory activities like cycling (Pedisic and Bauman, 2015). At the same time, PAQs rely on participant recall and are subject to participants' interpretation of intensity, and some PAQs do not offer reporting for certain activities or combinations of activities (Prince *et al.*, 2008; Dyrstad *et al.*, 2014). Therefore, multiple methods might be employed in a single study, with additional data, complementing and supporting the primary data. For instance, PAQs and physical activity diaries might provide insight into activity types and context to data obtained from accelerometers.

2.8 Conclusions

Physical inactivity is a leading cause of pre-mature death from chronic disease worldwide. In New Zealand, 49% of adults (53% women) are insufficiently active for health. The overwhelming evidence for the benefits of physical activity, including reducing the risk of the major non-communicable diseases, highlights the major public health issues associated with physical inactivity. Many diseases that are moderated by physical activity have higher prevalence among women than men. New Zealand women are less physically active and more inactive, than men. Furthermore, New Zealand is the third most obese nation in the OECD, with greater obesity prevalence among women than men. There are also wide ethnic disparities in rates of obesity, physical in/activity and disease prevalence among the female population in New Zealand. Taken together, these factors contribute to some particularly vulnerable groups of New Zealand women being at substantially greater risk of certain diseases than men or other women.

No single method of physical activity assessment seems to fulfil all requirements in understanding physical activity profiles. Although contemporary physical activity data analysis methods are being developed, for many researchers, more traditional methods might remain most appropriate. Indeed, the most suitable methods and technologies for collecting and analysing physical activity data may be guided by the specific research focus and physical activity characteristics of interest. Data from a range of sources can provide a comprehensive understanding of the physical activity profiles of a population and its implications on health and obesity-related outcomes.

The paucity of objective physical activity data among New Zealand women, especially in relation to health outcomes, is a gap that must be addressed to better understand the implications of the physical activity levels and profiles of this population. Furthermore, elucidating the ethnic-specific relationships between physical activity, body composition and health markers is of considerable public health consequence. The availability and interpretation of such data could better inform government and other bodies tailoring physical activity-based health improvement initiatives to New Zealand women of different ethnicities. Ultimately, these approaches could improve the long term health outcomes of New Zealand, and other, women.

2.9 References

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Chapter 3 Exploring the challenges in obtaining physical activity data using hip-worn accelerometers

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3.1 Abstract

Background: Quality objective physical activity data are required to inform physical activity-based health improvement initiatives, however, various challenges undermine acquisition of such data.

Objectives: To examine the efficacy and challenges of a hip-worn accelerometry protocol in women of different ethnicities. Specific objectives included determining accelerometer-wear compliance rates and understanding the barriers and acceptability of wearing accelerometers.

Methods: Healthy New Zealand women (n = 406) of three ethnicities (Māori, Pacific, European) aged 16–45 years wore hip-mounted Actigraph wGT3X+ accelerometers for 7 consecutive days under a 24-h wear protocol. Post hoc, a sub-sample (n = 45) was interviewed to investigate comfort/convenience and burdens of accelerometer-wear.

Results: Wear-compliance (≥10 h/day, ≥4 day) was 86%. European women returned more valid data (92.7%, $p < 0.04$) than Māori (82.1%) or Pacific (73.0%) women. Twenty-two participants (5.4%) had completely missing data; 13 due to lost accelerometers. Burden of accelerometer wear was greatest during sleeping (66.7%) due to discomfort. Embarrassment of accelerometer visibility through clothing and consequent restricted clothing choices caused high burden in social settings (45.2%).

Conclusion: Discomfort during sleeping, embarrassment due to perceived appearance in social settings and ethnicity are key factors affecting the efficacy of collecting physical activity data from women using hip-worn accelerometers. Refining accelerometer design to reduce size and subsequent participant burden should improve acceptability and wear-compliance. Increasing overall participant compliance by reducing burden and ensuring appropriate understanding of study aims and relevance should reduce attrition and improve wear-compliance and data quality when collecting accelerometry data from women of different ethnicities.

3.2 Introduction

Physical activity is an important and modifiable risk factor for many chronic diseases (e.g. cardiovascular disease, type 2 diabetes) (Warburton *et al.*, 2006; Lee *et al.*, 2012). Conversely, the negative health consequences of inactivity are equivalent in impact to the health risks of smoking and obesity (Lee *et al.*, 2012). However, despite overwhelming evidence for the benefits of physical activity, participation rates are declining worldwide, and are below levels recommended for health in substantial portions of the population (Ng and Popkin, 2012).

Good-quality objectively measured physical activity data are vital to informing decisions by national health bodies on physical activity-based health initiatives. Historically, population-level assessment of physical activity behaviour has been characterised using self-report questionnaires (Health and Social Care Information Centre, 2015; Ministry of Health, 2015). However, the increasing practicality and economic viability of accelerometers for population-based studies have led to their utilisation in numerous national surveys (e.g. NHANES (Centers for Disease Control and Prevention, 2014), British Whitehall II Study (Bell *et al.*, 2015)). Using accelerometers to objectively assess physical activity under free-living conditions provide activity intensity, duration, timing and frequency, eliminating the need for participant recall, as relied upon with self-report methods (Troiano *et al.*, 2014).

Despite their recognised value, quality objective physical activity data are difficult to obtain. Various challenges undermine their acquisition in scientific research, leading to reduced compliance and data quantity. High rates of non-compliance, resulting in insufficient wear-time and data (32%) (Troiano *et al.*, 2008) and lost accelerometers (7%) (Hagstromer *et al.*, 2007) are not uncommon. Notwithstanding these known limitations with data collection, little is published regarding the drivers of non-compliance in accelerometer-based studies (Trost *et al.*, 2005). One of the few studies to document accelerometer-wear acceptability among women, reported that appearance, comfort and convenience were major barriers to compliance (Huberty *et al.*, 2015). However, perceptions of acceptability vary among different groups of women (Pollard and Guell, 2012). American women preferred accelerometers worn on the upper arm rather than on the hip (Huberty *et al.*, 2015), whereas South Asian Muslim women rated hip worn devices more favourably than those on the upper arm (Pollard and Guell, 2012). Among these women, their typical clothing influenced preference for accelerometer placement, highlighting the contrasting perceptions of acceptability in different populations (Pollard and Guell, 2012; Huberty *et al.*, 2015). Therefore, if factors contributing to non-compliance in specific populations can be identified and understood in context, improved study protocols might be designed to increase participant engagement and maximise compliance to accelerometry protocols. This could lead to more reliable and representative data on which to base physical activity recommendations for population-specific health improvement initiatives.

The aim of this investigation was to examine the experiences of women wearing hip-worn accelerometers over a 7-day period. Specifically, these data were used to identify possible contributors to accelerometer-wear non-compliance. These findings will contribute to overcoming the challenges and improving the efficacy of objective physical activity assessments in women.

3.3 Methods

This study reports data obtained from objectively measured physical activity within the women's EXPLORE (Examining Predictors Linking Obesity Related Elements) study (Kruger *et al.*, 2015), conducted in Auckland, New Zealand between September 2013 and May 2015. A semi-structured telephone interview was conducted post hoc with a sub-sample to investigate the acceptability of the accelerometry protocol. The full methodology of the EXPLORE study is described elsewhere (Appendix 4; Kruger *et al.*, 2015); the study flow is shown in Appendix 5. The study was approved by the Massey University Human Ethics Committee (Southern A, Reference No.13/13) and conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from and a Health and Demographic Questionnaire (Appendix 6) was completed by all participants prior to any other data collection.

3.3.1 Participants

Healthy, pre-menopausal women (n = 406), aged 16–45 years were recruited from Auckland, New Zealand. The women were of Māori (n = 84), Pacific (n = 89) or European (n = 233) descent. Ethnicity was determined by self-identification and having at least one parent of the particular ethnicity. Inclusion criteria consisted of being post-menarche but pre-menopausal and not pregnant, breastfeeding or diagnosed with any metabolic condition.

3.3.2 Accelerometer protocol

Tri-axial accelerometers (Actigraph wGT3X+, Pensacola, FL) were used to assess physical activity over seven consecutive days. Accelerometers attached to an elastic belt were fitted on participants' right hip by an experienced researcher. During fitting, researchers explained the correct positioning and orientation of the accelerometer, and the importance of collecting objectively measured physical activity data. Participants were instructed to wear the accelerometer at all times (excluding water-based activities) during a typical week. Instructions were reinforced on an information sheet (Appendix 7) given to each participant, along with pictures showing correct wear. On Day 6, participants were reminded to stop wearing the accelerometer on Day 7, and to immediately return it in the pre-paid envelope provided. To be considered as having valid data, participants must have worn the accelerometer during waking hours for ≥10 h/day (Matthews *et al.*, 2012) for ≥4 (week and/or weekend) days (Tudor-Locke *et al.*, 2012).

3.3.3 Accelerometry experience interview

A sub-sample (*n* = 88) of the main study was selected for a short (3–4 min) semi-structured telephone interview to explore the barriers to and acceptability of the accelerometry protocol. The sub-sample consisted of all participants with insufficient accelerometer data (*n* = 49), plus a random sample of participants with valid data (*n* = 39). A minimum of three attempts were made to contact participants by telephone. During the telephone interview, participants were asked if they had worn the accelerometer for the full seven days as directed, and to rate their experience of accelerometer-wear. These ratings covered overall comfort and the convenience of wearing the accelerometer in each of four lifestyle domains: day to day (e.g. work, home, university), social, sport/exercise and sleep. For each domain, participants were asked "How convenient was it to wear the accelerometer for [domain name]?", followed by "Can you explain why you gave that score for [domain name]?". If necessary, participants were asked open-ended questions to encourage elaboration of their answers; participants received no prompts based upon any specific themes.

3.3.4 Anthropometry

Anthropometric assessment was conducted using the International Society for the Advancement of Kinanthropometry (ISAK) protocol (Marfell-Jones *et al.*, 2006) described by

Kruger et al. (2015). Briefly, height (m) and body mass (kg) were measured to calculate BMI (kg/m^2). Body fat percentage was assessed via air displacement plethysmography (BodPod, 2007A, Life Measurement Inc., Concord, CA; using manufacturer-supplied software V4.2+) incorporating measured thoracic volume and Siri equation (Siri, 1961).

3.3.5 Statistical analysis

All statistical analyses were carried out using SPSS Statistics 22 for Windows (SPSS Inc., Chicago, IL). Normality of data was confirmed using histograms and Kolmogorov–Smirnov tests. Descriptive data are presented as mean ± standard deviation. Independent *t*-tests and Chi square analysis were used on these parametric data to compare data against physical and demographic characteristics. One-way ANOVA was used to compare wear data between ethnic groups. The level of significance was set at $p < 0.05$ for all analyses. Interview responses were recorded, and raw data were reviewed using an inductive approach allowing for formation of core categories based on the study aims and objectives. Findings are presented as two core categories with underlying themes, supported by direct quotes of participants' experiences.

3.4 Results

In total, 406 women participated in the study (Table 3.1), of whom 350 (86%) provided valid accelerometer data (≥10 h/day on ≥4 week and/or weekend days). In determining the valid accelerometer wear criteria, an independent *t*-test was used to compare *any 4 days* ($n = 350$), with *4 days including 1 weekend day* ($n = 325$). *Any 4 days* was used as the criteria, since no significant differences in any variables of interest were detected between the two criteria (*p*-values 0.635 to 0.992), and a slightly larger sample size was achieved with *any 4 days*.

Women with valid data were older ($t(404) = -4.7$, $p < 0.001$) and more likely to be in fulltime employment ($x^2(2) = 8.94$, $p = 0.011$) than those with insufficient data. Average daily waking wear-time for participants with insufficient data was 9.1 ± 1.1 h; for participants with valid data, daily waking wear-time was 13.7 ± 0.3 h. More valid data were returned from European (92.7%) than Māori (82.1%) or Pacific (73.0%) women ($F(2, 405) = 11.8$, $p < 0.001$). No significant differences in body composition measures were found between the total population, and those with and without valid data.

Table 3.1. Demographic and body composition characteristics of participants

	Total[a]	Valid data[b]	Insufficient data obtained		
			Total[a]	Insufficient wear-time	No data[a]
n (%)	406 (100.0)	350 (86.0)	56 (13.8)	34 (8.4)	22 (5.4)
Age (y)	30.9 ± 8.7	31.6 ± 8.5	26.3 ± 8.1*	24.1 ± 7.1*	29.7 ± 8.5
BMI (kg/m^2)	27.4 ± 6.4	27.1 ± 5.9	29.3 ± 8.9	28.8 ± 8.4	30.2 ± 9.7
BF% (%)	34.3 ± 8.3	34.0 ± 8.1	36.0 ± 9.4	35.4 ± 9.3	36.9 ± 9.8
Wear-time (h/day)		13.7 ± 0.3			
Employed	187	170	17*	4*	13
Ethnicity (n, %)					
Māori	84 (100.0)	69 (82.1)	15 (17.9)	10 (11.9)	5 (6.0)
Pacific	89 (100.0)	65 (73.0)	24 (27.0)	16 (18.0)	8 (9.0)
European	233 (100.0)	216 (92.7)	17 (7.3)	8 (3.4)	9 (3.9)

Values are mean ± SD or *n* (%); Abbreviations: BMI, body mass index; BF%, body fat percentage.
[a] Includes two participants whose data were lost due to hardware failure; [b] Valid accelerometer data defined as ≥10 h/day for ≥4 day;
*significantly different from participants with valid data $p < 0.05$.

3.4.1 Missing accelerometer data

Twenty-two participants (5.4%) had completely missing accelerometer data (Table 3.2), including 13 participants (3.2%) whose accelerometers were lost. Pacific women were more likely to lose accelerometers than European women ($x^2(2) = 11.07$, $p = 0.004$). No common themes were identified to explain lost accelerometers.

Table 3.2. Breakdown of missing accelerometer data (n = 22)

Reason for missing data	*n*
Participant non-compliance (did not wear accelerometer at all)	7
Accelerometer hardware failure	2
Accelerometer lost	13
Posted but not received	3 (Pacific = 1, NZE = 2)
Given to someone else to return	2 (Māori = 1, Pacific = 1)
Simply lost	8 (Māori = 2, Pacific = 5, NZE = 1)

Abbreviations: NZE, New Zealand European.

3.4.2 Qualitative results from interviews

Of the 88 participants in the interview sample, 46 (52.3%) were successfully contacted, with one declining to participate. Of the 45 interviewed participants (age 29.4 ± 9.0 years; BMI 30.1 ± 9.0 kg/m^2; BF% 36.0 ± 10.0%), 25 returned insufficient data and 20 returned valid data.

Responses regarding wear-compliance revealed that 23 participants (51%) failed to wear the accelerometer for the full seven days. Wear non-compliance responses were categorised into "Discomfort/inconvenience" (*n* = 16) and "Forgetfulness" (*n* = 13). Some responses were recorded under both categories.

The general comfort of wearing the accelerometer was investigated using a rating scale of 1 (worst) to 4 (best), followed by comments explaining the particular rating. The average comfort rating was 2.8. Comments were categorised as "Comfort" or "Discomfort". Examples of comments include:

- "It was uncomfortable at first but was OK once I got used to it",
- "It was fine most of the time except sleeping",
- "I didn't really notice it",
- "It was uncomfortable to sleep and it moved around too much when I was walking".

Responses to the convenience of wearing accelerometers in the four lifestyle domains were categorised as "Burden" or "Acceptable". Convenience data are presented in Table 3.3, with participant comments in Table 3.4.

Table 3.3. Interview convenience responses

Domain	Response categories	*n*	Valid data (%)	Rating	Age (y)	BMI (kg/m^2)	BF% (%)
Day to day	Burden	14	21.4	3.1	24.7 ± 5.7	26.1 ± 7.9	32.3 ± 9.5
(n = 45)	Acceptable	31	58.1	3.5	31.8 ± 9.5*	32.1 ± 9.0*	37.9 ± 9.8*
Social	Burden	19	47.4	3.0	27.3 ± 9.4	27.1 ± 6.5	32.0 ± 7.6
(n = 42)	Acceptable	23	52.2	3.7	31.6 ± 9.0	32.7 ± 9.6*	39.6 ± 9.1*
Sport	Burden	15	53.3	3.0	31.2 ± 7.5	32.8 ± 9.9	38.6 ± 10.2
(n = 40)	Acceptable	25	52.0	3.5	29.6 ± 10.2	29.6 ± 10.2	35.4 ± 8.5
Sleep	Burden	30	36.7	2.2	28.1 ± 8.8	29.8 ± 9.1	36.0 ± 10.2
(n = 45)	Acceptable	15	66.7	3.5	32.7 ± 9.0	31.0 ± 9.3	36.4 ± 9.7

Values are mean ± SD. Note: Variance in *n* for each domain occurred as some participants did not engage in the domain during the 7 days. Abbreviations: BMI, body mass index; BF%, body fat percentage
[a] Valid data indicate the percentage of participants within each Burden and Acceptable category who returned valid data (≥10 h/day for ≥4 days); [b] Rating column is the mean rating for each domain and is on a scale of 1 (worst) – 4 (best).
*significantly different to Burden within domain $p < 0.05$.

Table 3.4. Participant comments regarding convenience of accelerometer-wear in each lifestyle domain

Domain	Participant comments
Day to day	"OK because there was a good reason for it. There was a meaning to it." "Fine, other than being uncomfortable." "Remembering was a pain at first but no big deal otherwise."
Social	"Didn't sit well with nice clothes. It was best with jeans." "It was fine but I had to think about what clothes to wear cos it stuck out and showed with some." "Was uncomfortable and showed through clothes. Going out was worst." "Couldn't wear some clothes cos lots of them it showed and looked dumb."
Sport	"It moved a lot when I did exercise and was uncomfortable cos of my tummy shape." "Felt less weird, kind of like it felt more sporty." "OK but it rode up sometimes."
Sleep	"I mostly sleep on that side so was really uncomfortable and annoying." "Sleeping was the most uncomfortable. It dug in and got in the way." "Terrible! I stopped wearing it to bed in the end." "Sleeping was really bad, it was really annoying and uncomfortable."

Sleeping was the domain of greatest burden (66.7%). Sleep burden responses were 100% due to discomfort. Day to day was the domain of lowest burden (31.1%), whilst social settings were burdensome for 45.2% of participants. Participants who reported burden in social and day to day had lower BMI and BF% than those with acceptable responses for these domains (Table 3.3). In the social domain, all burden responses referenced clothing and related to the accelerometer protruding or showing through clothing, causing discomfort or embarrassment (Table 3.4). Some participants found wearing the accelerometer acceptable in almost all domains; common responses were: "It was fine"; "It was no worries".

3.5 Discussion

Women's experiences of wearing hip-worn accelerometers were examined to identify possible barriers to compliance and acceptability of their use in physical activity research. Few data were available regarding factors influencing the acceptability of hip-worn accelerometers over extended periods. A number of issues were identified that might influence accelerometer-wear compliance and acceptability, and may have contributed to accelerometer losses or non-wear. Comfort, convenience and demographic differences (particularly ethnicity) were identified as the most likely contributors to participant burden and non-compliance in this study.

Rates of compliance in accelerometer-based studies are often reported, but less data are published on attrition (i.e. unreturned accelerometers due to loss during data collection, uncontactable participants, lost to follow-up). Attrition in the current study (3.2%) was substantially lower than was reported in Swedish adults (6.9%) (Hagstromer *et al.*, 2007), although higher than in a large ongoing study of older American women (2.1%) (Lee and Shiroma, 2014). Overall, no consistent patterns were identified as to how or why accelerometers were lost in the present study. Whether or not losses would have been reduced with face-to-face collection rather than postal return of devices is debatable. Well-structured postal returns are recommended as an effective alternative to face-to-face collection (Trost *et al.*, 2005) and is the method employed in many large-scale studies (Hagstromer *et al.*, 2007; Troiano *et al.*, 2008; Lee and Shiroma, 2014). Even when collection of outstanding devices was arranged, some were never recovered despite numerous attempts to do so. Following failed collection, some participants became unresponsive (unanswered phone calls, emails, messages) whilst others subsequently admitted losing the device. Replacement cost of lost devices, although a large financial burden on projects, is secondary to the unrecoverable data lost along with devices, so minimising attrition is important in maximising data collection.

Valid data (86%) were relatively high compared to some large studies (40–94%) (Hagstromer *et al.*, 2007; Troiano *et al.*, 2008; Roth and Mindell, 2013) and may be attributable to the 24-h wear protocol employed to capture both physical activity data and some aspects of sleep. Daily waking wear-time (13.7 ± 0.3 h) was comparable to that reported in other New Zealand adults (14.1 ± 1.2 h) (Cerin *et al.*, 2014) and young American women (14.6 ± 1.0 h) (Green *et al.*, 2014) when devices were worn only during waking hours. Wearing the accelerometer at all times, rather than during waking hours only, may have reduced incidents of participants forgetting to replace the device each morning. Indeed, in protocols instructing removal for sleeping, participants reported difficulty remembering to replace devices each morning (Pollard and Guell, 2012; Troiano *et al.*, 2014). Huberty *et al.* (2015) also concluded that 24-h wear protocols likely reduced reliance on participant memory to replace devices after sleeping. Furthermore, in a waking wear protocol, discrepancies between participants' documented sleep/wake times and wear-times evident from accelerometry indicated accelerometers were not always replaced immediately upon waking (Pollard and Guell, 2012). Overcoming reliance on participants' memory to replace devices each morning meant waking wear data collection commenced immediately after participants woke each morning. However, the burden of discomfort during sleeping was highlighted by many participants and must be considered (discussed further below). Arguably, greater wear-time may have been achieved if devices were not removed for water activities. Almost half of participants in the present study reported sometimes forgetting to replace the device after showering, and some removed the device for prolonged periods while at the beach. Others (Perry *et al.*, 2010; Huberty *et al.*, 2015) have similarly reported that forgetting to replace accelerometers after removal for water activities may have affected wear-time. Although the wGT3X+ is waterproof (Actigraph LLC, 2016), if worn during water activities, the elastic belt would become wet and need replacing with a dry belt or risk greater discomfort, thereby increasing participant burden and likely reducing compliance. Despite high ratings of discomfort and inconvenience in the present study, wear-time was comparable to previous reports (Cerin *et al.*, 2014; Green *et al.*, 2014). Similarly, when accelerometers were trialled at different body locations, variations in location preference and levels of acceptability did not significantly affect compliance (Berendsen *et al.*, 2014).

Differences in demographic and lifestyle characteristics have been reported between participants with and without valid data (Loprinzi *et al.*, 2013; Roth and Mindell, 2013). Lifestyle data were not collected in the current study; however, some demographic differences were identified. Accelerometer losses were substantially higher among Pacific women than others. Furthermore, women with valid data were older and more likely to be European than those with insufficient data. Māori and European compliance could not be compared with previous research due to a paucity of existing data, however, Pacific women's compliance (73%) was slightly higher than in another study of New Zealand Pacific women (68%) (Oliver *et al.*, 2009). Cultural lifestyles and values reportedly influence how Pacific peoples view health care and status (Ministry of Health, 2012). The social and cultural contexts of health and Pacific peoples' sometimes limited understanding of the benefits of a physically active lifestyle (Ministry of Health, 2012) may have contributed to higher attrition and non-compliance among Pacific women. Similar limitations in health literacy and lifestyle understanding have also been reported in migrant and indigenous populations. Although no differences in comfort/convenience ratings were evident between the ethnic groups, different preferences for accelerometer placement have been reported according to ethnic and cultural background. South Asian Muslim women living in the United Kingdom rated hip-worn Actigraph GT3X accelerometers more favourably than the upper arm placement of Sensewear Armbands (Pollard and Guell, 2012). Conversely, American Caucasian women preferred Armbands over the GT3X (Huberty *et al.*, 2015). In both studies, clothing influenced placement preference, although interestingly, the specific issues differed between the groups (Pollard and Guell, 2012; Huberty *et al.*, 2015). Whereas the Muslim women were embarrassed by the upper arm placement of the Armband, finding it uncomfortable under traditional tight-sleeved tops (Pollard and Guell, 2012), American women were satisfied by the Armband's easy concealment under clothing (Huberty *et al.*, 2015). In agreement with the present study, the American women regarded the hip placement of the GT3X as annoying, embarrassing and uncomfortable (Huberty *et al.*, 2015). Such distinct cultural preferences highlight the need for population-specific investigations to better understand the physical activity habits of different groups, along with the cultural and lifestyle factors contributing to participant non-compliance.

Sleep was clearly the most burdensome domain, with over three-quarters of respondents reporting some degree of discomfort wearing the accelerometer whilst sleeping. Participants' comments ranged from the accelerometer being "a bit of a nuisance at first" to "so bad I couldn't sleep with it". In contrast, American women assessing accelerometer acceptability during sleep, rated devices acceptably and similarly whether worn on the wrist or upper arm (Huberty *et al.*, 2015). Importantly though, no other known studies have assessed hip-worn accelerometers for acceptability during sleep. It is difficult to determine to what extent dissatisfaction from wearing the accelerometer whilst sleeping influenced compliance, since compliance was higher in the current study than in some others (Hagstromer *et al.*, 2007; Cerin *et al.*, 2014). In another 24-h wear protocol, the Actigraph GT3X was worn on the hip during waking hours and then transferred to a wrist strap for sleeping (Huberty *et al.*, 2015). This protocol also had low participant acceptability, however, dissatisfaction related to the additional burden of swapping straps, rather than overall discomfort, as in the present study.

Previous research in women examining accelerometer-wear acceptability at different body locations identified comfort, convenience and appearance as barriers to compliance (Berendsen *et al.*, 2014; Huberty *et al.*, 2015). In the present study, all burden from accelerometer-wear in social settings related to clothing; participants were embarrassed by the visibility of accelerometers through clothing. Consequently, devices were either not worn or clothing choices became restricted, requiring careful consideration in order to minimise embarrassment. Interestingly, women regarding social and day to day accelerometer-wear as burdensome had lower BMI and BF% than those regarding these domains as acceptable. Although no supporting evidence could be found, it could be that the burden for these women in day to day and social settings might result from hip-worn accelerometers being more apparent on their slimmer body, especially if tight-fitting clothing was worn. Women wearing devices at other body locations (e.g. thigh, upper arm, wrist) also reported concerns over clothing, appearance and embarrassment (Pollard and Guell, 2012; Berendsen *et al.*, 2014; Huberty *et al.*, 2015). In line with current findings, these women reported high levels of burden and unacceptability, largely due to discomfort and visibility of devices through clothing.

An alternative to hip-wear is wrist-worn accelerometers. Traditionally used for sleep assessment, more recent devices and newly developed algorithms have enabled the use of wrist-worn accelerometers for assessing physical activity. However, in an investigation of accelerometers worn at different body locations, wrist-worn GENEActiv devices were rated with low acceptability due to appearance and difficulty in hiding the device (Huberty *et al.*, 2015). Nevertheless, NHANES adopted wrist placement of devices in 2011–2012, with improved compliance over previously used hip-worn devices (Troiano *et al.*, 2014). Accelerometer size has reduced markedly in recent years (Chen and Bassett, 2005), but most research-quality devices are likely still visible and unacceptable to some extent, regardless of wear location. Until research-quality movement-sensing devices are slimlined and/or stylish, compliance or at least wearer acceptability will likely remain suboptimal for free-living individuals. Since compliance is critical to accurate quantification of physical activity behaviours (Trost *et al.*, 2005), minimising participant burden regarding comfort, convenience and acceptability is vital to obtaining good-quality objective physical activity data.

With only 52% of the sub-sample contactable for the interview, participants' experiences of accelerometer-wear have limited generalisability. However, since very few published studies report accelerometer-wear comfort and acceptability, the current findings provide valuable insight and may lead to improved accelerometry protocols and wear-compliance in future studies. Importantly, all data regarding compliance and attrition relate to the entire study population (*n* = 406). Although this sample was not evenly spread across the ethnic groups, only some findings might have differed had a more balanced sample been available. For instance, accelerometer losses may have been even higher than the 13 observed had groups been of equal size; Pacific women made up only 22% of the sample, yet accounted for 54% of lost devices. In contrast, extrapolating data to reflect equal group sizes would have reduced valid data returns only slightly, from the observed 86.0% to 82.6%. Although participants were reminded on Day 6 to return accelerometers, additional communication may have encouraged compliance, especially in those who were compliant only initially (Perry *et al.*, 2010; Matthews *et al.*, 2012). Furthermore, travel compensation (petrol vouchers) was given to participants at the time of fitting the accelerometer. Withholding vouchers until the accelerometer and sufficient data were returned might have encouraged compliance and accelerometer return.

Such strategies are recommended by others to promote compliance (Trost *et al.*, 2005; Sirard and Slater, 2009). The 24-h wear protocol may have affected compliance both positively and negatively. Although the burden of discomfort whilst sleeping seemed not to adversely affect compliance, wear-time may have been even higher if devices were more comfortable for sleep-wear. Dissatisfaction and non-wear caused by sleep-wear discomfort may have negated potential increases in wear-time gained when participant memory was not relied upon to replace devices after sleeping. Accordingly, the benefits and additional data gained from wear during sleeping should be carefully considered in future protocols.

3.6 Conclusions

Accelerometer-wear compliance during a physical activity assessment in women of three different ethnicities was examined. Barriers to wearer acceptability and compliance to the hip-worn accelerometry protocol were identified through a semi-structured telephone interview. Although no single factor was identified as the sole determinant of compliance, a number of possible contributors emerged. Arguably the biggest contributors to non-compliance were discomfort (mainly during sleeping) and embarrassment (related to clothing in social settings) caused by accelerometer size and placement. Future protocols should consider the burden of discomfort whilst sleeping, maintaining a balance between participant burden and acquisition of the desired data, ensuring neither compliance nor data quality are unnecessarily compromised. Despite advancing technology, the GT3X+ and other research-quality accelerometers remain relatively large and conspicuous. If devices were more comfortable, and smaller and less conspicuous, or stylish and socially acceptable (e.g. Fitbit™), then wear-compliance in physical activity research might increase. Pacific women recorded higher attrition and lower compliance than other women; factors possibly attributable to the known limited understanding of health and healthy lifestyle factors (e.g. physical activity) of some Pacific women (Ministry of Health, 2003; Ministry of Health, 2012). Furthermore, the vital role of many women in the family is often prioritised ahead of their own health and wellbeing, and possibly also the priority given to a study of this nature (Koloto and Sharma, 2006; Schluter *et al.*, 2011). Increasing participants' understanding of the importance of both the study and the lifestyle factors being examined might improve engagement, and consequently encourage adherence to accelerometry protocols.

This study highlights key issues around the overall compliance of participants regarding accelerometer-wear. These issues must be appropriately addressed in order to improve wear-compliance and collection of high-quality accelerometry data, particularly from women of different ethnicities. With non-compliance largely focused on discomfort, embarrassment and device visibility, encouraging designers and engineers to improve these aspects in future accelerometer design may reduce participant burden and increase compliance. Careful considerations of the pitfalls regarding comfort and wearer acceptability, and ensuring appropriate understanding of study aims and relevance should encourage participant engagement even further, thereby improving compliance and subsequent data quality. Responding to the issues identified in this study may guide future protocols and study designs across all populations, improving the efficacy and participant acceptability of physical activity research using hip-worn accelerometers.

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Chapter 4 Ethnic differences in levels of physical activity and associations with body composition and metabolic health markers

4.1 Abstract

Background: Many body composition characteristics and metabolic health markers are improved with physical activity, but may vary with ethnicity.

Objective: The study aim was to investigate ethnic differences in physical activity levels of overweight-obese women, and relationships between physical activity and their body composition and metabolic health markers.

Methods: Participants were 175 healthy overweight-obese (BMI ≥25.0 kg/m^2, BF% ≥30.0%) New Zealand women (Māori, Pacific, European), aged 16-45 years. Physical activity was assessed over 7 consecutive days using triaxial accelerometers. Anthropometry was measured, and body composition (total/regional fat and lean mass) was assessed via Bodpod and DXA. A clustered cardiometabolic risk (CCMR) score was calculated from measured indicators of central obesity, dyslipidaemia, hypertension, hyperglycaemia. Associations between physical activity and measured variables were examined using Pearson's correlations adjusted for confounders.

Results: Physical activity guidelines were achieved by more European women (67%, $p < 0.001$) than Māori (49%) or Pacific (32%) women. After adjusting for confounders, achieving guidelines was associated inversely with regional fat percentages and positively with body lean % and CCMR for all women combined ($p < 0.001$) and for Māori ($p \leq 0.021$) and European ($p \leq 0.036$, except CCMR $p = 0.071$) women. MVPA was associated with BMI ($r = -0.22$, $p = 0.008$), BF% ($r = -0.21$, $p = 0.011$), lean mass % ($r = 0.18$, $p = 0.027$) and CCMR ($r = 0.20$, $p = 0.017$) for all women. For Māori women, MVPA bouts were strongly ($r \leq -0.50$, $p < 0.005$) associated with total and regional fat percentages and CCMR. For Pacific women, only waist-to-hip ratio ($r = -0.35$, $p = 0.036$) was associated with MVPA. MVPA was associated with no measured variables for European women.

Conclusion: Associations for improved body composition and metabolic disease risk markers with higher levels of physical activity were apparent for Māori and European, but not Pacific women. Data suggest that factors at least as impactful as physical activity may influence body composition and metabolic disease risk in Pacific women.

4.2 Introduction

Regular participation in physical activity is crucial for disease prevention and for maintaining a healthy body weight (Swift *et al.*, 2014; World Health Organization, 2015). Excessive weight gain (and subsequent obesity) substantially increases the risk of a range of negative health consequences, including cardiovascular disease and type 2 diabetes (World Health Organization, 2015). Excess fat mass, regardless of BMI, also has negative consequences on metabolic health (De Lorenzo *et al.*, 2013). Therefore, individuals who are overweight or obese, whether defined by BMI or BF%, are at far greater risk of adverse health outcomes than their normal-weight counterparts. Total and regional fat mass (Strath *et al.*, 2008; Larsen *et al.*, 2014; Drenowatz *et al.*, 2016; Whitaker *et al.*, 2017) and cardiometabolic disease risk (Scheers *et al.*, 2013; Green *et al.*, 2014) have been inversely associated with all levels of physical activity. Further, adults who exercise regularly gained less fat with weight gain, and lost more fat with weight loss, than sedentary individuals over a three year follow-up (Kyle *et al.*, 2006). For these reasons physical activity guidelines were developed by the WHO (World Health Organization, 2010) and implemented in many countries recommending minimum levels of physical activity to improved health and prevent weight gain (Division of Nutrition *et al.*, 2008; Bull & the Expert Working Groups, 2010; World Health Organization, 2010; Australian Government Department of Health, 2014; Ministry of Health, 2015c).

The location of body fat is also important; excessive fat in the android region, poses greater risk of inflammation and subsequent chronic metabolic diseases (e.g. type 2 diabetes, cardiovascular disease) than equally excessive gynoid fat (Gasteyger and Tremblay, 2002). Systemic inflammation associated with abdominal obesity can lead to an increased risk of metabolic syndrome along with dyslipidaemia, hypertension and impaired glucose homeostasis, and subsequently further increase the risk of type 2 diabetes and cardiovascular disease (Brooks *et al.,* 2010). Furthermore, visceral abdominal fat seems to contribute more to metabolic disease risk than subcutaneous or intramuscular abdominal fat (Berg and Scherer, 2005). Conversely, physical activity moderates many markers of metabolic disease risk (e.g. triglycerides, lipids) (Scheers *et al.*, 2013) and has been inversely associated with clustered cardiometabolic risk score (Wijndaele *et al.*, 2009; Cooper *et al.*, 2014; Wijndaele *et al.*, 2014). Indeed, physical activity is frequently prescribed to improve outcomes in those suffering from, or at risk of, obesity-related diseases (World Health Organization, 2010).

Obesity among New Zealand women is increasing at an alarming rate. Currently, 61.5% of New Zealand women are overweight or obese (Ministry of Health, 2015a), putting a large portion of the New Zealand female population at significant disease risk (De Lorenzo *et al.*, 2013; World Health Organization, 2015). Over the last three decades, the BMI of New Zealand women has increased at a rate (1.2 kg/m^2 per decade) and to a level (28.1 kg/m^2), second only to the United States among high income countries (Finucane *et al.*, 2011). However, rates of obesity vary widely across different ethnic groups in New Zealand; 88.6% of Pacific women are classified as either overweight or obese, compared to only 37.1% of Asian New Zealand women (Ministry of Health, 2015a). Ethnic variations also exist in obesity-related and physical activity-mediated disease prevalence (Ministry of Health, 2015b); Pacific women are at substantially higher risk (RR 3.48) of type 2 diabetes, relative to non-Pacific women (Ministry of Health, 2015b).

Despite evidence for improved obesity outcomes in response to physical activity (McGuire and Ross, 2012; Larsen *et al.*, 2014), few investigations (McGuire and Ross, 2012; Drenowatz *et al.*, 2016) have examined the effects of different levels of physical activity on fat distribution, or their combined effects on metabolic disease risk, across different ethnicities. However, understanding the implications of physical activity on body composition and metabolic health in various populations is vital to developing effective physical activity-based health improvement and weight-loss initiatives, and may require ethnic-specific approaches. Therefore, the aim of this study was to describe the ethnic-specific differences in levels of physical activity among overweight-obese New Zealand women, and the relationships between physical activity, body composition and metabolic health markers of these women.

4.3 Methods

This cross-sectional study reports objectively measured physical activity data, as well as body composition data and markers of metabolic health, obtained as part of the women's EXPLORE study (Kruger *et al.*, 2015), conducted in Auckland, New Zealand. The full methodology of the EXPLORE study is described elsewhere (Appendix 4; Kruger *et al.*, 2015); the study flow is shown in Appendix 5. The study was approved by the Massey University Human Ethics Committee: Southern A, Reference No.13/13 and conducted in accordance with the Declaration of Helsinki. Prior to data collection, written informed consent was obtained from participants.

4.3.1 Participants

A total of 406 healthy pre-menopausal women aged 16-45 years of Māori (*n* = 84), Pacific (*n* = 89) or European (*n* = 233) descent were recruited for the EXPLORE study (Kruger *et al.*, 2015). Of these, 206 healthy overweight-obese women with BMI ≥25 kg/m^2 and BF% ≥30.0% (World Health Organization, 2006; Romero-Corral *et al.*, 2008) were included in the current study. Ethnicity was determined by self-identification and having at least one parent of the particular ethnicity. Inclusion criteria consisted of being post-menarche but pre-menopausal. Participants were excluded if they were pregnant, lactating or diagnosed with any metabolic condition or chronic illness.

4.3.2 Physical activity measurement

Triaxial accelerometers (Actigraph wGT3X+, Pensacola, FL, USA) were used to assess physical activity over 7 consecutive days. Accelerometers sampled at a frequency of 100 Hz and data were downloaded using the low frequency extension in 60 s epochs. Accelerometers were secured on an adjustable belt over participants' right hip on the mid-axillary line. Participants were instructed to wear accelerometers at all times (excluding water-based activities) during a typical week. Data were considered valid if the accelerometer was worn for ≥10 h/day (Matthews *et al.*, 2012) on ≥4 week or weekend days (Tudor-Locke *et al.*, 2012); 175 participants returned valid data and 31 participants returned insufficient (*n* = 19) or no (*n* = 12) data.

Non-wear and sleep times were determined and removed using a publicly available algorithm (Barreira *et al.*, 2015). Non-wear time was defined as intervals ≥60 consecutive minutes of 0 counts/min with exception for 1-2 min of activity during that time. Algorithms were run via MATLAB (R2011b 7.13.0.564, The MathWorks Inc., Natick, MA) computer software. Widely used and validated cut-points were used to identify physical activity levels (counts/min): sedentary (0-99), light (100-2019), moderate (2020-5998), vigorous (≥5999) and MVPA (≥2020) (Troiano *et al.*, 2008); time was averaged across all valid days. In line with physical activity guidelines (World Health Organization, 2010) 10-min bouts of MVPA (MVPA10; min/week) were identified as ≥10 consecutive minutes above the MVPA threshold, with allowance for interruptions of 1 or 2 min below the threshold (Troiano *et al.*, 2008).

4.3.3 Body composition assessment

Anthropometric assessment was conducted using ISAK protocols (Marfell-Jones *et al.*, 2006) described by Kruger *et al.* (2015). Briefly, waist and hip circumferences were measured using a metal Lufkin tape and height was measured using a calibrated Harpenden stadiometer, and recorded to the nearest 0.1 cm. Body mass was assessed using the electronic scale incorporated in the air displacement plethysmography device. Measured variables were used to calculate: BMI (kg/m^2), body mass divided by height squared; waist-to-hip ratio, waist circumference divided by hip circumference. Total BF% was assessed using air displacement plethysmography (BodPod, 2007A, Life Measurement Inc, Concord, CA; manufacturer supplied software V4.2+) incorporating measured thoracic volume and Siri equation (Siri, 1961). Total and regional (android, gynoid) lean mass, and regional fat mass were determined from whole body dual-energy X-ray absorptiometry (DXA; Hologic QDR Discovery A; Hologic Inc, Bedford, MA; APEX v3.2 software).

4.3.4 Metabolic health markers

Fasting venous blood samples were drawn between 7:00 and 9:30 am into EDTA (ethylene diamine tetraacetic acid) and serum vacutainer tubes. An aliquot of EDTA whole blood was immediately frozen at -80 °C for HbA1c analysis. Remaining blood was centrifuged at 3500 rpm for 15 mins at 4 °C to obtain plasma and serum samples. Samples were aliquoted and frozen at -80 °C for later analysis. Serum insulin was measured using ADVIA Centaur immunoassay kits (Siemens Healthcare Diagnostics). Automated Dimension Vista system (Siemens Healthcare Diagnostics) was used to measure serum levels of lipids (cholesterol, HDL-c, triglycerides) and glucose. Cholesterol-to-HDL-c (Chol:HDL) ratio and LDL-c were calculated from measured variables. HbA1c was measured on frozen EDTA whole blood using high performance liquid chromatography (Biorad Variant instrumentation, USA).

Blood pressure was measured twice using an automated blood pressure monitor (Riester Ri Champion, Rudolf Riester GmbH, Jungingen, Germany) on the arm not involved in blood sampling, after 5 minutes of seated rest.

A clustered cardiometabolic risk score was calculated (Brage *et al.*, 2004; Healy *et al.*, 2008; Wijndaele *et al.*, 2014), incorporating indicators of central obesity (waist circumference), dyslipidaemia (triglycerides, HDL-c), hypertension (systolic and diastolic blood pressure) and hyperglycaemia (fasting glucose and insulin). Each variable was standardised by computing its *z*-scores ($z = ((\text{value} - \text{mean})/\text{SD})$) after normalising ($\log_{10}$) glucose, insulin and triglycerides. HDL-c was then inverted so that a higher value indicated higher risk, and systolic and diastolic blood pressure were averaged. Individual *z*-scores were summed, and divided by the number of variables. A lower clustered cardiometabolic risk score indicates relatively lower cardiometabolic disease risk.

4.3.5 Dietary analysis

An online food frequency questionnaire, validated in New Zealand populations (Houston, 2014), was completed by participants. Questionnaire data were analysed using Foodworks dietary analysis software (FoodWorks Professional 7; Xyris Software, Australia; New Zealand Food Composition Database), from which total energy intake was calculated and used as a covariate in the analysis.

4.3.6 Statistical analysis

All statistical analyses were carried out using SPSS Statistics 22 for Windows (SPSS, Inc., Chicago, IL). All data were checked for normality using histograms and Kolmogorov–Smirnov tests. Non-parametric data were tested for homogeneity using Levene's tests, log-transformed if significant variance was found, and tested again for normality. Parametric data are reported as mean ± SD, and non-parametric data as median (25^{th}, 75^{th} percentiles). For comparison of physical activity, body composition and clustered cardiometabolic risk score against ethnicity, one-way ANOVA was used for parametric, and Kruskal-Wallis for non-parametric data. For reporting against physical activity guidelines, independent *t*-tests were performed. To account for non-normal distribution of data, bootstrapping (1000 samples) was undertaken to normalise data in order to perform partial correlations adjusted for covariates of age and total energy intake. Significance was set at $p < 0.05$ for all analyses.

4.4 Results

Of the 206 overweight-obese women recruited from the EXPLORE study, 175 (Māori $n = 37$, Pacific $n = 54$, European $n = 84$) returned valid accelerometry data (≥10 h/day ≥4 week and/or weekend days) and were included in the final analysis (Table 4.1). In determining valid accelerometer wear criteria, an independent *t*-test was used to compare *any 4 days* ($n = 350$), with *4 days including 1 weekend day* (*n* = 325). *Any 4 days* was used as the criteria, since no significant differences in any variables of interest were detected between the two criteria (*p*-values ranged from 0.635 to 0.992), and a slightly larger sample size was achieved with *any 4 days*.

4.4.1 Body composition

All women had BMI ≥25 kg/m^2 and BF% ≥30.0%, but European women had lower BMI and waist circumference than Māori and Pacific women (BMI 29.2, 32.6 and 33.2 kg/m^2, waist circumference 87.1, 93.0 and 95.0 cm, for European, Māori and Pacific, respectively). Body lean % and BF% were not significantly different between the three ethnic groups (p = 0.150), nor were any body composition variables significantly different (p < 0.05) between Māori and Pacific women (Table 4.1)

4.4.2 Metabolic health markers

Most metabolic markers were within normal ranges, except insulin for Māori and Pacific, and cholesterol and LDL-c for all groups. Metabolic markers varied by ethnicity and many were more favourable among European than Māori or Pacific women (Table 4.1). Compared to European women HbA1c and insulin were higher and HDL-c was lower among Māori and Pacific women (p < 0.001); and cholesterol (p = 0.001) and LDL-c (p = 0.018) were significantly lower among Pacific women only. Clustered cardiometabolic risk scores were also significantly lower among European (-0.23, p < 0.001) than Māori (0.26) or Pacific (0.17) women.

Table 4.1. Physical characteristics and metabolic health markers for each ethnic group

	Healthy reference range[a]	Māori (*n* = 37)		Pacific (*n* = 54)		European (*n* = 84)		
		Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	*p*
Physical characteristics								
Age (y)		31.9 ± 8.5	16.5-43.8	31.6 ± 9.2	16.8-44.8	33.1 ± 8.3	16.6-45.3	0.505
Body mass (kg)		90.2 ± 17.0	64.4-136.8	93.1 ± 15.1	65.6-134.1	80.5 ± 11.2‡*	60.4-114.8	<0.001
Height (cm)		166.2 ± 4.3	152.4–182.0	167.4 ± 5.6	154.1-181.5	166.0 ± 6.9	147.7–183.8	0.364
BMI (kg/m^2)	18.5-24.9	32.6 ± 5.8	25.0-49.1	33.2 ± 5.2	25.4-48.1	29.2 ± 3.7‡*	25.0-44.4	<0.001
Body fat (%)	22.0-29.9	40.9 ± 5.8	31.3-52.9	40.2 ± 5.5	30.8–53.0	38.9 ± 5.7	30.2-53.4	0.149
Body lean (%)		62.8 ± 5.2	49.3-71.5	63.6 ± 4.6	53.3-75.4	64.5 ± 4.3	55.4-72.8	0.150
Waist circumference (cm)	<80.0	93.0 ± 11.0	75.7-121.6	95.0 ± 10.8	74.9-127.3	87.1 ± 8.6‡*	71.2-108.3	<0.001
Waist-to-hip ratio	<0.8	0.80 ± 0.06	0.69-0.91	0.81 ± 0.06	0.67-0.96	0.79 ± 0.06*	0.66-0.93	0.298
Android fat (%)[b]		40.5 (37.0, 44.5)	30.0-50.4	39.3 (37.1, 43.0)	31.4-50.1	38.3 (33.1, 41.4)‡	25.6-52.4	0.027
Gynoid fat (%)[b]		39.3 (37.4, 42.1)	33.0-52.9	38.8 (37.1, 41.3)	28.2-47.6	39.9 (36.4, 43.2)	29.6-49.6	0.241
Metabolic health markers								
Systolic BP (mmHg)	<130	119 ± 12	96-146	121 ± 10	101-146	117 ± 10	95-152	0.134
Diastolic BP (mmHg)	<80	77 ± 10	58-104	76 ± 10	54-103	74 ± 8	59-100	0.129
HbA1c (mmol/mol)	<40	30.4 ± 4.9	19.0–41.0	30.8 ± 3.2	26.0–38.0	27.8 ± 3.3‡*	19.0–34.0	<0.001
Fasting glucose (mmol/L)	<5.5	4.86 ± 0.47	4.10–6.00	4.88 ± 0.42	4.00-6.50	4.71 ± 0.41	3.80–6.00	0.048
Insulin (mU/L)	5-13	16.7 ± 8.3	4.7-33.4	19.6 ± 11.8	6.0-66.1	11.3 ± 6.3‡*	2.6-45.5	<0.001
Cholesterol (mmol/L)	<4.0	4.59 ± 0.71	3.40-6.50	4.25 ± 0.83	2.70-7.40	4.81 ± 0.95*	3.30-8.60	0.003
HDL-c (mmol/L)	≥1.0	1.31 ± 0.32	0.80-1.95	1.36 ± 0.34	0.78-2.49	1.55 ± 0.35‡*	0.73-2.46	<0.001
Triglycerides (mmol/L)	<1.7	1.34 ± 0.64	0.42-2.84	1.03 ± 0.64	0.47-4.24	1.06 ± 1.03	0.37-9.20	0.002
LDL-c (mmol/L)	<2.0	2.68 ± 0.71	0.80–4.00	2.42 ± 0.73	1.10-4.90	2.83 ± 0.92*	1.10-6.40	0.024
Chol:HDL ratio	<4.0	3.69 ± 0.92	1.88-5.96	3.26 ± 0.80	1.81-5.27	3.26 ± 0.93‡	1.68–6.00	0.049
CCMR		0.26 ± 0.60	-0.83-1.62	0.17 ± 0.60	-0.90-1.63	-0.23 ± 0.55‡*	-1.58-1.35	<0.001

Values are mean ± SD, or [b]median (25th, 75th percentile). Abbreviations: BMI, body mass index; BP, blood pressure; HbA1c, glycosylated haemoglobin; HDL-c, high-density lipoprotein cholesterol; LDL-c, low-density lipoprotein cholesterol; CCMR, clustered cardiometabolic risk score. [a] Healthy reference ranges from New Zealand Primary Care Handbook 2012 (New Zealand Guidelines Group, 2012). ‡ significantly different to Māori ($p < 0.05$); * significantly different to Pacific ($p < 0.05$).

4.4.3 Physical activity

European women spent significantly more time in moderate, MVPA and MVPA10 ($p < 0.001$) compared to Māori or Pacific women (Table 4.2). Pacific women spent significantly more time (min/d) in sedentary behaviour (490 ± 67) compared to European (452 ± 75) or Māori (450 ± 56) women ($p = 0.004$). Many women performed no vigorous physical activity over the 7-day data collection period (Māori, 57%; Pacific, 67%; European, 39%).

Physical activity guidelines were met by 56.0% of all women. Within each ethnicity, physical activity guidelines were met by more European ($p = 0.001$, 66.7%) than Māori (48.7%) or Pacific (31.5%) women.

Table 4.2. Physical activity data by ethnicity

	Māori (*n* = 37)		Pacific (*n* = 54)		European (*n* = 84)		*p*
Physical activity (min/d)							
Sedentary	450 ± 56	327-596	490 ± 67‡	328-647	452 ± 75*	263-622	0.004
Light	328 ± 80	203-541	306 ± 66	165-552	329 ± 82	166-498	0.202
Moderate	20 (14, 33)	5-74	21 (11, 31)	4-80	33 (22, 44) ‡*	4-98	<0.001
Vigorous	0 (0, 2)	0-22	0 (0, 1)	0-23	1 (0, 3)	0-27	0.611
MVPA	21 (16, 35)	5-74	22 (11, 32)	4-80	35 (23, 48) ‡*	4-109	<0.001
MVPA10[a]	28 (0, 86)	0-270	24 (0, 90)	0-360	87 (37, 162) ‡*	0-420	<0.001
Physical activity guidelines							
Achieved	48.7%		31.5%		66.7%‡*		<0.001

Values are mean ± SD or median (25th, 75th percentile) and range. Abbreviations: MVPA, moderate to vigorous physical activity; MVPA10, MVPA accumulated in bouts ≥10 min.
[a] MVPA10 is presented as min/week.
‡significantly different to Māori ($p < 0.05$); *significantly different to Pacific ($p < 0.05$).

4.4.4 Associations of physical activity with measured markers

Across and within ethnicities, sedentary behaviour was not significantly associated with any measured markers ($p < 0.05$). For all women combined, MVPA and MVPA10 were associated inversely with BMI, BF% and clustered cardiometabolic risk score and positively with body lean % ($p < 0.05$). For Māori women, all measured markers (except waist-to-hip ratio) had medium or large inverse associations with both MVPA and MVPA10 (Table 4.3). For Pacific women, only waist-to-hip ratio was significantly inversely associated with MVPA and MVPA10; and for European women, no measured markers were significantly associated with either MVPA or MVPA10 physical activity.

For all women, meeting physical activity guidelines was associated ($p < 0.001$) with BMI ($t(173) = -4.10$), BF% ($t(173) = -3.89$), body lean % ($t(165) = 3.77$), waist circumference ($t(173) = -4.10$), android fat % ($t(164) = -3.85$), gynoid fat % ($t(164) = -3.06$) and clustered cardiometabolic risk score ($t(168) = -4.01$, $p = 0.003$).

Among Māori women, meeting physical activity guidelines was associated inversely with BF% ($t(35) = -3.55$, $p = 0.001$), android fat % ($t(35) = -2.94$, $p = 0.006$), gynoid fat % ($t(35) = -2.76$, $p = 0.009$) and clustered cardiometabolic risk score ($t(35) = -3.81$, $p = 0.001$) and positively with body lean % ($t(35) = 2.41$, $p = 0.021$). For European women, meeting physical activity guidelines was associated inversely with gynoid fat % ($t(80) = -2.19$, $p = 0.032$) and android fat % ($t(80) = -2.19$, $p = 0.032$) and positively with body lean % ($t(81) = 2.13$, $p = 0.036$). For Pacific women, no measured variables differed between those who did and did not met physical activity guidelines.

In determining associations between physical activity and the variables of interest a large number of tests were performed; however the number of significant results at each particular significance level far exceeded the expected number of false positive results. A total of 96 tests were conducted for Table 4.3, from which approximately 5, 1 and 0.1 false positive results would be expected at significance levels of 0.05, 0.01 and 0.005, respectively. In total, 22, 12 and 7 significant associations were found at each respective *p*-value. Although it is not possible to determine which of these observations likely constitute the expected false positives, the remaining observations (17, 11, and almost 7, respectively) do indicate that physical activity, especially among overweight-obese Māori women, is likely associated with improved health indicators.

Table 4.3. Associations between sedentary and physical activity behaviours, and obesity-related risk markers

	Sedentary		MVPA		MVPA10	
Total sample (*n* = 175)						
BMI	0.10	(-0.07, 0.25)	-0.22	(-0.39, -0.04)**	-0.22	(-0.37, -0.05)**
BF%	0.04	(-0.12, 0.17)	-0.22	(-0.40, -0.04)**	-0.21	(-0.37, -0.05)*
Waist circumference	0.08	(-0.11, 0.26)	-0.15	(-0.35, 0.04)	-0.15	(-0.33, 0.03)
Waist-to-hip ratio	0.02	(-0.14, 0.20)	0.01	(-0.20, 0.20)	0.06	(-0.15, 0.24)
Body lean %	-0.08	(-0.25, 0.08)	0.16	(-0.04, 0.35)	0.18	(0.01, 0.36)*
Android fat %	0.07	(-0.10, 0.23)	-0.19	(-0.41, 0.01)	-0.16	(-0.38, 0.04)
Gynoid fat %	-0.00	(-0.18, 0.16)	-0.16	(-0.33, 0.02)	-0.15	(-0.32, 0.02)
CCMR	-0.03	(-0.21, 0.14)	-0.19	(-0.35, -0.05)	-0.20	(-0.35, -0.06)*
Māori (*n* = 37)						
BMI	-0.22	(-0.47, 0.05)	-0.38	(-0.63, -0.03)*	-0.45	(-0.64, -0.27)**
BF%	-0.20	(-0.49, 0.12)	-0.59	(-0.78, -0.32)***	-0.54	(-0.70, -0.34)***
Waist circumference	-0.15	(-0.48, 0.15)	-0.35	(-0.62, -0.05)*	-0.44	(-0.65, -0.27)*
Waist-to-hip ratio	0.22	(-0.21, 0.55)	-0.05	(-0.39, 0.25)	-0.01	(-0.39, 0.24)
Body lean %	0.21	(-0.15, 0.57)	0.39	(0.06, 0.62)*	0.48	(0.28, 0.66)**
Android fat %	-0.26	(-0.57, 0.06)	-0.50	(-0.71, -0.22)***	-0.62	(-0.77, -0.47)***
Gynoid fat %	-0.31	(-0.65, 0.06)	-0.43	(-0.68, -0.09)*	-0.51	(-0.70, -0.30)***
CCMR	-0.25	(-0.60, 0.10)	-0.52	(-0.75, -0.29)***	-0.51	(-0.69, -0.36)***
Pacific (*n* = 57)						
BMI	0.01	(-0.43, 0.41)	-0.16	(-0.60, 0.22)	-0.25	(-0.65, 0.13)
BF%	0.02	(-0.32, 0.34)	-0.06	(-0.52, 0.29)	-0.24	(-0.62, 0.11)
Waist circumference	0.13	(-0.46, 0.56)	-0.22	(-0.60, 0.15)	-0.29	(-0.64, 0.04)
Waist-to-hip ratio	0.10	(-0.39, 0.51)	-0.35	(-0.61, -0.04)*	-0.34	(-0.61, -0.01)*
Body lean %	-0.87	(-0.47, 0.32)	0.12	(-0.20, 0.52)	0.25	(-0.06, 0.57)
Android fat %	0.25	(-0.25, 0.60)	-0.09	(-0.48, 0.20)	-0.15	(-0.48, 0.11)
Gynoid fat %	-0.10	(-0.38, 0.22)	0.01	(-0.35, 0.30)	-0.06	(-0.40, 0.23)
CCMR	-0.05	(-0.53, 0.37)	-0.14	(-0.49, 0.16)	-0.26	(-0.57, 0.01)
European (*n* = 84)						
BMI	0.26	(0.06, 0.45)	0.02	(-0.25, 0.30)	0.06	(-0.24, 0.37)
BF%	0.14	(-0.09, 0.36)	-0.11	(-0.39, 0.16)	-0.06	(-0.31, 0.19)
Waist circumference	0.11	(-0.14, 0.33)	0.11	(-0.23, 0.41)	0.16	(-0.14, 0.43)
Waist-to-hip ratio	-0.05	(-0.28, 0.19)	0.18	(-0.11, 0.45)	0.22	(-0.05, 0.47)
Body lean %	-0.22	(-0.43, 0.02)	0.05	(-0.24, 0.36)	0.03	(-0.22, 0.31)
Android fat %	0.13	(-0.10, 0.36)	-0.06	(-0.39, 0.27)	0.03	(-0.27, 0.31)
Gynoid fat %	0.19	(-0.07, 0.44)	-0.16	(-0.43, 0.09)	-0.11	(-0.35, 0.12)
CCMR	-0.02	(-0.22, 0.17)	0.11	(-0.14, 0.31)	0.10	(-0.13, 0.28)

Pearson's partial correlations adjusted for age and total energy intake. Data are correlation coefficients (*r*) and 95% confidence intervals.
Abbreviations: MVPA, moderate to vigorous physical activity; MVPA10, MVPA accumulated in bouts ≥10 min; BMI, body mass index; BF%, body fat percentage; CCMR, clustered cardiometabolic risk score.
*$p < 0.05$, **$p < 0.01$, ***$p < 0.005$.

4.6 Discussion

The aim of this study was to examine ethnic differences in objectively measured physical activity levels of overweight-obese New Zealand women, and the relationships between the physical activity, body composition and metabolic health markers of these women. The impact of physical activity on markers of health and disease has been extensively examined, but this study presents novel and important findings. This is the first time that ethnic differences in objectively measured physical activity have been investigated in relation to distinct body composition and metabolic disease risk profiles in New Zealand women of different ethnicities. Given that obesity prevalence in New Zealand women is the third highest in the OECD (OECD, 2015), understanding associations between obesity and modifiable lifestyle factors, such as physical activity, has major relevance to public health.

Individuals who are overweight-obese are at substantially increased risk of many physical activity-moderated diseases (e.g. type 2 diabetes) (De Lorenzo *et al.*, 2013; World Health Organization, 2015). For this reason, the physical activity levels of specifically healthy, overweight-obese women were examined to identify the risk factors for chronic diseases that might be modified most by physical activity. Physical activity guidelines were met by 56% of the total group of overweight-obese women, which is higher than the 47% reported in the New Zealand Health Survey for all women, and for Māori, Pacific and European women individually (Ministry of Health, 2015a). In contrast, ethnic differences in levels of physical activity in the current study were substantial; 66.7% of European women met the physical activity guidelines, compared to 48.7% of Māori and only 31.5% of Pacific women. In line with ethnic differences for meeting the guidelines, MVPA was over 50% higher among European women (35 min/day) relative to Māori (21 min/day) or Pacific (22 min/day) women ($p < 0.001$). Ethnic differences in physical activity levels were also reported in the United States, where fewer Hispanic and African-American adults (~44%) met physical activity guidelines compared to Caucasian or native populations (~54%) (Centers for Disease Control and Prevention, 2014). Cultural lifestyles and values reportedly influence how some populations view health care and status (Ministry of Health, 2012), and may affect the understanding of and priority given to health and healthy lifestyle factors, such as physical activity (Koloto and Sharma, 2006; Schluter *et al.*, 2011; Ministry of Health, 2012).

Examining physical activity in relation to body composition revealed interesting differences between the ethnic groups. Meeting physical activity guidelines was inversely associated with all body composition markers (except waist-to-hip ratio and a positive association with body lean %) and clustered cardiometabolic risk score across the total group of women. However, women from different ethnicities might respond differently to increased physical activity. Meeting the physical activity guidelines was associated with lower regional fat percentages and higher body lean % for both Māori and European women, and also with lower total BF% for Māori women only. In contrast, meeting physical activity guidelines had no significant impact on any measured markers for Pacific women. Associations for improved body composition and reduced metabolic disease risk with meeting physical activity guidelines is particularly encouraging for the potential health improvement of Māori and European women; evidence which should be used to reinforce the benefits of meeting physical activity guidelines. The fact that no associations were found among Pacific women should not be dismissed as physical activity being irrelevant among these women. Pacific women are at substantially increased risk of type 2 diabetes, so engaging in any exercise may still be beneficial to improve the health of this group (Aune *et al.*, 2015). Furthermore, only 32% of Pacific women met the physical activity guidelines, so it might be that too few Pacific women were sufficiently active for any effect to be detected in this group. There may also be other unidentified factors (e.g. diet composition, genetics) that are more impactful than physical activity on the body composition and metabolic health of Pacific women.

Associations for MVPA and MVPA10 reflected those presented for meeting physical activity guidelines, that is, MVPA or MVPA10 were associated inversely with BMI, BF% and clustered cardiometabolic risk score and positively with body lean % across the total group of women. For Māori women, MVPA and MVPA10 were favourably associated with all body composition variables (except waist-to-hip ratio) and clustered cardiometabolic risk score, indicating that spending more time being physically active is associated with more favourable body composition (e.g. lower BF% and BMI) and lower risk of cardiometabolic diseases. However, associations between MVPA and metabolic disease risk markers are inconsistent. MVPA was inversely associated with clustered cardiometabolic risk score among middle-aged adults at risk of type 2 diabetes (Cooper *et al.*, 2014; Wijndaele *et al.*, 2014) and with improved lipids and insulin sensitivity in women of all ages (Scheers *et al.*, 2013; Green *et al.*, 2014). To the contrary, MVPA was not associated with cardiometabolic outcomes in other adults at risk of type 2 diabetes, although was inversely associated with BMI and waist circumference (Henson *et al.*, 2013). Associations with BMI and waist circumference were also reported among American adults; those accumulating 30 min of MVPA10 had lower BMI and waist circumference than those accumulating the same amount of MVPA in bouts shorter than 10 minutes (Strath *et al.*, 2008). A similar trend was observed in the current study with stronger correlations for BMI and waist circumference with MVPA10 than MVPA. Maintaining MVPA for 10 or more minutes might require greater effort than simply reaching but not maintaining the MVPA intensity, and could explain the larger effects with MVPA10 (Strath *et al.*, 2008). These findings support physical activity guidelines for accumulating physical activity in bouts of 10 minutes or more (Ministry of Health, 2015c).

For European women neither MVPA nor MVPA10 were associated with any measured variables, and for Pacific women, only waist-to-hip ratio was inversely associated with MVPA and MVPA10. These findings are intriguing, especially given the extensive associations found for MVPA and MVPA10 among Māori women. European women had lower cardiometabolic diseases risk scores, BMI and waist circumference and were already relatively active (67% met physical activity guidelines), so higher levels (intensity or duration) of physical activity might be required to effect changes in the body composition of this relatively healthier group. However, the lack of association between physical activity and all variables except waist-to-hip ratio among Pacific women is again difficult to explain. No measured variables (body composition or metabolic) differed significantly between Māori and Pacific women, yet large associations with physical activity were found among Māori but none among Pacific women. Sedentary time was higher among Pacific women than others, but was associated with no body composition or metabolic markers in any groups, doing little to explain the observed differences in associations with physical activity. A possible explanation, and one for further investigation, is that average accelerometer counts varied within the MVPA (or other intensity) range despite similar total time within the range. For instance, Māori women may have averaged 5000 cpm for 20 min/day, whereas Pacific may have averaged only 3000 cpm for the same duration; both within the MVPA range (≥2020 cpm) but with vastly different total volume and energy expenditure. Further investigation is also required to uncover whether other factors more influential in these relationships than physical activity (e.g. diet composition, genetics) may have confounded results. Nevertheless, physical activity of any amount should be encouraged in all ethnic groups given the findings from the total group of overweight-obese women, and the overwhelming evidence in the literature for the benefits of physical activity. In essence, women performing more physical activity are likely at lower risk of metabolic diseases than those who are less active (Sattelmair *et al.*, 2011; Aune *et al.*, 2015).

Body composition, including relationships between BMI and BF%, differs markedly across ethnic groups (Rush *et al.*, 2009; Camhi *et al.*, 2011) and was evident in the current study. Even though all women were overweight-obese, European women had significantly lower BMI and waist circumference ($p < 0.001$) than Māori or Pacific women, yet fat and lean percentages were not significantly different ($p < 0.05$) between the three groups. A study of young women with obesity similarly reported higher BMI among Polynesian (Māori and Pacific combined) than European women, despite no differences in BF% between the groups (Rush *et al.*, 1999). As a consequence of this (Rush *et al.*, 1999) and other (Swinburn *et al.*, 1996; Swinburn *et al.*, 1999; Rush *et al.*, 2007; Rush *et al.*, 2009) research, ethnic-specific BMI cut-offs for classifying overweight-obesity have been suggested. However, when comparing the BMI-BF relationship of Māori and European adults with reference to metabolic disease risk, a positive association was found (Taylor *et al.*, 2010), rejecting the need for ethnic-specific BMI cut-offs. These findings are supported by results from the current study, with large positive associations ($r > 0.60$, $p < 0.001$) between BMI, BF% and waist circumference and clustered cardiometabolic risk score.

A major strength of the study was the inclusion and comparison of women representing three major New Zealand ethnic groups, accounting for 69% of New Zealand women. Objectively measured physical activity levels of Māori, Pacific and European women and the associations with body composition and markers of metabolic health have not previously been reported. The findings from this study provide valuable information on which to base future research and to guide implementation of physical activity guidelines in these groups. The study was strengthened by the inclusion of objectively measured physical activity using accelerometers, rather than self-report methods with potential recall bias, and the use of total energy intake as a covariate. Furthermore, the comprehensive body composition analysis provided both total and regional body composition assessment. Although the inclusion of only overweight-obese women in this analysis might limit the generalisability of results to women of other body composition profiles, these findings do provide valuable evidence in this group who are at particularly high risk of many chronic diseases.

As with any cross-sectional study, causal relationships cannot be determined. Whether physical activity is responsible for improved body composition, or more favourable body composition profiles promote physical activity participation, is unknown and requires further investigation. The study was limited by the small sample size due to substantial difficulties recruiting Pacific, and particularly Māori women. Power calculations were conducted to give a minimum of 37 participants in each group to detect an effect size of 0.58 with 80% power. At this number of participants, correlations of 0.44 were able to be detected with 80% power at a significance level of $p < 0.05$. As explained in the Results section, a large number of tests were conducted on a small sample size, but the high number of significant observations do indicate that physical activity, especially among overweight-obese Māori women, is likely associated with improved health indicators. Although all women in the current study were overweight-obese, they were all otherwise healthy, and most biomarkers were within normal ranges. Associations for improved metabolic health markers and clustered cardiometabolic risk score with increased physical activity might be less apparent in this group of women than if an already unhealthy population was examined. Furthermore, the level of physical activity observed in some of the study population may have been insufficient to detect improvements in some markers.

4.7 Conclusions

This study provides valuable evidence of ethnic differences in associations of physical activity with body composition and metabolic health markers in overweight-obese Māori, Pacific and European women. Meeting physical activity guidelines was widely and strongly associated with more favourable body composition and clustered cardiometabolic risk scores for all overweight-obese women, and for Māori and European women in particular. Hence, the health of Māori and European women could benefit substantially from meeting or exceeding physical activity guidelines. Very few associations with physical activity were revealed for Pacific women. However, more Pacific women could be encouraged to achieve physical activity guidelines; the observed low prevalence (32%) of meeting guidelines may have been insufficient to detect the impact of physical activity in this group. Furthermore, understanding social and cultural reasons why physical activity is lower among Māori, and particularly Pacific women, might expand knowledge of family and lifestyle factors and provide avenues to promote physical activity participation in the wider New Zealand community. Given the alarming prevalence of obesity and obesity-related diseases in New Zealand, further research is also required to more deeply explore the observed differences between ethnic groups, and to elucidate factors (e.g. diet composition, genetics) among Pacific women that might be more impactful than physical activity. It does seem though, that the effects of physical activity might be optimised by tailoring physical activity-based weight loss and health improvement initiatives to the specific ethnic populations.

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Chapter 5 Replacing sedentary time with active behaviour to predict improved body composition and metabolic health markers

Data submitted and currently in review: O'Brien, W. J., Walsh, D. C. I., Shultz, S. P., Fink, P. W., Breier, B. H. & Kruger, R. Replacing sedentary time with physically active behaviour predicts improved body composition and metabolic health outcomes. *Journal of Physical Activity and Health (in review).*

5.1 Abstract

Background: Physical activity can improve long-term health outcomes, but discretionary leisure-time is limited, so choosing physical activities most beneficial to health is critical.

Objective: To predict changes in body composition and metabolic health markers associated with increased physical activity in women of different body composition profiles and ethnicities.

Methods: Healthy women (*n* = 327) aged 16-45y, were stratified by body composition profile based on BMI and BF%. Overweight-obese women (*n* = 175) were further stratified by ethnicity (Māori, Pacific, European). Sedentary behaviour and physical activity were assessed via accelerometry. Fat and lean mass (total, regional) and metabolic blood markers were assessed. An isotemporal substitution paradigm reallocating 30 min/day sedentary to physical activity predicted body composition and metabolic health marker outcomes.

Results: Among overweight-obese women, most body composition and some metabolic markers improved when sedentary time was reallocated to physical activity of moderate or greater intensity. In particular, Māori women had significant improvements predicted for waist circumference (10.0%), BF% (14.8%), BMI (15.3%), android fat% (12.5%) and insulin (42.2%); and for Pacific women, waist-to-hip ratio (5.3%). Among normal-weight women, vigorous physical activity predicted increased total lean mass (9.7%) in women with normal BF%, and reduced BF% (13.0%) in those with excess BF%. Predicted improvements were sufficient to bring many women back within healthy ranges for a number of variables.

Conclusion: Overweight-obese women, particularly of Māori decent, might especially benefit from more physically active lifestyles. Normal-weight women with excessive BF% might most benefit from high-intensity physical activity. Physical activity recommendations to improve long-term health should reflect the needs and current activity levels of specific populations.

5.2 Introduction

Physical activity is known to effectively reduce disease risk and improve long-term health and weight management outcomes (Swift *et al.*, 2014; World Health Organization, 2015). Hence, physical activity guidelines were developed for this purpose (World Health Organization, 2010; Garber *et al.*, 2011; Ministry of Health, 2015c). Indeed, women meeting physical activity guidelines had 14% lower risk of coronary heart disease (Sattelmair *et al.*, 2011) and 33% reduced risk of type 2 diabetes (Grontved *et al.*, 2014) relative to inactive women. However, recommendations for particular volumes and intensities of physical activity (e.g. 30 min/day at moderate intensity) do not state which specific behaviour such activity should replace. This discrepancy is especially important since discretionary leisure time is finite; engaging in one activity prevents using that same period of time to perform an alternative activity. Therefore, identifying which activities provide the greatest benefit to overall health is critical. For example, 30 min/day spent walking instead of watching television would have quite different effects on metabolic health markers than if already active behaviour (e.g. basketball) was replaced with walking. To account for the finite nature of available leisure time, isotemporal substitution analysis has been used to predict the most beneficial volume and intensity of physical activity on indicators of disease risk and health, while total time is held constant (Mekary *et al.*, 2009).

Isotemporal substitution analysis is used in physical activity research, to reallocate time from sedentary to more active behaviours (Mekary *et al.*, 2009) in order to predict cardiometabolic health benefits of a more physically active lifestyle (Buman *et al.*, 2014; Healy *et al.*, 2015). This analytic technique has also been used to predict changes in simple body composition variables (e.g. BMI) (Huang *et al.*, 2016; Van Der Berg *et al.*, 2017), but has not been used to examine changes in detailed body composition variables such as total and regional lean and fat mass. Excess fat mass, regardless of BMI, has negative consequences on metabolic health (De Lorenzo *et al.*, 2013). Individuals with normal BMI but unapparent excessive BF% may be at similar metabolic risk to their visibly obese counterparts (De Lorenzo *et al.*, 2006; Marques-Vidal *et al.*, 2010; Romero-Corral *et al.*, 2010; Olafsdottir *et al.*, 2016). The specific location of fat mass is also important. Excessive fat in the android region poses greater risk of inflammation and chronic diseases (e.g. type 2 diabetes, cardiovascular disease) than equally excessive gynoid fat (Bastien *et al.*, 2014). Understanding the effects of increased physical activity on such measures of obesity is of increasing public health importance in many countries worldwide (World Health Organization, 2010), and in New Zealand in particular, where obesity prevalence ranks third in the OECD (OECD, 2015).

Body composition is known to vary across different ethnic groups. Ethnic differences in BMI, BF% and fat distribution have been reported repeatedly (Carroll *et al.*, 2008; Rush *et al.*, 2009; Camhi *et al.*, 2011; Sluyter *et al.*, 2011), including among Hispanic, African-American and Caucasian women in the United States (Carroll *et al.*, 2008; Camhi *et al.*, 2011), and in Māori, Pacific and European populations in New Zealand (Rush *et al.*, 2009; Sluyter *et al.*, 2011). Specifically, for any given BMI value, European women have higher BF% than Māori or Pacific women (Rush *et al.*, 2009). Large ethnic disparities also exist in obesity prevalence among New Zealand women. Overall, 62% of New Zealand women have a BMI above the healthy range (i.e. ≥25 kg/m^2) (Ministry of Health, 2015a), yet overweight-obesity prevalence ranges from 89% (Pacific) to 37% (Asian) (Ministry of Health, 2015a). Subsequently, similar ethnic disparities are evident in obesity-related disease risk and prevalence in the New Zealand population (Ministry of Health, 2015b). For example, type 2 diabetes prevalence is substantially higher among Pacific (14.9%) than Māori (7.7%) or European (4.9%) women (Ministry of Health, 2015b), mirroring the ranking of obesity prevalence among these groups (Ministry of Health, 2016).

Given the worldwide epidemic of obesity, and its associated complications, understanding the potential health benefits of specific increases in physical activity is of significant public health importance, and could contribute to the implementation of effective health-improvement initiatives. Therefore, the aim of this study was to evaluate the potential benefits of replacing sedentary behaviour with more physically active behaviours on body composition and metabolic health markers, especially in vulnerable population groups. A secondary aim was to further examine ethnic differences in population groups with higher metabolic disease risk to gain a better understanding of population-specific physical activity requirements.

5.3 Methods

This cross-sectional study reports objectively measured physical activity, body composition and metabolic data, obtained as part of the women's EXPLORE study (Kruger *et al.*, 2015) conducted in Auckland, New Zealand. The full methodology of the EXPLORE study is described elsewhere (Appendix 4; Kruger *et al.*, 2015); the study flow is shown in Appendix 5. The study was approved by the Massey University Human Ethics Committee: Southern A, Reference No.13/13 and conducted in accordance with the Declaration of Helsinki. Prior to data collection, written informed consent was obtained from participants.

5.3.1 Participants

The EXPLORE study (Kruger *et al.*, 2015) recruited 406 healthy pre-menopausal women aged 16-45 years of Māori, Pacific or European descent. Of these, 381 fitted the body composition criteria for the current study and were considered for analysis. Participants were regarded as a particular ethnicity if they identified with, and had at least one parent of, that ethnicity. Inclusion criteria consisted of being post-menarche but pre-menopausal. Participants were excluded if they were pregnant, lactating or diagnosed with any metabolic condition or chronic illness.

5.3.2 Physical activity

Tri-axial accelerometers (Actigraph wGT3X+, Pensacola, FL) were used to assess physical activity over seven consecutive days. Accelerometers sampled at 100 Hz frequency and data were downloaded using the low frequency extension in 60-s epochs. Accelerometers were worn on an elastic belt over participants' right hip at all times (excluding water-based activities) during a typical week. To be considered for final analysis, participants must have returned accelerometer data for ≥10 h/day (Matthews *et al.*, 2012) for ≥4 week and/or weekend days (Tudor-Locke *et al.*, 2012). Valid data were returned from 327 participants; 54 participants returned insufficient (*n* = 33) or no (*n* = 21, including 11 lost and eight unworn accelerometers, and two due to hardware failure) data.

Non-wear and sleep time were determined and removed using a publicly available algorithm (Barreira *et al.*, 2015). Non-wear time was defined as intervals ≥60 consecutive min of 0 cpm, with exception for 1-2 min of activity during that time. Algorithms were run using MATLAB (R2011b 7.13.0.564, The MathWorks Inc., Natick, MA) computer software. Widely used and validated cut-points (cpm) were used to identify physical activity levels: sedentary (0-99), light (100-2019), moderate (2020-5998) and vigorous (≥5999) physical activity and MVPA (≥2020) (Troiano *et al.*, 2008).

5.3.3 Anthropometry and body composition

Anthropometric assessment was conducted using ISAK protocols (Marfell-Jones *et al.*, 2006) as described elsewhere (Kruger *et al.*, 2015). Briefly, waist and hip circumferences and height were measured to the nearest 0.1 cm. Body mass (kg) was assessed using the electronic scales incorporated in the air displacement plethysmography device (BodPod, 2007A, Life Measurement Inc, Concord, CA; manufacturer software V4.2+). BMI (kg/m^2) was calculated from assessed height and body mass. BodPod was used to assess total BF% using measured thoracic volume and Siri equation (Siri, 1961). Regional (android, gynoid) fat and total and regional lean mass were determined from whole body dual-energy X-ray absorptiometry (Hologic QDR Discovery A with APEX v3.2 software; Hologic Inc, Bedford, MA).

Participants were categorised into body composition profile groups based on BMI and BF%. BMI classifications were normal (18.5–24.9 kg/m^2) or high (≥25 kg/m^2) based on internationally recognised cut-off points (World Health Organization, 2006). BF% was classified as normal (18.0-29.9%) or high (≥30.0%), according to previous research (Okorodudu *et al.*, 2010). The three body composition groups were: normal BMI and normal BF% (NN); normal BMI and high BF% (NH); high BMI and high BF% (HH).

5.3.4 Metabolic biomarkers

Fasting venous blood samples were drawn between 7:00 and 9:30 am into EDTA and serum vacutainer tubes. An aliquot of EDTA whole blood was immediately frozen at -80 °C for later HbA1c analysis with high performance liquid chromatography (Biorad Variant instrumentation, USA). Remaining blood was centrifuged at 3500 rpm for 15 mins at 4 °C, to obtain plasma and serum samples. Samples were aliquoted and frozen at -80 °C for later analysis. Plasma ghrelin was measured using Milliplex immunoassay kits (Millipore Corp, Billerica, MD) and Bioplex 200 multiplex system (Bio-Rad Laboratories, Hercules, CA; V.6.0 Bioplex software). Serum insulin was measured using ADVIA Centaur immunoassay kits (Siemens Healthcare Diagnostics). Serum cholesterol, HDL-c, glucose and triglycerides were measured using automated Dimension Vista procedures (Siemens Healthcare Diagnostics). Cholesterol to HDL-c ratio and LDL-c were calculated from measured variables. Blood pressure was measured twice using an automated blood pressure monitor (Riester Ri Champion, Rudolf Riester GmbH, Jungingen, Germany) after 5 minutes of seated rest.

5.3.5 Dietary analysis

Total energy intake was calculated from an online semi-quantitative food frequency questionnaire analysed using Foodworks Professional 7 (Xyris Software, Australia; New

Zealand Food Composition Database (New Zealand Institute for Crop & Food Research, 2006)) for use as a covariate in the analysis.

5.3.6 Statistical analysis

All statistical analyses were carried out using SPSS Statistics 22 for Windows (SPSS, Inc., Chicago, IL). Normality of data was confirmed using histograms and Kolmogorov–Smirnov tests. Data are reported as mean ± SD. One-way ANOVA was used to compare physical activity, body composition and metabolic data between body composition profile and ethnic groups. The level of significance was set at $p < 0.05$ for all analyses.

Linear regression was used to examine associations between metabolic markers and body composition variables, and 30-min time blocks of sedentary behaviour, light, moderate and vigorous physical activity and MVPA. Time blocks of 30 min/day were chosen to roughly align with physical activity guidelines (150 min/week, commonly interpreted as 30 min/day on 5 day/week) (World Health Organization, 2010). Isotemporal substitution models were used to estimate the effects of substituting 30 min/day of any activity with 30 min/day of any other level of activity, whilst holding total wear-time constant. All time reallocation is 30 min/day of the stated physical activity intensity. For each outcome variable in this isotemporal substitution model, the total wear-time variable plus all activities, except the activity of interest, were entered into the model simultaneously, thus time was constrained (i.e. isotemporal). Isotemporal substitution allows direct comparison of the activity of interest and the metabolic and body composition outcome variables. Predicted percentage changes in outcome variables were determined using the difference between predicted and measured means of each variable, divided by the measured mean of the variable, multiplied by 100. Covariates in all models were age and total energy intake; BMI was also included for metabolic variables.

5.4 Results

A total of 327 participants within the body composition groups of interest returned valid accelerometer data (≥10 h/day on ≥4 week and/or weekend days) and were included in the analysis (Table 5.1). In determining accelerometer wear criteria, an independent *t*-test was used to compare *any 4 days* (n = 350), with *4 days including 1 weekend day* (n = 325). *Any 4 days* was used as the criteria, since no significant differences in any variables of interest were detected between the two criteria (*p*-values 0.635 to 0.992), and a slightly larger sample size was achieved with *any 4 days*.

Table 5.1. Participant physical and metabolic health characteristics

	Healthy reference range	Total (*n* = 327)	NN (*n* = 94)	NH (*n* = 58)	HH (*n* = 175)	*p*
Physical characteristics						
Age (y)		31.7 ± 8.5	29.6 ± 8.1	33.2 ± 8.4*	32.4 ± 8.6*	0.010
Body mass (kg)		75.4 ± 16.7	61.4 ± 6.9	65 ± 5.6	86.4 ± 14.9*†	<0.001
Height (cm)		167.0 ± 6.5	167.7 ± 6.4	167.7 ± 6.3	166.5 ± 6.6	0.244
BMI (kg/m^2)	22.0-24.9	27.0 ± 5.9	21.8 ± 1.6	23.1 ± 1.3	31.2 ± 5*†	<0.001
Body fat (%)	18.0-29.9	34.3 ± 7.9	24.9 ± 3.2	33.5 ± 3.0*	39.7 ± 5.7*†	<0.001
Waist (cm)	<80.0	82.2 ± 12.5	70.7 ± 4.8	74.6 ± 3.9*	90.8 ± 10.4*†	<0.001
Hip (cm)		107.0 ± 10.7	97.4 ± 4.8	101.5 ± 4.1*	113.9 ± 9.5*†	<0.001
Waist-to-hip ratio	<0.8	0.77 ± 0.06	0.73 ± 0.04	0.74 ± 0.04	0.8 ± 0.1*†	<0.001
Android fat (%)		33.6 ± 7.5	25.5 ± 4.1	31.7 ± 4.6*	38.8 ± 5.2*†	<0.001
Gynoid fat (%)		37.5 ± 4.7	33.3 ± 3.6	38.7 ± 3.4*	39.5 ± 4.2*	<0.001
Metabolic health markers						
Systolic BP (mmHg)	<130	116 ± 10	114 ± 8	114 ± 9	119 ± 11*†	<0.001
Diastolic BP (mmHg)	<80	73 ± 8	70 ± 7	72 ± 8	75 ± 9*†	<0.001
HbA1c (mmol/mol)	<40.0	28.5 ± 3.7	27.9 ± 3.5	27.1 ± 2.8	29.3 ± 3.9*†	<0.001
Fasting glucose (mmol/L)	3.5-5.4	4.7 ± 0.4	4.5 ± 0.4	4.6 ± 0.3	4.8 ± 0.4*†	<0.001
Insulin (mU/L)	3.0-25.0	11.8 ± 8.4	8.2 ± 5.4	8.0 ± 3.4	15.1 ± 9.5*†	<0.001
Cholesterol (mmol/L)	<5.0	4.6 ± 0.9	4.6 ± 1.0	4.8 ± 0.9	4.6 ± 0.9	0.179
HDL-c (mmol/L)	>1.0	1.6 ± 0.4	1.8 ± 0.5	1.7 ± 0.4	1.4 ± 0.4*†	<0.001
Triglycerides (mmol/L)	<2.0	1.0 ± 0.7	0.8 ± 0.3	0.9 ± 0.4	1.1 ± 0.9*†	<0.001
LDL-c (mmol/L)	<3.4	2.6 ± 0.8	2.4 ± 0.8	2.8 ± 0.8	2.7 ± 0.8	0.037
Chol:HDL ratio	<4.5	3.1 ± 0.9	2.7 ± 0.8	3.0 ± 0.7	3.4 ± 0.9*†	<0.001
Leptin (ng/ml)		10.4 ± 8.0	4.4 ± 2.7	7.7 ± 4.4*	14.5 ± 8.4*†	<0.001
Ghrelin (pg/ml)		46.7 ± 37.8	53.6 ± 42.4	48.2 ± 31.5	42.5 ± 36.6	0.069

Data are mean ± SD. Abbreviations: BMI, body mass index; BF%, body fat %; NN, normal BMI normal BF%; NH, normal BMI high BF%; HH, high BMI high BF%; Waist, waist circumference; Hip, hip circumference; BP, blood pressure; HbA1c, glycosylated haemoglobin; HDL-c, HDL-cholesterol; LDL-c, LDL-cholesterol; Chol:HDL ratio, cholesterol to HDL-c ratio.
*significantly different to NN at $p < 0.05$; †significantly different to NH at $p < 0.05$.

5.4.1 Total population

Across the total population, all metabolic health markers were within healthy reference ranges (Table 5.1). All body composition variables were predicted to improve when sedentary time was reallocated to moderate or vigorous physical activity (Figure 5.1); larger improvements were predicted with time reallocated into vigorous than into moderate physical activity. Reduced BMI was predicted with time reallocation from sedentary to moderate (-7.1%) and

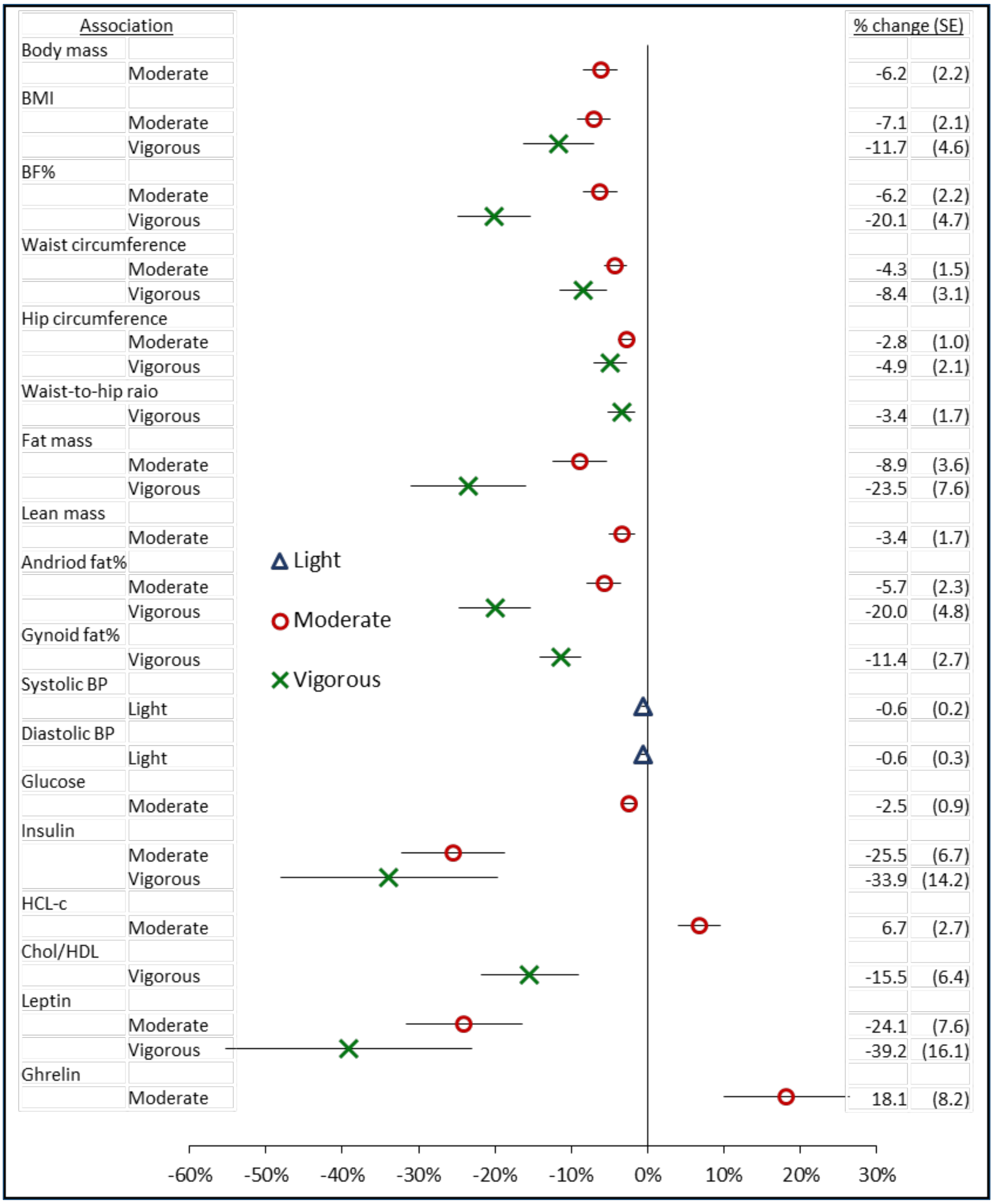

Figure 5.1. Predicted changes (%) in body composition and metabolic variables for all participants

Figure shows percentage changes in body composition and metabolic variables for all participants (n = 327) with 30 min/day reallocated from sedentary to light, moderate or vigorous physical activity using isotemporal substitution regression models. Covariates were age and total energy intake for body composition variables, and age, total energy intake and BMI for metabolic variables. Bars are standard error (SE).
Symbols: Triangle, light physical activity; Circle, moderate physical activity; Cross, vigorous physical activity. Abbreviations: BMI, body mass index; BF%, body fat percentage; BP, blood pressure; HDL-c, high-density lipoprotein cholesterol; Chol/HDL, cholesterol to HDL-c ratio.
Only significant associations ($p < 0.05$) are shown.

vigorous (-11.7%) physical activity, equating to BMI reductions of -1.9 and -3.2 kg/m^2, respectively. Reduced BF% was predicted with reallocation of sedentary to moderate (-6.2%) and vigorous (-20.1%) physical activity, equating to -2.1 and -6.9 percentage points, respectively.

Many metabolic variables were predicted to improve with reallocation of sedentary time to physical activity (Figure 5.1). Time reallocation to vigorous physical activity predicted reduced insulin (-33.9%, -4.0 mU/L), leptin (-39.2%, -4.1 ng/ml), ghrelin (-40.8%, -19.1 pg/ml) and cholesterol to HDL-c ratio (-15.5%, -0.5).

5.4.2 Body composition profile groups

All participants were stratified into body composition profile groups (Table 5.1). Sedentary time (p = 0.897) and light physical activity (p = 0.251) did not differ significantly between the groups. NN women spent significantly more time in moderate, vigorous and MVPA ($p \leq 0.001$) than NH or HH women (Table 5.2). No vigorous physical activity was performed by 55% of HH women, violating assumptions for the isotemporal model. Hence, vigorous physical activity was removed from all models for the HH group.

Table 5.2. Physical activity and sedentary data for participants

		Activity intensity (min/day)					
	n	Sedentary	Light	Moderate	Vigorous	MVPA	MVPA10[a]
NN	94	462 ± 77	320 ± 81	36 ± 19	3 (0, 10)	44 ± 23	142 ± 125
NH	58	468 ± 71	303 ± 74	29 ± 14†	2 (0, 6)†	34 ± 18†	107 ± 91
HH	175	463 ± 71	322 ± 77	29 ± 17†	0 (0, 3)†	31 ± 18†	81 ± 88†
p-value		0.897	0.251	0.001	<0.001	<0.001	<0.001
HH group							
Māori	37	450 ± 56	328 ± 80	25 ± 16	0 (0, 2)	21 (16, 35)	28 (0, 86)
Pacific	54	490 ± 67‡	306 ± 66	23 ± 16	0 (0, 1)	22 (11, 32)	24 (0, 90)
European	84	452 ± 75*	329 ± 82	34 ± 16‡*	1 (0, 3)	35 (23, 48) ‡*	87 (37, 162)‡*
p-value		0.004	0.202	<0.001	0.611	<0.001	<0.001

Values are mean ± SD or median (25^{th}, 75^{th} percentile). Abbreviations: MVPA, moderate to vigorous physical activity; MVPA10, MVPA accumulated in bouts of ≥10 min; NN, normal BMI normal BF%; NH, normal BMI high BF%; HH, high BMI high BF%.
[a] MVPA10 is presented as min/wk.
Significance: Body composition groups: †significantly different to NN ($p < 0.05$); Ethnic groups: ‡significantly different to Māori ($p < 0.05$); *significantly different to Pacific ($p < 0.05$).

Many body composition and metabolic markers were significantly less favourable ($p < 0.05$) among HH women compared to NN or NH women (Table 5.1). For HH women, reallocating sedentary time to moderate physical activity predicted reduced body mass (-5.0 kg), BMI (-2.2 kg/m^2), BF% (-1.7 percentage points), lean mass (-2.3 kg) and waist circumference (-3.7 cm) (Figure 5.2). Reallocating time from sedentary, light or moderate to vigorous physical activity predicted increased lean mass (4.4, 4.1 and 5.1 kg, respectively) for NN women, and decreased BF% (-4.4, -4.5 and -6.1 percentage points, respectively) for NH women. Leptin was significantly lower among NN women ($p < 0.001$), and was predicted to decrease by 21.0% (-0.9 mU/L) with sedentary reallocation to moderate physical activity (Figure 5.2).

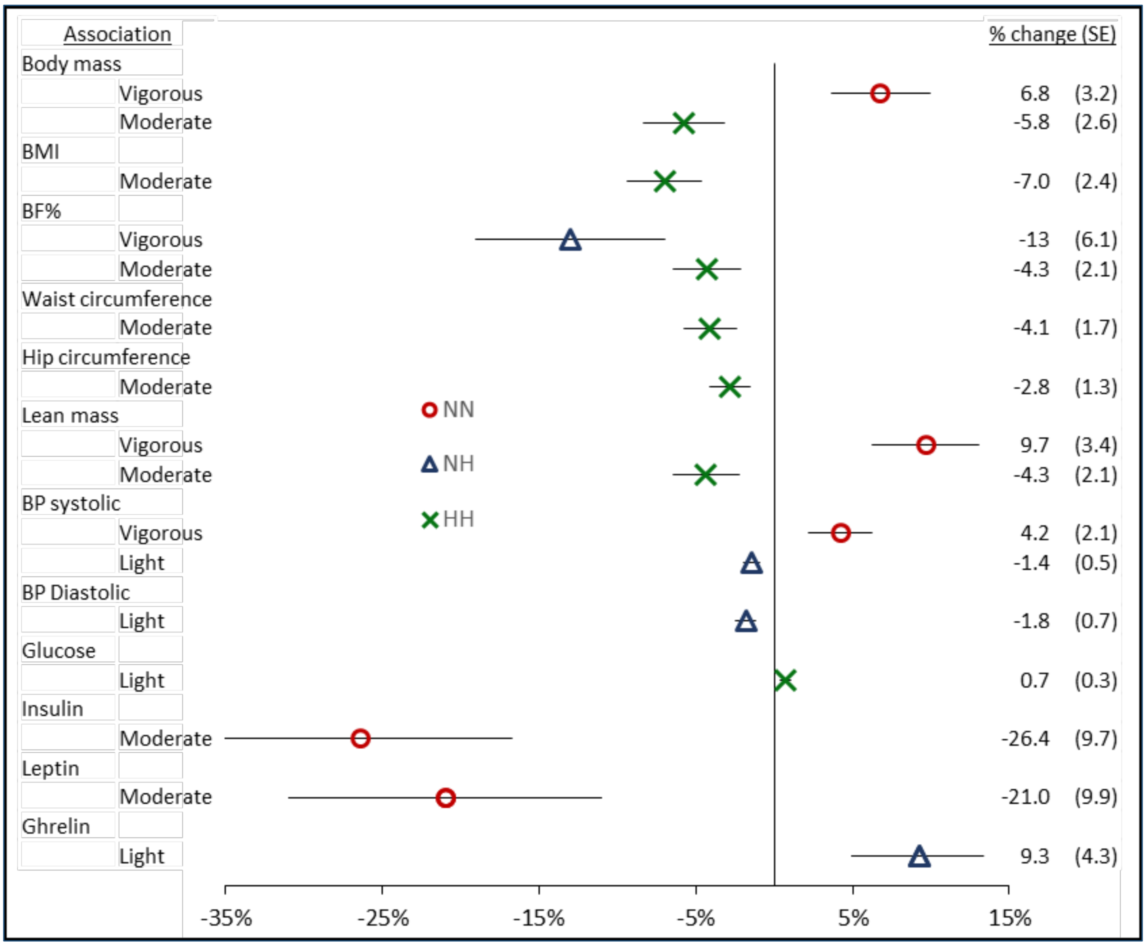

Figure 5.2. Predicted changes (%) in body composition and metabolic variables by body composition profile group

Figure shows percentage changes in body composition and metabolic variables with 30 min/day reallocated from sedentary time to light, moderate or vigorous physical activity using isotemporal substitution regression models. Data are for each body composition profile group (NN, n = 94; NH, n = 58; HH, n = 175). Covariates were age and total energy intake for body composition variables, and age, total energy intake and BMI for metabolic variables. Bars are standard error (SE).
Symbols are: Triangle, NN; Circle, NH; Cross, HH. Abbreviations: NN, normal BMI normal BF%; NH, normal BMI high BF%; HH, high BMI high BF%; BMI, body mass index; BF%, body fat percentage; BP, blood pressure.
Only significant associations ($p < 0.05$) are shown.

5.4.3 Overweight-obese (HH) group

The overweight-obese body composition profile group was stratified by ethnicity. European women had lower BMI and waist circumference ($p < 0.001$) and many more favourable metabolic health markers compared to Māori or Pacific women (Table 5.3). Reallocating sedentary time to physical activity predicted few changes for European (BMI, systolic BP) or Pacific (waist-to-hip ratio) women. Among Māori women, reallocation of sedentary time to MVPA predicted improvements in BMI (-15.3%), BF% (-14.8%), waist circumference (-10.0%) and android fat% (-12.5%) and insulin (-42.2%) (Figure 5.3).

Table 5.3. Participant characteristics of HH group, stratified by ethnicity

	Māori (*n*=37)	Pacific (*n*=54)	European (*n*=84)	*p*
Physical characteristics				
Age (y)	31.9 ± 8.5	31.6 ± 9.2	33.1 ± 8.3	0.505
Body mass (kg)	90.2 ± 17.0	93.1 ± 15.1	80.5 ± 11.2ǂ*	<0.001
Height (cm)	166.2 ± 4.3	167.4 ± 5.6	166.0 ± 6.9	0.364
BMI (kg/m^2)	32.6 ± 5.8	33.2 ± 5.2	29.2 ± 3.7ǂ*	<0.001
Body fat (%)	40.9 ± 5.8	40.2 ± 5.5	38.9 ± 5.7	0.149
Body lean (%)	62.8 ± 5.2	64.5 ± 4.3	63.6 ± 4.6	0.222
Waist circumference (cm)	93.0 ± 11.0	95.0 ± 10.8	87.1 ± 8.6ǂ*	<0.001
Waist-to-hip ratio	0.80 ± 0.06	0.81 ± 0.06	0.79 ± 0.06*	0.298
Android fat (%)[a]	40.5 (37.0, 44.5)	39.3 (37.1, 43.0)	38.3 (33.1, 41.4)ǂ	0.027
Gynoid fat (%)[a]	39.3 (37.4, 42.1)	38.8 (37.1, 41.3)	39.9 (36.4, 43.2)	0.241
Metabolic health markers				
Systolic BP (mmHg)	119 ± 12	121 ± 10	117 ± 10	0.134
Diastolic BP (mmHg)	77 ± 10	76 ± 10	74 ± 8	0.129
HbA1c (mmol/mol)	30.4 ± 4.9	30.8 ± 3.2	27.8 ± 3.3ǂ*	<0.001
Fasting glucose (mmol/L)	4.86 ± 0.47	4.88 ± 0.42	4.71 ± 0.41	0.048
Insulin (mU/L)	16.7 ± 8.3	19.6 ± 11.8	11.3 ± 6.3ǂ*	<0.001
Cholesterol (mmol/L)	4.59 ± 0.71	4.25 ± 0.83	4.81 ± 0.95*	0.003
HDL-c (mmol/L)	1.31 ± 0.32	1.36 ± 0.34	1.55 ± 0.35ǂ*	<0.001
Triglycerides (mmol/L)	1.34 ± 0.64	1.03 ± 0.64	1.06 ± 1.03	0.002
LDL-c (mmol/L)	2.68 ± 0.71	2.42 ± 0.73	2.83 ± 0.92*	0.024
Chol:HDL ratio	3.69 ± 0.92	3.26 ± 0.80	3.26 ± 0.93ǂ	0.049

Values are mean ± SD, or [a]median (25th, 75th percentile). Abbreviations: BMI, body mass index; BP, blood pressure; HbA1c, glycosylated haemoglobin; HDL-c, high-density lipoprotein cholesterol; LDL-c, low-density lipoprotein cholesterol; Chol:HDL ratio, cholesterol to HDL-c ratio.
ǂ significantly different to Māori ($p < 0.05$); * significantly different to Pacific ($p < 0.05$).

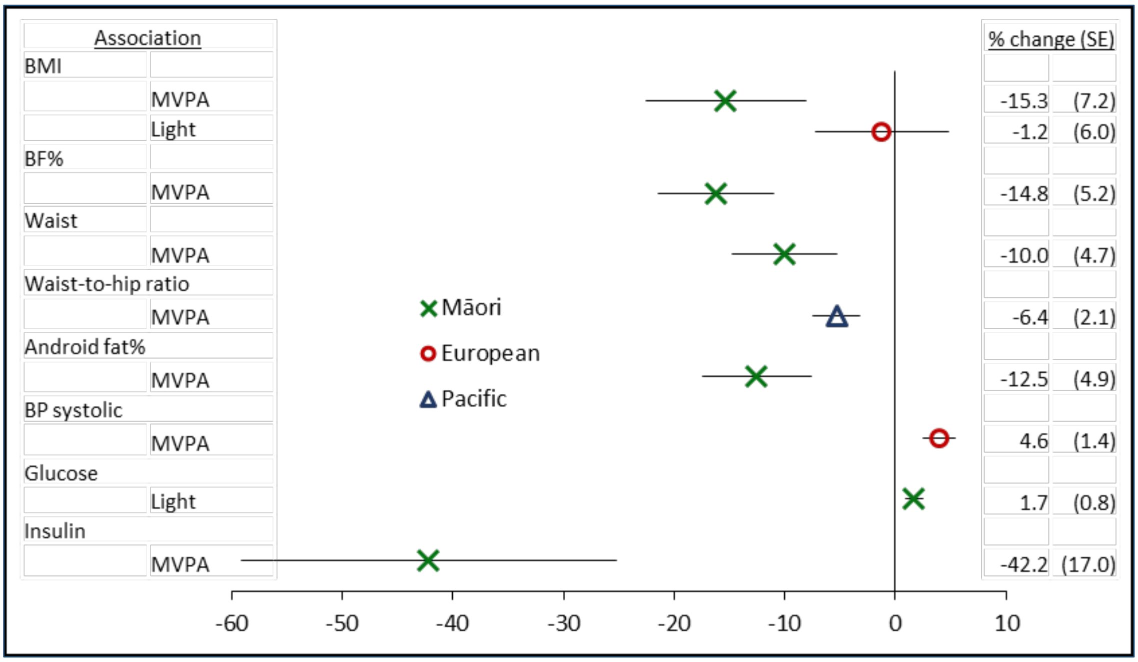

Figure 5.3. Predicted changes (%) in body composition and metabolic variables of overweight-obese women by ethnicity

Figure shows percentage changes in body composition and metabolic variables with 30 min/day reallocated from sedentary time to light physical activity or MVPA using isotemporal substitution regression models. Data are for each ethnic group (Māori, n = 37; European, n = 84; Pacific, n = 54).
Symbols are: Triangle, Māori; Circle, European; Cross, Pacific. Abbreviations: BMI, body mass index; BF%, body fat percentage; BP, blood pressure.
Covariates were age and total energy intake for body composition variables, and age, total energy intake and BMI for metabolic variables. Bars are standard error (SE).
Only significant associations ($p < 0.05$) are shown.

5.5 Discussion

The aim of this study was to investigate the cross-sectional associations of increasing physical activity volume and intensity on body composition and metabolic health markers of New Zealand women, especially those from particularly vulnerable body composition profile and ethnic groups. An isotemporal substitution model was used to examine the effects on outcome variables of substituting time in one physical activity intensity with equal time engaged in physical activity of different intensity. Isotemporal substitution analysis has not previously been used to predict changes in regional body composition, nor has it been conducted in women stratified by body composition profile groups or ethnicity. Thus, these findings more robustly describe the importance of physical activity, and specifically physical activity intensity, on improved health indicators as related to a large portion of the New Zealand female population.

The main finding was the differential association of increased physical activity on body composition and metabolic health variables among women of different body composition profiles and ethnicities. Reallocating time from sedentary to other physical activity intensities predicted improvements in most body composition and metabolic health variables for overweight-obese (HH) women; improvements that were even more pronounced among Māori women. The HH women are the most vulnerable group, with the highest adiposity and greatest metabolic disease risk, indicated by the many metabolic health markers that, although largely with normal ranges, were significantly higher than for the normal-weight women.

The HH women engaged in significantly less physical activity than did NN or NH women, and 55% performed no vigorous physical activity. Hence any increases in physical activity would likely have a marked effect on the body composition of these overweight-obese women. Indeed, the improvements predicted among this group (body mass, -5.0 kg; BMI -2.2 kg/m^2; BF%, -1.7 percentage points; lean mass, -2.3 kg; waist circumference, -3.7 cm) occurred with just 30 min/day reallocated from sedentary to more active behaviour. Potential exists for metabolic and body composition improvements of even greater magnitude if longer or more intense exercise was performed by this at-risk group. Significantly improved body composition (total, abdominal, subcutaneous and visceral fat) was also reported among previously inactive women with obesity following a 14-week moderate-intensity exercise intervention (Ross *et al.*, 2004). In other exercise training studies of obese women, moderate intensity (continuous aerobic) exercise and MVPA were more effective than high intensity exercise at reducing total and android fat mass (Keating *et al.*, 2014) and increasing lean mass (Drenowatz *et al.*, 2016). Unfortunately in the current study, insufficient vigorous physical activity was performed by many HH women to enable its analysis for this group.

The single body composition change predicted for NH women, a 13% reduction in BF% with vigorous physical activity, was a particularly important finding for this group. A decrease of this magnitude would move the BF% of this group to 29.1%, meaning that many of these women would fall within a healthy BF% range (18.0-29.9%), and potentially reduce the metabolic disease risk currently posed by their excessive body fatness. Although not evident in variables within the current models, such substantial reductions in BF% would likely also benefit the health of these women through improved substrate utilisation via enhanced metabolic flexibility, along with improved insulin signalling and sensitivity (Battaglia *et al.*, 2012; Goodpaster and Sparks, 2017). More extensive changes among the NH group might have been expected given the evidence for increased metabolic disease risk among NH women (De

Lorenzo *et al.*, 2007; Kruger *et al.*, 2010; Romero-Corral *et al.*, 2010). Indeed, leptin was the only biomarker that differed significantly to the NN group; a finding also reported by Kruger *et al.* (2010). In contrast to findings among the NH group, changes in moderate, but not vigorous physical activity reduced fat mass and percentage among non-overweight adults (Drenowatz *et al.*, 2016). Vigorous physical activity was also required to predict increased total lean mass, and subsequent total body mass among NN women. This group were healthy and predominantly active, so even greater increases in their physical activity levels would likely be required to elicit significant changes in other body composition measures.

An important and unexpected finding was the extensive benefits predicted for overweight-obese Māori women, but not for Pacific or European women of the same body composition profile. Māori women are at elevated risk of type 2 diabetes (RR 1.84) and cardiovascular disease (RR 2.20 for ischemic heart disease) and have higher prevalence of obesity (RR 1.69) than non-Māori women (Ministry of Health, 2015b). Hence, the predicted improvements in BMI, BF%, android fat%, waist circumference and insulin for Māori women are particularly important and relevant for their long-term health. Just 30 min/day of sedentary time reallocated to MVPA predicted a reduction in insulin of 42.7% (7.0 mU/L), sufficient to return insulin concentrations to well within the healthy range. Exercise is known to improve insulin sensitivity, especially in obese populations (Balducci *et al.*, 2010; Jorge *et al.*, 2011; Kleist *et al.*, 2017), and improves metabolic flexibility and the ability of the body to switch between glucose and lipid metabolism depending on demands (Gabriel and Zierath, 2017; Goodpaster and Sparks, 2017). In this light, the body composition and insulin improvements predicted with increased physical activity present significant potential to improve the long-term health of, especially overweight-obese, Māori women.

In contrast to predictions for Māori women though, the lack of significant change predicted for Pacific women with increased physical activity was intriguing. Pacific women are at even greater risk of type 2 diabetes (RR 3.48 vs non-Pacific women) than their Māori counterparts (Ministry of Health, 2015b) and have alarmingly high obesity prevalence (69.5%, (Ministry of Health, 2015a)), yet only waist-to-hip ratio changed significantly (-5.0%, -4.8 cm). Nevertheless, waist-to-hip ratio is an important indicator of central adiposity and disease risk (Mathieu *et al.*, 2009; Coutinho *et al.*, 2013), so any improvement in this measure is a positive indicator for this group. The distinct differences between the ethnic groups in predicted responses to increased physical activity are unlikely related to different levels of physical activity, since MVPA time did not differ significantly between Māori and Pacific women (p = 1.00). Variations in predicted body composition responses to physical activity are also unlikely related to body composition differences between these groups. Percentages of fat and lean mass also did not differ significantly between the three groups ($p > 0.15$), even though BMI was higher among Māori and Pacific, than European women; no body composition variables differed between Māori and Pacific women. Similarly, BMI but not BF% differed between obese young Pacific and European adolescents (Rush *et al.*, 1999; Sluyter *et al.*, 2011). Ethnicity-dependent variations in body composition have also been reported in response to physical activity (Van Dyck *et al.*, 2015; Whitaker *et al.*, 2017), although no studies were found to compare the current ethnic groups. Relationships between physical activity intensity and body composition may have differed had other accelerometer cut-off points been used (Gába *et al.*, 2016), although this is not possible to determine from the current analysis. Furthermore, even though no differences in levels of physical activity were detected between Māori and Pacific women, the possibility exists for different levels of activity within each intensity range. For instance, one group may perform 20 min/day averaging 3000 cpm while the other group might spend the same amount of time averaging 5000 cpm; both within the moderate range (2020-5998 cpm), but representing quite different total volumes of physical activity (and subsequent energy expenditures).

Across all body composition profile and ethnic groups, reallocation of sedentary time to moderate physical activity or MVPA was associated with few changes in metabolic health markers. Most notably, >20% reductions in insulin and leptin were predicted for all women combined, for NN women, and for HH Māori women (insulin only). Lower concentrations of insulin and leptin were also reported in adults with increased MVPA, and in those engaging in daily physical activity sufficient to meet physical activity guidelines, compared to less active adults (Buman *et al.*, 2014; Tudor-Locke *et al.*, 2017; Vella *et al.*, 2017). Slight increases in fasting glucose were predicted among HH and Māori women with light physical activity, but these were largely counteracted in terms of type 2 diabetes risk by the substantial improvements predicted for insulin. Associations for metabolic markers with increased physical activity might have been more pronounced in women with substantial disease risk profiles (Cloostermans *et al.*, 2015). The current study population, although 54% overweight-obese, were all healthy, with no known history of major diseases, and all biomarkers (except insulin in the HH group) were within healthy ranges. It may also be that some women were not sufficiently active to enable associations between physical activity and changes in metabolic health markers to be detected.

Among the strengths of this study was the inclusion of total energy intake as a covariate in the isotemporal model to account for imbalances between energy intake and expenditure. The use of accelerometers to obtain objective physical activity data was a further strength. However, the accelerometers (and cut-points) used may not be the most effective at distinguishing sedentary behaviour from light physical activity or at detecting differences in overall physical activity volume (Kozey-Keadle *et al.*, 2011; Evenson *et al.*, 2015; Gába *et al.*, 2016). Some isotemporal studies have reported beneficial effects of replacing sedentary time with light physical activity (Buman *et al.*, 2014; Ekblom-Bak *et al.*, 2016a, Ekblom-Bak *et al.*, 2016b), whilst others report no effect (Hamer *et al.*, 2014); in the current study, few variables were affected by this reallocation. Low rates of participation in vigorous physical activity precluded analysis of this highest physical activity intensity among the HH group; such analysis would have been interesting, had data been available. However, some individuals may not be capable, or willing, to exercise at an intensity sufficient to meet the vigorous threshold (Blair *et al.*, 2004), and even analysis of lower intensities provides valuable evidence for the beneficial effects of physical activity. Finally, as with any cross-sectional study, and given the theoretical nature of the time substitution in the current analysis, inference of causality is not possible.

5.6 Conclusions

In summary, important changes in body composition and metabolic health markers were predicted by reallocating sedentary time to moderate, vigorous or MVPA, dependent on the ethnicity and body composition profiles of New Zealand women. This novel application of isotemporal substitution analysis has not previously been applied to groups stratified by body composition profile nor ethnicity, and has highlighted distinct differences in metabolic disease risks associated with these groups. Not unexpectedly, the overweight-obese women were significantly less active than other women, and were predicted to benefit most from increased physical activity. Of particular significance were substantially improved body composition and metabolic health markers predicted among overweight-obese Māori women. For women of normal BMI, vigorous, but not moderate, physical activity was associated with reduced BF% among those with high BF%, and with increased total lean mass among those with normal BF%; both favourable changes with important metabolic implications. The current findings demonstrate important differential predictions from increased physical activity on body composition and metabolic health markers, dependent on body composition profile and ethnicity in some particularly vulnerable populations. Well-designed intervention studies are required to confirm these findings in order to generate more specific physical activity recommendations. Interventions and recommendations aimed at improving body composition and metabolic health outcomes, should carefully consider the population under investigation, their metabolic health needs and the specific activity intensity with which to replace sedentary time.

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Chapter 6 Ethnic-specific suggestions for physical activity based on existing recreational physical activity preferences

6.1 Abstract

Background: New Zealand has a high prevalence of, and ethnic and gender disparity in, obesity and non-communicable diseases that are mediated by physical activity.

Objective: To examine recreational physical activity preferences of New Zealand women, in order to develop ethnic-specific suggestions that will encourage physical activity participation whilst aligning with national physical activity guidelines.

Methods: Healthy Māori, Pacific and European women (*n* = 331) aged 16-45 years (BMI 18.7-49.2 kg/m^2) completed an online Recent Physical Activity Questionnaire to assess recreational physical activities and to determine prevalence of meeting physical activity guidelines. These existing physical activity preferences were tailored to make ethnic-specific suggestions aimed at increasing participation and reducing the burden of obesity and chronic disease.

Results: Achievement of physical activity guidelines amongst the ethnic groups was: Māori 74%; Pacific 60%; European 70%. Walking was the most popular activity by participation across all women (Māori 72%, Pacific 60%, European 83%), followed in all groups by floor exercise (Māori 54%, Pacific 37%, European 56%). Gym-type activities (e.g. weights) and jogging were also common across ethnic groups. Group/team activities (dance, netball, touch football) were amongst the top-10 activities for Māori and Pacific, but not European women.

Conclusion: Improving the physical activity habits and subsequent health of New Zealand women, and their communities, might be achieved by tailoring existing physical activity preferences to develop ethnic-specific physical activity suggestions. Family/whānau-based (netball, touch), community-linked (hula, dance) and outdoor activities could be important avenues to improve physical activity habits of specific ethnic women.

6.2 Introduction

Physical activity is well known for its positive health effects, including disease prevention, weight management and improved metabolic health (Blair and Morris, 2009; Lee *et al.*, 2012; Swift *et al.*, 2014). Conversely, physical inactivity is associated with increased risk of many non-communicable diseases (e.g. cardiovascular disease, type 2 diabetes) (World Health Organization, 2016), and ranks 4th as a risk factor for mortality in Australasia (Lim *et al.*, 2012). Hence, physical activity guidelines have been established in many countries (Division of Nutrition *et al.*, 2008; World Health Organization, 2010; Department of Health, 2011; Australian Government Department of Health, 2014; Ministry of Health, 2015c; Rütten *et al.*, 2016) aimed at reducing the risk of non-communicable diseases, improving overall health and maintaining a healthy body weight (World Health Organization, 2010; Garber *et al.*, 2011; Australian Government Department of Health, 2014; Ministry of Health, 2015c). New Zealand physical activity guidelines recommend the accumulation of ≥150 min of at least moderate intensity aerobic exercise (e.g. brisk walking, swimming), spread throughout each week (Ministry of Health, 2015c). This level of activity represents the most basic recommendations; even greater health benefits may be gained from longer or more intense (e.g. running instead of walking) activity. In addition, muscle strengthening exercise (e.g. weights) at least twice a week is recommended (Ministry of Health, 2015c). Recommended physical activity may take place in a variety of settings, from formal and structured sport (e.g. organised club netball competition), to casual exercise alone or with friends (e.g. walking on the beach). Physical activity guidelines are based on duration and intensity, rather than specific types of activities. Hence, it is often not clear exactly what is required, nor which prescribed activities are equivalent to other more preferred activities. Encouraging the pursuit of personally or culturally interesting and relevant activities might increase participation in all forms of physical activity, thereby alleviating some of the health burden caused by physical inactivity.

Currently, only 48% of New Zealand adults are sufficiently active to meet the national guidelines (Ministry of Health, 2016); women are less active (45%) and more inactive (18%) than men (51% and 13%, respectively) (Ministry of Health, 2016). Time constraints and financial burden are common barriers to physical activity participation among New Zealand adults (Schluter *et al.*, 2011); however, childcare responsibilities and social support pose particular barriers for women (Bellows-Riecken and Rhodes, 2008; Schluter *et al.*, 2011). Parenthood, and in particular motherhood, is associated with reduced recreational physical activity in many countries (Brown and Trost, 2003; Bellows-Riecken and Rhodes, 2008), and likely also in New Zealand. Providing strategies to overcome some of these barriers might encourage greater physical activity participation among some women, especially if focussed on women from certain groups (e.g. young mothers, overweight women).

In some ethnic groups, social-cultural reasons may prevent participation in physical activity. Cultural values may inhibit female participation in exercise (Gordon *et al.*, 2013); or religious beliefs might disallow Sunday sport participation (World Health Organization, 2007; Gordon *et al.*, 2013). On the other hand, physical activity can be about freedom, independence, and community-building (KTV Consulting, 2017). For example, Māori value whānau (i.e. family), which is one of the imperatives for exercise participation (Progressive Training, 2017), whilst local iwi or kaupapa-led initiatives (e.g. Māori-specific netball clubs) enable community members to engage in activities, both socially and competitively. In a similar way, Pacific peoples have strong connections to the church and community, and these values are the focus of many locally driven physical activity initiatives, such as inter-church sports competitions (Ministry for Pacific Peoples, 2017). Cultural initiatives such as these have the potential to promote increased physical activity participation by providing support, familiarity and security to participants.

Some segments of the population are over-represented in certain health statistics that are mediated by physical activity (Ministry of Health, 2015b). Considerable ethnic disparities exist in obesity prevalence, with higher rates among Pacific women (69.5%) compared to Māori (47.6%) and European/Other (30.6%) women (Ministry of Health, 2015a). Pacific women are also at 3.48 times greater risk of type 2 diabetes than non-Pacific women, whilst risk of ischemic heart disease is 2.20 times higher among Māori than non-Māori women (Ministry of Health, 2015b). The risk of these, and other chronic diseases, is substantially attenuated by almost all levels of physical activity (Sattelmair *et al.*, 2011; Aune *et al.*, 2015). For example, risk of coronary heart disease was 14% lower among women meeting basic physical activity guidelines compare to those who did not (Sattelmair *et al.*, 2011). Promoting the benefits of physical activity involvement to population groups with higher metabolic disease risk will be important in overcoming the negative health consequences of physical inactivity. However, the prescriptive nature of physical activity guidelines may seem daunting, hard to interpret, and difficult for some individuals or groups to engage with. Hence, the purpose of this study was to examine the recreational physical activity habits of New Zealand women of different ethnicities to identify each group's unique physical activity preferences. The resulting data were then used to determine how existing physical activity preferences might be tailored for each ethnic group to better align with physical activity recommendations and to improve participation.

6.3 Methods

This cross-sectional study reports subjectively measured physical activity data obtained as part of the women's EXPLORE study (Kruger *et al.*, 2015) conducted in Auckland, New Zealand. The full methodology of the EXPLORE study is described elsewhere (Appendix 4; Kruger *et al.*, 2015); the study flow is shown in Appendix 5. The study was approved by the Massey University Human Ethics Committee: Southern A, Reference No.13/13 and conducted in accordance with the Declaration of Helsinki. Prior to data collection, written informed consent was obtained from participants.

6.3.1 Participants

Participants (n = 331) were healthy pre-menopausal women aged 16-45 years of Māori (n = 57), Pacific (n = 65) or European (n = 209) descent. Ethnicity was determined by self-identification and having at least one parent of that ethnicity. Inclusion criteria consisted of being post-menarche but pre-menopausal. Participants were excluded if they were pregnant, lactating or diagnosed with any metabolic condition or chronic illness.

6.3.2 Physical activity data

Participants completed the validated RPAQ (Besson *et al.*, 2010) adapted for online entry (SurveyMonkey; Palo Alto, CA) (Appendix 8). Levels of physical activity were assessed in four domains (home, work, recreational, transport) over the previous 4-weeks. The RPAQ contained a list of 35 groups of recreational activities, as well as four "Other" activities (for other or New Zealand specific activities) against which participants recorded frequency and duration of participation. The RPAQ has shown good validity for estimating total and physical activity energy expenditure and of time spent in vigorous physical activity, and good reliability for physical activity energy expenditure (ICC = 0.76) and across activity intensities except transport (ICC 0.74-0.86; transport 0.32, p = 0.0001) (Besson *et al.*, 2010).

6.3.3 Data processing

Data were manually cleaned in accordance with questionnaire guidelines (MRC Epidemiology Unit, 2006). Any activities listed under "Other" were considered individually and added to the listed activity that was most similar in type, intensity and MET value (Moy *et al.*, 2006; Ainsworth, 2011). Data were then processed using SPSS Statistics 22 for Windows (SPSS, Inc., Chicago, IL) according to questionnaire guidelines, which included Ainsworth's Compendium of Physical Activities (Ainsworth, 2011) to assign METs to activities. Moderate intensity activities were those of 3.0-6.0 METs; vigorous intensity activities were >6.0 METs. When comparing activities against physical activity guidelines (Ministry of Health, 2015c), only those with a substantial aerobic component were included. These activities included: swimming, cycling, walking, hiking, running, lawn mowing, digging, aerobics, conditioning exercise, dancing, tennis, squash, table tennis, golf, football/touch/rugby, rowing/waka ama, netball/volleyball, ice skating and martial arts. All data were tested for normality using Kolmogorov-Smirnov tests. Descriptive data are presented as means ± SD. Mann-Whitney and Kruskal-Wallis tests were used to compare activity time with employment and child variables, and ethnicity, respectively.

6.4 Results

RPAQ data were obtained from 331 participants (57 Māori, 65 Pacific, 209 European; Table 6.1) across a wide BMI range (18.7-49.2 kg/m^2). Women spent an average of 6.94 h/day in sedentary behaviour. A total of 261 women were employed (part or full time; 30.3 ± 13.5 h/week), 63.6% of whom held sedentary jobs.

Participants spent 67.7 ± 53.9 min/day engaged in recreational activities, at an energy cost of 5.5 ± 4.8 MET·h/day or 20.8% of total activity energy expenditure (Table 6.2). Employed women spent more time in recreational activities than women who were not employed (p = 0.030, r = 0.12). Overall, recreation time did not differ significantly between those with and without children (p = 0.087); however, Pacific women with children spent less time in recreational activities than Pacific women without children (p = 0.026, r = -0.27). Physical activity guidelines were met by 68.8% of participants. Fewer Pacific women (60.0%) than Māori (73.7%) or European (70.3%) women ($\chi^2(2)$ = 9.02, p = 0.011; (Table 6.2) met the guidelines.

Table 6.1. Participant characteristics and allocation of time in different categories

	Total	Māori	Pacific	European
n (%)	331 (100)	57 (17.2)	65 (19.6)	209 (63.1)
Age (years)	31.5 ± 8.3	31.1 ± 8.3	29.0 ± 8.9	32.4 ± 8.0
BMI (kg/m^2) [a]				
18.5-24.9 (%)	48.9	42.1	13.9	61.7
25.0-29.9 (%)	26.0	26.3	24.6	26.3
≥30.0 (%)	25.1	31.6	61.5	12.0
Employed (%) [a]	78.9	82.5	56.9	84.7
Mother (%) [a]	37.5	56.1	33.9	33.5
Time allocation (h/day, % of 24 h)				
Work (employed only) [b]	4.33 (18.0)	4.53 (18.9)	4.11 (17.1)	4.33 (18.0)
Total sedentary (non-work) [c]	6.94 (28.9)	7.50 (31.3)	7.14 (29.8)	6.73 (28.0)
Screen time (non-work) [d]	4.54 (18.9)	5.02 (20.8)	4.14 (17.3)	5.43 (22.6)
Recreation	1.13 (4.7)	1.20 (5.0)	1.03 (4.3)	1.14 (4.8)

Abbreviations: BMI, body mass index. [a] Values are % of *n*; [b] Work is mean time for only participants employed full or part time; [c] Total sedentary time, not including unallocated time; [d] Screen time is also included in Total sedentary.

Table 6.2. Breakdown of recreational time of participants

	Total (*n* = 331)	Māori (*n* = 57)	Pacific (*n* = 65)	European (*n* = 209)	*p*
Recreation (min/day)					
Total recreation time [a]	67.7 ± 53.9	72.0 ± 55.2	61.8 ± 63.6	68.4 ± 49.2	0.087
Moderate intensity [b]	48.6 ± 42.0	49.8 ± 37.2	43.2 ± 51.6	49.8 ± 39.6	**0.022**
Vigorous intensity [c]	15.6 ± 24.6	18.6 ± 25.2	10.8 ± 24.6	16.2 ± 24.0	**< 0.001**
Energy expenditure (MET·h/day)	5.5 ± 4.8	6.0 ± 5.1	4.7 ± 5.2	5.5 ± 4.6	0.058
Participants meeting PA guidelines (%) [d]	68.8	73.7	60.0	70.3	**0.011**

Values are mean ± SD. Abbreviations: MET, metabolic equivalent of task; PA, physical activity. [a] Total recreation time, including light, moderate and vigorous intensity activities; [b] 3.0-6.0 METs; [c] >6.0 METs; [d] % of participants who recorded ≥150 min/wk of at least moderate intensity aerobic (≥3.0 METs) activity. **Bold** typeface indicates significant differences between groups.

Walking was the most popular activity across the total population by duration (79.8 ± 138.6 min/week), frequency (1.5 ± 1.7 times/week), participation (76.7%) and energy expenditure (0.67 ± 1.15 MET·h/day), and also when stratified by ethnicity (Table 6.3, Figure 6.1). All gym-type activities (weights, aerobics, floor exercise, conditioning exercise) were among the top 10 activities across all ethnicities, based on time, frequency, participation and energy expenditure (Table 6.3, Figure 6.1). Jogging accounted for the greatest energy expenditure for Māori (0.92 ± 2.10 MET·h/day) and European (0.80 ± 1.77 MET·h/day) women. For Pacific, the highest energy expenditure came from walking (0.68 ± 2.13 MET·h/day), followed by music performance (0.33 ± 0.78 MET·h/day (Table 6.3).

Table 6.3. Top 10 activities by participation for each ethnic group

Activity	% participation	Time (min/day)	Frequency (times/week)	MET·h/day	Activity METs	Required min/day[a]
Māori (*n* = 57)						
Walking	*72%*	*10.2 ± 13.8*	*1.33 ± 1.54*	*0.60 ± 0.82*	*3.5*	*26*
Floor exercise	*54%*	*5.4 ± 8.4*	*1.19 ± 1.54*	*0.34 ± 0.58*	*4.0*	*N/A*
Jogging	**53%**	**7.8 ± 18.0**	**0.98 ± 1.54**	**0.92 ± 2.10**	**7.0**	**13**
Conditioning exercise	*42%*	*4.2 ± 8.4*	*0.63 ± 1.05*	*0.38 ± 0.76*	*5.5*	*16*
Weights	*40%*	*7.2 ± 14.4*	*0.84 ± 1.33*	*0.36 ± 0.71*	*3.0*	*N/A*
Dance	*39%*	*6.6 ± 18.0*	*0.56 ± 1.19*	*0.49 ± 1.34*	*4.5*	*20*
Weeding	*37%*	*1.8 ± 4.2*	*0.21 ± 0.63*	*0.16 ± 0.31*	*4.5*	*N/A*
Netball/Volleyball	*28%*	*4.2 ± 13.8*	*0.35 ± 0.77*	*0.39 ± 1.26*	*5.5*	*16*
Aerobics	**26%**	**3.0 ± 8.4**	**0.35 ± 0.84**	**0.33 ± 1.00**	**7.0**	**13**
DIY	*26%*	*1.8 ± 4.8*	*0.07 ± 0.21*	*0.14 ± 0.34*	*4.5*	*N/A*
Pacific (*n* = 65)						
Walking	*60%*	*11.6 ± 36.5*	*1.26 ± 1.96*	*0.68 ± 2.13*	*3.5*	*26*
Floor exercise	37%	2.9 ± 7.7	0.84 ± 1.54	0.20 ± 0.51	4.0	N/A
Music performance	35%	7.4 ± 17.3	0.84 ± 1.75	0.33 ± 0.78	2.5	N/A
Weights	*35%*	*6.1 ± 15.2*	*0.63 ± 1.19*	*0.30 ± 0.76*	*3.0*	*N/A*
Jogging	**35%**	**2.8 ± 6.8**	**0.42 ± 0.84**	**0.32 ± 0.79**	**7.0**	**13**
Netball/Volleyball	*34%*	*3.4 ± 10.2*	*0.35 ± 0.63*	*0.31 ± 0.94*	*5.5*	*16*
Conditioning exercise	*26%*	*2.1 ± 4.9*	*0.42 ± 1.05*	*0.19 ± 0.45*	*5.5*	*16*
Dance	*25%*	*5.5 ± 19.2*	*0.35 ± 1.05*	*0.41 ± 1.44*	*4.5*	*20*
Aerobics	**23%**	**4.3 ± 11.8**	**0.49 ± 1.19**	**0.51 ± 1.38**	**7.0**	**13**
Swim (leisure)	*18%*	*0.8 ± 2.0*	*0.07 ± 0.21*	*0.08 ± 0.20*	*6.0*	*15*
European (*n* = 209)						
Walking	*83%*	*11.8 ± 12.4*	*1.61 ± 1.61*	*0.69 ± 0.72*	*3.5*	*26*
Floor exercise	*56%*	*4.9 ± 9.7*	*1.19 ± 1.68*	*0.33 ± 0.65*	*4.0*	*N/A*
Weights	*54%*	*11.8 ± 19.8*	*1.12 ± 1.47*	*0.59 ± 0.99*	*3.0*	*N/A*
Jogging	**48%**	**6.8 ± 15.2**	**0.84 ± 1.33**	**0.80 ± 1.77**	**7.0**	**13**
Conditioning exercise	*38%*	*6.4 ± 15.9*	*0.70 ± 1.26*	*0.58 ± 1.46*	*5.5*	*16*
Weeding	*34%*	*1.9 ± 4.9*	*0.21 ± 0.49*	*0.14 ± 0.37*	*4.5*	*N/A*
Swim (leisure)	*29%*	*1.4 ± 4.9*	*0.28 ± 0.77*	*0.14 ± 0.49*	*6.0*	*15*
Watering garden/lawn	26%	1.1 ± 3.1	0.35 ± 0.98	0.03 ± 0.08	1.5	N/A
Aerobics	**22%**	**3.4 ± 9.0**	**0.42 ± 1.05**	**0.40 ± 1.05**	**7.0**	**13**
DIY	*22%*	*3.9 ± 15.2*	*0.21 ± 0.70*	*0.29 ± 1.14*	*4.5*	*N/A*

Bold typeface - activities of vigorous intensity (>6.0 METs); *Italic* typeface - activities of moderate intensity (3.0-6.0 METs); Standard typeface – activities of light intensity (<3.0 METs); N/A – activity not sufficiently aerobic or intense to contribute to meeting physical activity guidelines. Abbreviations: MET, metabolic equivalent of task.

[a] Approximate minimum time (min/day) required on 5 day/week in order to meet aerobic component of physical activity guidelines, equivalent to 150 min/week of at least moderate intensity (≥3.0 METs) aerobic activity from the particular activity alone.

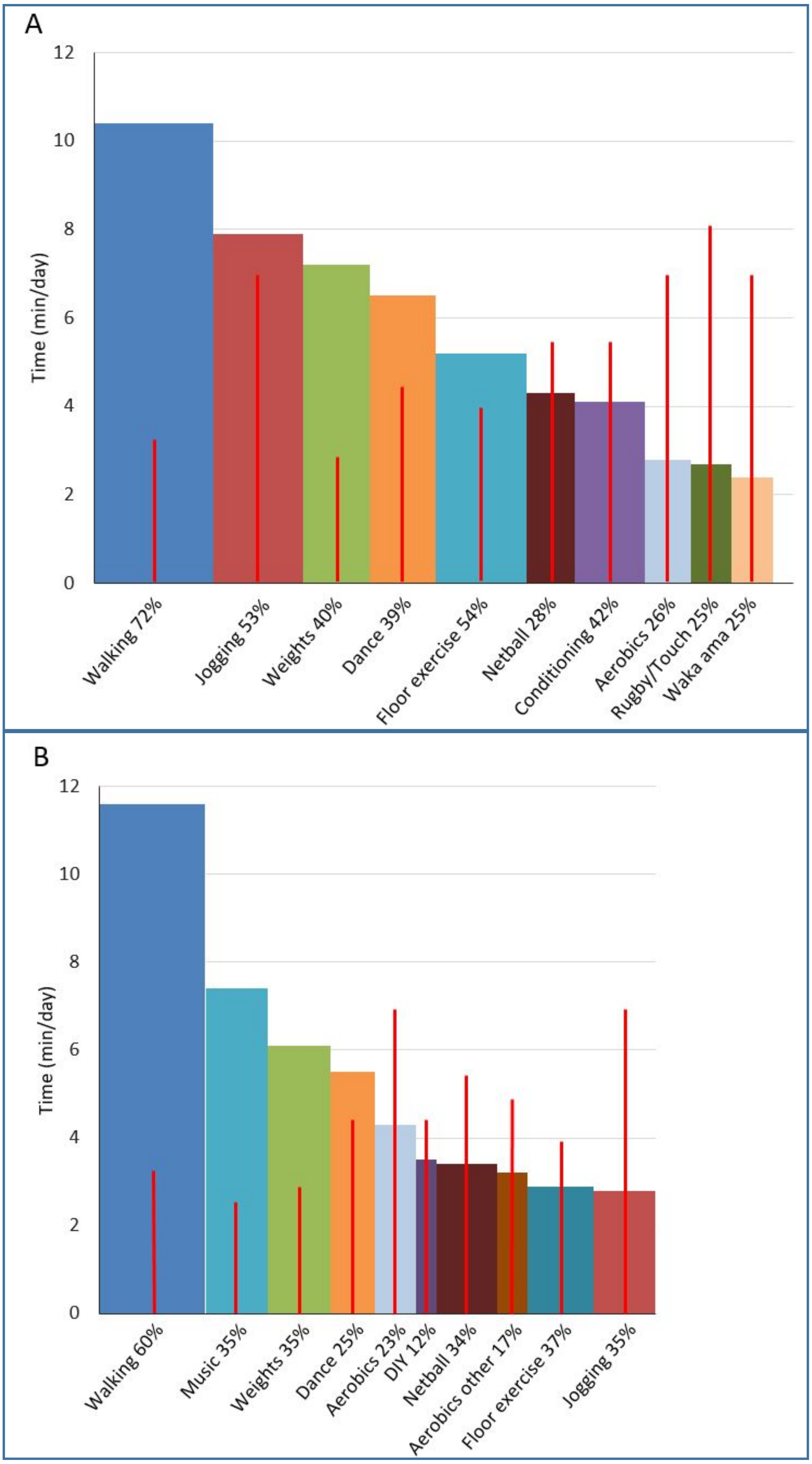

Figure 6.1. Top 10 activities (by time) per ethnic group

Time (min/day) spent performing each of the 10 most time consuming activities for each ethnic group. (A) Māori, (B) Pacific, (C) European. Height of bars indicates time (min/day) spent performing each activity. Width of bars indicates percentage of women participating in the activity. Red bars indicate relative intensity of the activity (METs). Numbers associated with activity labels also indicate percentage of women participating in the activity.

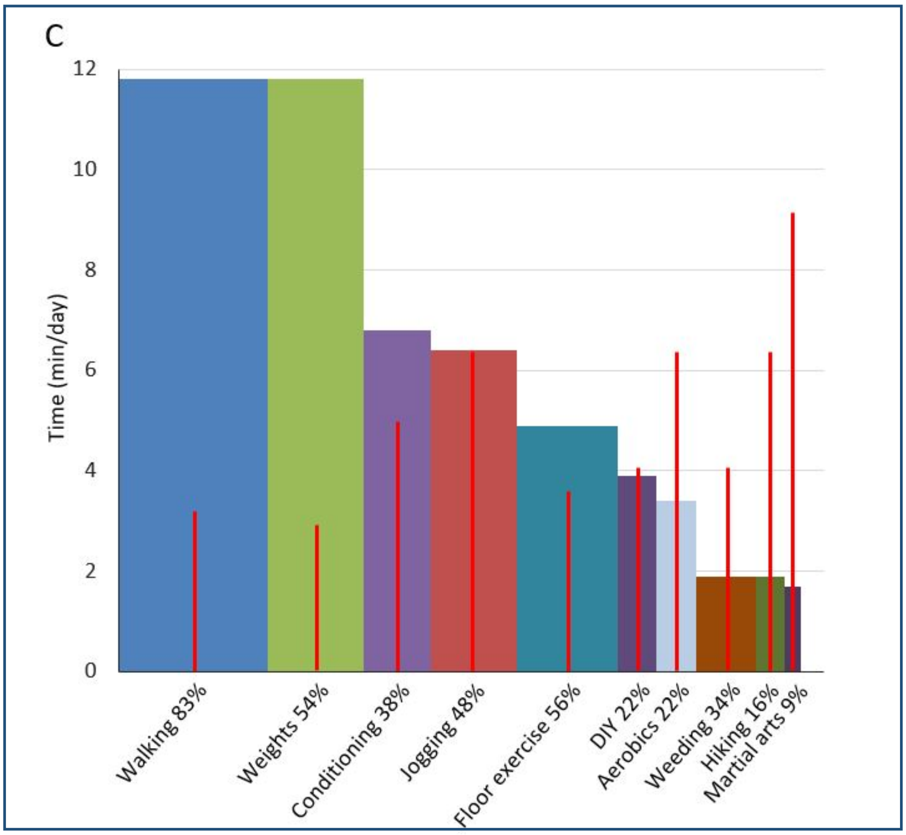

Figure 6.1 (continued). Top 10 activities (by time) per ethnic group

Time (min/day) spent performing each of the 10 most time consuming activities for each ethnic group. (A) Māori, (B) Pacific, (C) European. Height of bars indicates time (min/day) spent performing each activity. Width of bars indicates percentage of women participating in the activity. Red bars indicate relative intensity of the activity (METs). Numbers associated with activity labels also indicate percentage of women participating in the activity.

6.5 Discussion

In this study, the recreational physical activity habits of Māori, Pacific and European women living in New Zealand were examined, with the aim of identifying ethnic-specific activity preferences which could provide the basis of future physical activity recommendations. Many activities (e.g. walking, weights) were common across all three ethnicities, whilst others had specific cultural or ethnic connections. For example, dance (including traditional dance such as kapa haka) was popular among Māori women (39% participation), whilst performing music (35% participation) was popular among Pacific women.

One recreational pursuit, walking, stood out as clearly the most popular by participation, time, frequency and energy expenditure, across all ethnic groups (77% participation). Walking is also consistently the most popular recreational activity among women nationally (72% (Sport New

Zealand, 2015)) and in many other countries, including Australia (25% (Australian Bureau of Statistics, 2015)) and the United Kingdom (67% (Jones *et al.*, 2011)). Indeed, among Pacific women, walking accounted for almost twice the participation and nearly 40% more time than any other recreational activity. In contrast, European women spent equal time walking and doing weights (11.8 min/day); almost double the next most time consuming activities (conditioning exercise and jogging). The high incidence of walking reported among this cohort of women contributed to rates of meeting physical activity guidelines (70%) substantially higher than is reported nationally for women (45%). In contrast to national figures though, the prevalence of meeting guidelines varied by ethnicity and was higher among Māori (74%) and European (70%) women than Pacific women (60%).

After walking, the most popular activities across all ethnic groups were jogging and gym-type activities (aerobics, floor exercise, weights, conditioning), which are also highly ranked nationally (Sport New Zealand, 2015), in Australia (Australian Bureau of Statistics, 2015) and in the United Kingdom (Jones *et al.*, 2011). Although time and participation in gym-type activities was common across all ethnic groups, the context in which these activities occurred is unknown, and might vary between different groups. Whilst these activities may take place in traditional settings such as gyms, they may equally have occurred in church-based (Logan, 2017), whānau-focused (e.g. Koha Fit) (Progressive Training, 2017), or *boot-camp* settings, which are increasingly popular among many groups of women. Importantly, the environment in which exercise occurs can be as meaningful as the exercise itself, especially in the context of encouraging participation among certain populations (Ministry of Health, 2012). Adapting existing familiar activities into more acceptable and meaningful settings might further encourage physical activity participation and engagement and ultimately improve health outcomes.

6.5.1 Māori

Māori view health holistically as overall well-being or *hauora*, and regard the balance between physical, spiritual, psychological and family/social dimensions as important elements of well-being, rather than simply the absence of disease (Durie, 1985). For many Māori, sport participation is often about more than the sport itself; it provides a mechanism to fulfil a greater need for support, belonging and the provision of unified goals (e.g. through teamwork) (KTV Consulting, 2017). Team and groups activities were popular among Māori women, reflecting Māori cultural values of whānau (family) and whanaungatanga (connectedness).

Indeed, cultural (43.1%) and social (69.7%) values are important motivators for exercise participation among Māori adults (Sport New Zealand and Auckland Council, 2016). Team sports, such as touch football and netball, and various cultural activities (e.g. kapa haka) rated among the top 10 activities in the current study, and are also favoured nationally among Māori (Keane, 2013). Gym-type activities were also popular among Māori women, and some may have occurred in boot-camps or whānau-focused fitness sessions (Compass Health, 2017; Progressive Training, 2017), reflecting the desire for group connectedness and social support. Encouraging participation in the types activities already popular among Māori women (e.g. gym-type), but doing so in an appealing group environment (e.g. whānau-focused) might fulfil many of these important cultural needs and provide a simple avenue to engage more women, and possibly their whānau, into physical activity.

Conditioning and weights exercises (~40% participation), combined with high incidence of walking, ensured that many Māori women fulfilled all aspects of the physical activity guidelines, rather than simply the aerobic component, as is commonly reported in New Zealand (Ministry of Health, 2015c). Recommendations for resistance exercise such as weights and conditioning exercise in normal weekly physical activity is of particular relevance to Māori women. This group are at increased risk of type 2 diabetes (RR 1.84 vs non-Māori women) (Ministry of Health, 2015b) and resistance exercise is known to reduce risk by improving factors (e.g. mitochondrial function) important in the development of this disease (Grontved *et al.*, 2014; Aune *et al.*, 2015; Porter *et al.*, 2015). Other chronic diseases prevalent among Māori women (e.g. cardiovascular disease, (Ministry of Health, 2015b)) are also mediated by aerobic exercise (Sattelmair *et al.*, 2011; Armstrong *et al.*, 2015), making regular participation in a range of physical activities (aerobic, resistance, conditioning) particularly important for this group.

Based on Māori women's current physical activity habits, more women could easily achieve physical activity guidelines, simply by participating in already familiar and popular activities but being encouraged to do so in an environment that is acceptable, friendly and supportive (Table 6.4). For example, playing netball twice a week in a local community-based competition (60 min), attending a whānau-fit session at a local park (45 min), and walking or playing touch with whānau (45 min) would easily fulfil the 150 min/week of physical activity as set out in physical activity guidelines (Ministry of Health, 2015c). Substituting netball for waka ama (outrigger canoe) training would provide even greater health benefits by increasing muscular strength whilst still offering strong aerobic elements in a social team environment. Reallocating some existing walking time to a shorter duration of uphill walking, would increase intensity, and

Table 6.4. Potential activities and settings for inclusion in weekly physical activity

Ethnic group	Existing activities				Increasing health benefits of activity		
	Activity	Setting	Duration	METs	Strategy	Outcomes	METs
Māori							
	Netball	Local competition	½ game (30 min)	5.5	Enter team in Pa Wars tournament	More focused, higher intensity training. Commitment to training. Social.	>5.5
	Boot-camp	Park before work with sister or daughter	45 min	~6.0	Choose more challenging exercise options, reduce rest time between activities	Various exercise intensities to build CV fitness and strength	~7.0
	Kapa haka	With whānau	60 min	4.2			
	Touch football	Local park with whānau	45 min	6.4	Enter team in regular competition	Increased intensity and cardiovascular fitness and benefits. Commitment to team	>6.4
	Walk	Local park with friends and whānau	45 min	3.4	Take along rugby or soccer ball to pass/chase with children while walking	Higher intensity. Fun. Teaching children skills.	~6.0
	Waka ama	With whānau	40 min	~7	Mixed crew with older children	Increased CV fitness and strength	
Pacific							
	Touch football	Park with family or community members	20 min	6.4	Setup weekly competition with other families	More fun and social. Increased intensity and CV benefits	>6.4
	Netball	Local courts with church team	½ game (30 min)	5.5	Enter inter-church tournament	Goal to work toward. Increased intensity and CV benefits	
	Hula session	Church hall	45 min	4.5	Increase intensity of session	Increase CV fitness, co-ordination	>4.5

Ethnic group	Existing activities				Increasing health benefits of activity		
	Activity	Setting	Duration	METs	Strategy	Outcomes	METs
	Pacific Fiva fitness session	School hall with friends	45 min	~6.0	Sessions provide multiple intensity options – use weights where possible, run instead of walk, shorter rest periods	Fun, local, building strength and lean mass and CV fitness	~7.0
	Walk	In park with family after church	30 min	3.5	Walk on hilly terrain or carrying young child to increase resistance	Increased strength and lean mass, and CV fitness/benefits	~5.5
European							
	Gym session	Weights, crosstrainer	60 min	~4.0	Reduce weights time, increase aerobic (e.g. rowing), kickboxing class	Retain large amount of resistance exercise while increasing aerobic component	~6.0
	Walk	Around local area with friend	30 min	3.5	Family walk at beach (soft sand), take along Frisbee to throw around with children, piggy-back small children	Increase intensity (difficult terrain sand), fun, variety, setting example for children	≥5.5
	Swimming	Playing in wave with children	20 min	6.0	Swim out to buoy or standup paddle board while others remain with children	Increase CV fitness and muscular conditioning.	~6.5
	Jogging	From home with neighbour	30	7.0	Enter fun run with neighbours, workmates, other mums. Alternate walk/run for longer distances	Commitment to event, more focused training, goal to work toward, increased CV fitness.	7.0
	Boot-camp	Local park with friend	45	~6.0	Choose more challenging exercise options – jump v normal squats, run v walk between activities, increase speed/reps	Variety of exercise intensities to build CV fitness and strength	~7.0

Note: Activities are suggestions that could be included in weekly physical activity and would contribute to meeting physical activity guidelines. Strategies are included to alter some activities to further increase their health benefits. Abbreviations: METs, metabolic equivalents of task; CV, cardiovascular.

subsequent physiological and health benefits, whilst reducing total time requirements. Encouraging more Māori women to participate in these higher intensity activities would increase the cardiovascular benefits of exercise. At the same time, such activities provide a non-threatening and somewhat familiar pathway to increase or re-introduce physical activity, whilst maintaining or even enhancing the important aspects of whanaungatanga and hauora for these women.

6.5.2 Pacific

Music and dance were among the top four activities for Pacific women, with culture likely playing an important role. These activities might reflect a relative acceptance of culturally focused activities in preference to perceived selfish activities dedicated to health or fitness (e.g. running) (Gordon *et al.*, 2013). Culture and sport are interwoven with family, church and community in Pacific peoples' lives, and together, are vitally important (Gordon *et al.*, 2013; Ministry for Pacific Peoples, 2017). These values are reflected in the group and team settings in which six of the top 10 activities were likely performed. Team sports such as netball and volleyball (34% participation) were also popular among Pacific women in the current study, and nationally (approximately 14% in each sport, (Sport New Zealand, 2015)) and likely occurred in Pacific-focused teams and competitions (e.g. Auckland Samoa Netball Association (Auckland Samoa Netball Association, 2017)). Informal pop-up fitness sessions conducted in Pacific communities, are often community led in church halls and local parks (Ryan *et al.*, 2011). Hula exercise groups use traditional dance to maintain familiarity and connectedness whilst incorporating aerobic exercise elements (Compass Health, 2017). Furthermore, church-based group sessions such as "Faith-led Wellness" include physical activity as part of a healthy lifestyle programme (Logan, 2017).

At a national level, 26% of Pacific adults engage in recreational activities less than once per week (Sport New Zealand and Auckland Council, 2016), and was reflected in low participation in recreational physical activities by many Pacific women in the current study. Indeed, 38% of Pacific women performed no single activity more than once each week, suggesting that for many women, any activity they did perform was not done so habitually. Participation in three of the top six activities was for less than three minutes each day and by only 34-37% of women. Furthermore, the second most time-consuming activity, music performance, is of only light intensity (2.5 METs), meaning that a large proportion of recreational time was of low energy expenditure. Simply adding movement such as dance to music performance would substantially increase energy expenditure, whilst retaining the same setting.

Participation by 35% of Pacific women in weights exercises is particularly encouraging. This group are at especially high risk of type 2 diabetes (Ministry of Health, 2015b), and resistance exercise is known to protect against this disease (Grontved *et al.*, 2014; Aune *et al.*, 2015; Porter *et al.*, 2015). Regular physical activity of any type is a key factor in protecting against chronic diseases and improving general health and weight management (Sattelmair *et al.*, 2011; Krebs *et al.*, 2013; Aune *et al.*, 2015). Furthermore, physical activity of any amount is widely promoted as being better than none (World Health Organization, 2010; Ministry of Health, 2015c). Hence, steps must be taken to reengage many Pacific women in sports and group activities that provide a familiar, social and supportive pathway to increased physical activity. Group fitness sessions are an ideal setting to effectively combine aerobic exercise with weights to gain the physiological benefits of both activity types.

Healthy lifestyles are often not a priority for Pacific peoples in the absence of apparent disease symptoms (Bailey *et al.*, 2010) and may be influenced by cultural values and lifestyles (Ministry of Health, 2012; Gordon *et al.*, 2013). Successful implementation of physical activity initiatives rely on consideration of cultural and family ties, customs and social acceptance (World Health Organization, 2007). Pacific adults are more likely than non-Pacific to put others ahead of their own participation in physical activity (Sullivan *et al.*, 2003), with the vital role of women in the family often prioritised ahead of women's own health and wellbeing (Koloto and Sharma, 2006; Schluter *et al.*, 2011; Gordon *et al.*, 2013). Pacific mothers were less active than Pacific women without children, supporting evidence for social support and child-care as incentives for physical activity participation among Pacific mothers (Schluter *et al.*, 2011). Engaging in community and family group activities would likely mean other adults and older children would be available to mind children and play traditional or skill-based games, allowing Pacific mothers time to exercise. Mothers' behaviour might also normalise exercise among children, guiding them into a physically active lifestyle. Commitment to group activities, by default, requires some degree of commitment to physical activity, so engaging in physical activity in group settings would increase the likelihood of habituating participation in these activities.

Physical activity among Pacific women could be increased by playing half of a netball game twice a week (or one game and one training) with friends and family (60 min). A casual game of touch football (20 min) at a local park with family or community members would provide relatively high intensity exercise in a non-threatening, fun and accessible environment. At the same time, non-playing members might offer encouragement or engage in their own physical activity such as walking or playing with children. A hula session in the church hall (45 min) and a short family walk (30 min) after church, would provide a further 75 min of physical activity. Added together, these easily achievable sessions (in terms of physical demands, commitment and logistics; Table 6.4) would fulfil physical activity guidelines by providing familiar, fun exercise in a supportive and acceptable environment, whilst also fulfilling family and cultural needs.

6.5.3 European

The response of European women to messages promoting regular physical activity seems largely prescriptive, through convenient activities such as walking/jogging and gym-type exercise. European women spent equal time (11.8 min/day) walking and doing weights and also recorded high participation in other gym-type activities. Seventeen percent of European women performed only gym-type activities more than once each week, whilst 37% engaged in at least three of the four gym-type activities weekly. High physical activity participation by European women was a particularly positive and encouraging finding, however the time these women dedicated to physical activity could have been used more effectively. Weights (3.0 METs) and walking (3.5 METs) were the equal top activities by time commitment, yet these activities are the least intense of the top 10 for this group. Consequently, the greatest time was spent performing activities of the lowest energy cost. European women are also at elevated risk of cardiovascular disease (Ministry of Health, 2015b), so encouraging good quality aerobic exercise among this group would be highly beneficial in reducing disease risk (Garber *et al.*, 2011).

Most New Zealand adults engage in exercise primarily for fitness, health and enjoyment (~87%) (Sport New Zealand, 2015), but some other motivations may also be important (Sport New Zealand, 2015). Convenience is regarded more highly for exercise participation by European adults (45.6%) than by Māori (38.6%) or Pacific (28.3%) (Sport New Zealand, 2015), whereas cultural factors are more important to Māori (39.2%) and Pacific (35.3%) compared to European (28.2%) adults (Sport New Zealand, 2015). These ethnic differences might reflect the lack of any clearly defined European culture, especially in terms of specific activities that might be regarded as “cultural” or “traditional”. But the European culture might be more subtle, and may be represented by a liking of the outdoors (Ministry of Business Innovation and Employment, 2017). Indeed, the bush and water (lakes, rivers, beach/sea) are used more by European adults for their recreational activities (e.g. tramping, kayaking) than by Māori or

Pacific adults (Sport New Zealand, 2015). Since convenience ranks highly among European women (Sport New Zealand, 2015), simply modifying some existing physical activities to make them more time-efficient, effective and interesting, might encourage participation. Whilst many women enjoy typical gym environments for their consistency, familiarity and for motivation (Pridgeon & Grogan, 2012), others, especially those who are unaccustomed to exercise or have low body image, may be intimidated by such environments (Brudzynski & Ebben, 2010; Arikawa et al., 2011; Pridgeon & Grogan, 2012). This apprehension could be largely alleviated by moving existing activities into supportive, fun settings (e.g. boot-camps, female-specific gym classes); at the same time providing an incentive to commit to a specific time for exercise rather than relying on greater self-motivation to perform casual workouts (Pridgeon & Grogan, 2012). Therefore, if non-exercisers were encouraged into regular participation by performing activities in environments appealing to the individual (e.g. small, friendly or female-specific gyms, the outdoors), then exercise might become more focused on pleasure and enjoyment (Pridgeon & Grogan, 2012), rather than purely for the sake of exercise in unengaging environments.

Combining the time spent in walking and weights, many European women met all components of the guidelines. Even within current habits, merely substituting time spent in some activities into different activities already being performed could greatly increase health benefits (Table 6.4). A one-hour gym session (twice a week) might be broken up into 30 min conditioning exercise (e.g. rowing, crosstrainer), 20 min weights and 10 min floor exercises, or one gym session as described and one bootcamp. Almost half of women already jog, although only infrequently (less than once per week). Replacing some walking with jogging (or walk/jog while building fitness) would increase the physiological demand and cardiovascular benefits, whilst potentially reducing time investment. Walking around busy urban streets might be replaced with beach or bush walks, or intensified on challenging terrain (e.g. soft sand or hills) or with a load (e.g. pushing a buggie or piggy-backing a small child). Furthermore, substituting in some of the outdoor activities already mentioned might help to make the entire exercise experience more enjoyable and less burdensome. Some summer gym sessions could be replaced with beach activities oriented around family or friends. For instance, adults might take turns kayaking (3.5 METs) or standup paddle boarding (6 METs) whilst others swam or played cricket (5 METs) on the beach, delivering similar physiological benefits but in a pleasant and natural environment. Making any of these simple changes, with little or no additional time commitment, European women could greatly increase the health benefits gained from regular physical activity, whilst potentially increasing enjoyment and reducing the perceived burden of exercise.

The current study had several strengths. Use of the RPAQ provided valuable insight into the duration, frequency, and mode of recreational physical activities in which New Zealand women engage. Combined with the reporting of New Zealand's three main ethnic groups, these findings are valuable in informing suggestions based on familiar and popular activities specific to each ethnic group. This study does also have a number of potential limitations. Being questionnaire-based, these findings are susceptible to over-reporting, known to be more prevalent among less active and non-European New Zealanders (Moy *et al.*, 2008). The RPAQ does not record most non-sedentary at-home activities (e.g. child care), but this was unlikely to influence findings since recreational activities were the focus of this study. Furthermore, the context and environment in which activities took place is not known, and may be relevant when making suggestions based on current habits. The lack of socio-economic data collected is also a potential limitation, as socio-economic status is known to impact physical activity participation and health outcomes (Ministry of Health, 2016).

6.6 Conclusions

In this study, the physical activity preferences of women from three different New Zealand ethnic groups were examined. A common element across all ethnic groups was the high participation in walking, which contributed to almost 70% of all women meeting physical activity guidelines. Ethnic specific differences in other activities influenced suggestions aimed at increasing physical activity participation among these women. Māori women could be encouraged to build on existing team/group activities to increase their physical activity participation, and that of their whānau, whilst maintaining a sense of belonging and connectedness. Similarly, centring physical activity around family, church and community might be the most effective means to increase participation among Pacific women. In contrast, European women might benefit from swapping time among their existing preferred activities, or transferring some activities into environments more appealing to the individual (e.g. outdoors; small, friendly gyms), thus improving health outcomes and likely also enjoyment. Providing specific suggestions based on already established physical activity habits might encourage women and their families to increase physical activity participation and contribute to a reversal in New Zealand's alarming obesity and other health statistics. Understanding social/spiritual differences between people of different ethnicities, and how these relate to exercise participation, will enable better understanding of the specific exercise regimes and contexts most appropriate and acceptable to women from different ethnicities.

6.7 Glossary of Māori terms

Māori word	Meaning
Hapa kaka	Traditional dance
Hauora	Māori philosophy of health, overall wellbeing
Iwi	Tribe
Kaupapa	Purpose
Waka ama	Outrigger canoeing
Whānau	Family
Whanaungatanga	Connectedness

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Chapter 7 Final discussion and conclusions

7.1 Summary of study

The cross-sectional study reported in this thesis was a 21 month (September 2013 to May 2015) investigation into the physical activity profiles, body composition and metabolic health markers of 406 Māori, Pacific and European women. The women were aged 16-45 years and lived in Auckland, New Zealand. Objective (accelerometer) and subjective (questionnaire) physical activity data were collected, along with a comprehensive assessment of body composition and measurement of extensive blood markers to indicate metabolic health and disease risk. Data were used to understand ethnic differences in the physical activity profiles of these women, and to explore the consequences of physical activity on their body composition and markers of metabolic health.

Obtaining good quality objectively-measured physical activity data is essential for monitoring of population trends, and indeed relationships, of physical activity with health. Key to obtaining sufficient data of this nature is understanding barriers to accelerometer wear and compliance to study protocols. Hence, the **first study objective** was *to investigate the challenges associated with collecting objectively-measured physical activity data from New Zealand women of different ethnicities using hip-worn accelerometers*. The challenges of obtaining objective physical activity data were explored, with a focus on attrition and compliance, as well as the experience of wearing an accelerometer. Ethnic differences were revealed when the number of lost (attrition) and insufficiently worn (compliance) accelerometers was examined. Specifically, Pacific women had lower compliance and were more likely to loss accelerometers than other women. A sub-sample of women participated in a semi-structured telephone interview to investigate their experience of the 24-hr hip-worn accelerometer protocol. Discomfort during sleeping and embarrassment caused by visibility of the accelerometer, especially in social settings, were identified as major contributors to non-compliance, regardless of ethnicity.

Good quality data are crucial for the development of initiatives and recommendations aimed at improving long-term health through physical activity. But first, relationships of physical activity with markers of health must be understood in specific populations. Despite the challenges associated with obtaining accelerometer data from New Zealand women, sufficient data were acquired to enable investigation of the **second study objective**, *to determine the physical activity levels of overweight-obese New Zealand women, and examine ethnic differences in body composition and metabolic health markers and their associations with physical activity*. Overweight-obese women are a particularly vulnerable group who are at substantially increased risk of cardiovascular disease and type 2 diabetes (Chrostowska *et al.*, 2013; World Health Organization, 2015; Global BMI Mortality Collaboration *et al.*, 2016; The GBD 2015 Obesity Collaborators, 2017) and therefore formed the basis for the detailed analyses reported in Chapter 4. Obesity prevalence and disease risk vary widely among ethnic groups in New Zealand (Ministry of Health, 2015a; Ministry of Health, 2015b). Hence, an ethnic-specific approach was taken to gain a better understanding of whether ethnic differences in physical activity might contribute to these disproportionate risks of disease and obesity. A small number of important associations between physical activity and body composition and metabolic health markers were revealed among Pacific or European women. Furthermore, associations with these markers were strongly and positively correlated with physical activity and meeting physical activity guidelines among Māori women.

Once the general trends between physical activity and health markers were identified in New Zealand women, the third study (Chapter 5) predicted the implications on body composition and metabolic health markers of increased physical activity by replacing sedentary time with more physically active pursuits. Findings from Chapter 4 were supported by those fulfilling the **third objective** in which an isotemporal substitution paradigm was used to *investigate whether substituting sedentary behaviour with equal time in more physically active behaviours can predict improvements in the body composition and metabolic health markers of New Zealand women.* In this analysis participants were stratified by body composition profile groups to predict differences in the effects of physical activity on each of these groups. The overweight-obese women were further examined by ethnicity in an effort to understand ethnic differences in the implications of increased physical activity among this particularly at-risk group. Theoretically replacing 30 min/day of sedentary time with equal time in physical activity of moderate or greater intensity predicted strong and significant improvements in body composition and metabolic health markers for all women, overweight-obese women generally, and particularly for overweight-obese Māori women. In line with the associations indicated among Māori women in Chapter 4, substituting sedentary time with equal time in MVPA predicted meaningful improvements in total and regional fat percentages, BMI and waist circumference, and a substantial reduction in insulin. Findings from Chapter 4 and 5 indicate that responses to physical activity intensity and duration may have differential effects on health markers according to the specific population under investigation.

The first three analyses in this thesis focussed on acquiring good-quality, objective, physical activity data, and establishing associations with body composition and metabolic variables in order to understand the potential health benefits of physical activity in particular ethnic groups. Understanding the amount of physical activity likely required to effect changes in health markers is important when prescribing physical activity to specific groups. As results from Chapters 4 and 5 indicate, individual populations may require different levels of physical activity to predict improvements in health markers. Furthermore, a one-size fits all approach to exercise engagement is unlikely to be effective in all populations given the cultural priorities and values of different ethnic groups (Gordon *et al.*, 2013; Keane, 2013; Ministry for Pacific Peoples, 2017). Therefore, the logical final stage of this thesis was to examine the recreational component of physical activity (obtained using an RPAQ) to determine how the observed associations and predictions might translate into meaningful practical steps to materially improve the health of these women. Hence, the **final objective** was *to examine the recreational physical activity preferences of New Zealand women of different ethnicities to make ethnic-specific suggestions for meeting physical activity guidelines*. By tailoring the existing physical activity preferences of each ethnic group, suggestions were developed that might better enable women to meet physical activity guidelines by increasing physical activity participation and adherence through culturally interesting and relevant activities.

7.2 Discussion of main findings

The aim of this thesis was to robustly explore the physical activity profiles of Māori, Pacific and European women aged 16-45 years living in New Zealand, in order to understand ethnic differences in the physical activity profiles of these women, and to explore the consequences of physical activity on their body composition and markers of metabolic health.

Obtaining good quality objectively-measured physical activity data is essential to informing national and other health bodies on physical activity-based health improvement initiatives and recommendations. Key to obtaining these data is understanding factors, such as barriers to accelerometer wear and compliance to study protocols that might inhibit collection of sufficient data of this nature. Discomfort during sleeping (67%) and embarrassment caused by visibility of the accelerometer (45%) especially in social settings, were major contributors to non-compliance. Discomfort and embarrassment have been identified by others across a range of populations (Pollard and Guell, 2012; Berendsen *et al.*, 2014; Troiano *et al.*, 2014; Huberty *et al.*, 2015) as being burdensome and barriers to wear-compliance. In the current study, the embarrassment and discomfort associated with accelerometer wear were consistent across the three ethnic groups. No other studies have examined burdens and compliance to accelerometer protocols in an ethnic-specific manner, however, ethnic variations in barriers to wear-compliance have been reported. South-Asian Muslim women wearing traditional dress reported the upper arm placement of the Sensewear Armband as embarrassing and inconvenient, but that the hip-worn Actigraph GT3X was not (Pollard and Guell, 2012). American women, on the other hand, were untroubled by the placement of the Armband, but instead reported discomfort and embarrassment from the hip placement of the Actigraph GT3X (Huberty *et al.*, 2015). Improved understanding of the relationships between physical activity and risk factors in the causal pathways of chronic diseases is crucial to improving the health of many women. However, before this understanding can be achieved, barriers to the collection of physical activity data must be resolved.

Compliance in the current study saw 86% of participants return valid data, which is substantially higher than reported in some studies (Troiano *et al.*, 2008). Without this level of valid data the relationships between physical activity and metabolic health markers reported in Chapters 4 and 5 may not have been evident. However, compliance was inconsistent across the ethnic groups, impacting the volume of data collected and subsequently restricting the types of analyses possible. Greater compliance (and subsequent data quantity) from some groups may have enabled powerful regression modelling to predict even stronger or potentially different relationships with physical activity. Indeed, high recruitment (*n* = 233) and compliance (93%) among European women enabled analysis in Chapter 5 to be conducted by body composition profile groups. Conversely, recruitment among Māori women was low (*n* = 84), Pacific women accounted for 54% of accelerometers lost over the duration of the study and only 73% of Pacific women returned valid data (versus 82% for Māori and 93% for European). More detail analyses, as performed for European women, might have been particularly beneficial to better understand the physical activity profiles of Māori and Pacific women, especially given the increased metabolic disease risk (Ministry of Health, 2015a) of these groups of women.

Cultural differences might affect the way some groups interpret research information and the requirements of their participation (Warbrick *et al.*, 2016; Ministry for Pacific Peoples, 2017). Some Pacific peoples are known to have a limited understanding of health and healthy lifestyle factors (Koloto and Sharma, 2006; Schluter *et al.*, 2011; Ministry of Health, 2012), and when combined with sometimes ineffective communication by the research team, may have manifested in a lack of awareness of study aims and the lifestyle factors being investigated. Establishing cultural connections (e.g. liaison person) between researchers and participants may help to ensure that participants are fully aware of all aspects of studies in which they agree to participate (Ministry for Pacific Peoples, 2017). Indeed, a recent physical activity study employed a Pacific liason person responsible for the recruitment of Pacific women, as well as their transport to data collection sessions and collection and return of accelerometers (Slater, 2018). This culturally appropriate and meaningful strategy to engage Pacific women resulted in greatly increased recruitment (175 Pacific women recruited over a 14 month period) and approximately 30% lower attrition than was experienced in the current study. Given the large ethnic variations in physical activity mediated disease risk it is vital that factors affecting compliance be identified and either overcome or minimised in order to obtain the necessary data from sufficient participants to enable robust analysis and to draw informative conclusions. Achieving better engagement by tailoring recruitment and all aspects of data collection with effective communication that is relevant and appropriate for different groups, might be a first step to improving compliance or at least improving the understanding of factors affecting compliance. If this level of understanding was to be accomplished, greater wear-compliance, fewer lost accelerometers, and ultimately greater volume of data might be achieved to better inform researchers of the relationships between physical activity and markers of metabolic health.

Understanding levels of physical activity in any population is important since numerous health benefits are associated with meeting physical activity guidelines. For instance, women meeting guidelines are at reduced risk of coronary heart disease (-14%; Sattelmair *et al.*, 2011) and type 2 diabetes (-33%; Grontved *et al.*, 2014) relative to inactive women. However, comparison of physical activity among different ethnic groups is seldom reported. One study to do so is the annual NHANES survey in the United States; fewer Hispanic and African-American adults (~44%) meet physical activity guidelines compared to Caucasian or native populations (~54%) (Centers for Disease Control and Prevention, 2014). In the current study, European women were significantly more physically active than Māori or Pacific women, and adherence to physical activity guidelines by European women (66.7%) was more than twice that of Pacific women (31.5%; Māori 48.7%). Attainment of physical activity guidelines as determined from accelerometer data (Chapter 4) differed markedly from self-reported attainment across all groups in the New Zealand Health Survey (~47%; Ministry of Health, 2016) and in accumulation of individual activities from the RPAQ data reported in Chapter 6 (European 70%, Māori 74%, Pacific 60%). Conversely, sedentary time was significantly higher among Pacific women compared to Māori or European women; figures that are not available from either the New Zealand Health Survey (Ministry of Health, 2016) or the RPAQ (MRC Epidemiology Unit, 2006). Self-report physical activity data is susceptible to over-reporting among less active and non-European New Zealanders (Moy *et al.*, 2008) making it more suited to monitoring population-level trends in physical activity than for establishing clear relationships with health markers (Helmerhorst *et al.*, 2012; Health and Social Care Information Centre, 2015). This over-reporting may explain some of the discrepancy between the objectively measured data from accelerometers, and those from both the New Zealand Health Survey (Ministry of Health, 2015b) and the RPAQ. Furthermore, cultural lifestyles and values are suggested to influence understanding and attitudes toward health and healthy lifestyle factors, such as physical activity (Koloto and Sharma, 2006; Schluter *et al.*, 2011; Ministry of Health, 2012), and may have contributed to the lower rates of physical activity among the Pacific women in the current study, as well as their lower accelerometer wear compliance reported in Chapter 3.

Overweight-obese women are a particularly vulnerable group at substantially increased risk of cardiovascular disease and type 2 diabetes (Chrostowska *et al.*, 2013; World Health Organization, 2015; Global BMI Mortality Collaboration *et al.*, 2016; The GBD 2015 Obesity Collaborators, 2017), hence Chapters 4 and 5 report detailed analyses of the overweight/obese group. Within this group, body composition and metabolic risk indicators varied by ethnicity. European women had lower BMI and waist circumference and more favourable metabolic profiles (including HbA1c, insulin, HDL-c and clustered cardiometabolic risk score) than Māori or Pacific women who did not differ significantly from each other in any measured variables. Across all overweight-obese women, MVPA, MVPA10 and meeting physical activity guidelines were inversely associated with a range of body composition measures and with clustered cardiometabolic risk score. The isotemporal substitution paradigm used to theoretically replace 30 min/day of sedentary time with equal time in physically active behaviour predicted strong and significant improvements in body composition and metabolic health markers for all women, overweight-obese women generally, and particularly for overweight-obese Māori women. Significantly improved body composition (total, abdominal, subcutaneous and visceral fat) was also reported among previously inactive obese women following a 14-week moderate-intensity exercise intervention (Ross *et al.*, 2004). Reduction of body fat percentages has important positive health implications. Reduced adipose tissue in obese populations has potential to significantly improve metabolic flexibility, opening up metabolic pathways to enable adipose tissue to be used as an energy source (Battaglia *et al.*, 2012; Goodpaster and Sparks, 2017). In doing so, obesity may be further reduced along with the risk of obesity-related diseases such as type 2 diabetes.

Among the overweight/obese Māori women, MVPA, either sporadically or in bouts, and meeting physical activity guidelines were inversely associated with most body composition markers and with clustered cardiometabolic risk score. The correlations were large ($r > 0.50$) and highly significant ($p < 0.005$) between MVPA10 and BF%, android and gynoid fat percentage and clustered cardiometabolic risk score; similar, and only slightly weaker correlations were also found with MVPA and meeting physical activity guidelines. In line with these associations indicated among Māori women in Chapter 4, substituting sedentary time with equal time in MVPA (Chapter 5) predicted 10-15% improvements in total and regional fat percentages, BMI and waist circumference, and over 40% reduction in insulin. Predicted improvements of this magnitude were sufficient to move many of these currently metabolically at-risk overweight/obese women into the healthy body composition range (BMI 18.5–24.9 kg/m^2, BF% 18.0-29.9%; World Health Organization, 2006; Romero-Corral *et al.*, 2008) and within healthy ranges for many other variables, including insulin. The dramatic reduction in insulin would also likely substantially reduce the risk of type 2 diabetes among this group (McArdle *et al.*, 2013). The strong and compelling relationships between physical activity and these important markers of metabolic disease risk seen among overweight-obese Māori women are particularly important and relevant, especially given the high prevalence of obesity and cardiovascular disease among all Māori women (Ministry of Health, 2015a). Improvements of this nature and extent were predicted by replacing just 30 minutes each day of sedentary time with physically active behaviour. If physical activity of even greater volume or intensity was performed (i.e. levels in excessive of the basic physical activity guidelines), potential exists for even greater benefits to the long-term health of Māori women. Such additional physical activity could significantly reduce current levels of obesity (48%; Ministry of Health, 2015b) and cardiovascular disease (4.4%; Ministry of Health, 2015a) among Māori women.

Māori have strong values toward whanau (family) and whanaungatanga (connectedness) and are motivated to exercise through cultural and social engagement (Sport New Zealand and Auckland Council, 2016). These values and motivators are reflected in the team and cultural activities popular among this group in the current study, and nationally (Keane, 2013; Sport New Zealand, 2015). Making use of local facilities such as parks to exercise with whanau, and entering whanau or iwi-based team competitions (e.g. netball or touch football) would provide fun, familiar and relevant activities in which to encourage participation by more Māori women and their whanau. Accelerometer data from Chapter 4 indicate that many Māori women were already somewhat active, and almost half (49%) met the physical activity guidelines. Engaging more Māori women into moderate and vigorous activities has the potential to improve the numerous body composition and metabolic health markers predicted in Chapter 5 (including total and regional BF% and insulin). Promotion of familiar activities of this intensity in environments fostering whanau and whanaungatanga could substantially reduce the risk of cardiovascular disease, type 2 diabetes and obesity faced by Māori women.

Pacific women are at the greatest risk of metabolic diseases (e.g. RR 3.48 for type 2 diabetes; Ministry of Health, 2015a) and have the highest obesity prevalence (69.5%; Ministry of Health, 2015b) relative to non-Pacific women. Yet findings from Chapters 4 and 5 similarly indicate that for overweight-obese Pacific women, waist-to-hip ratio was the only measured variable associated with or predicted to improve with physical activity. However, a large number of Pacific women spent very little time performing physical activity of even moderate intensity and according to the accelerometer data reported in Chapter 4, 68% of Pacific women failed to meet physical activity guidelines. Pacific women are known to put others ahead of their own health, wellbeing and physical activity participation (Sullivan *et al.*, 2003; Koloto and Sharma, 2006; Schluter *et al.*, 2011) and 26% of Pacific adults exercise less than once per week (Sport New Zealand and Auckland Council, 2016). Furthermore, socio-economic status is known to affect exercise participation and other health outcomes (Ministry of Health, 2016). For instance, adults living in areas of highest deprivation are 25% less likely to be physically active than those living in areas of lowest deprivation (Ministry of Health, 2016). Pacific peoples hold lower socio-economic status than some other New Zealand ethnic groups (Ryan *et al.,* 2011; Ministry of Health, 2012), which may have contributed to the observed lack of physical activity participation, higher rates of obesity and less favourable health markers among some Pacific women. The low rates of physical activity performed by this group may have been statistically insufficient to detect associations with or predict improvements in body composition or metabolic disease risk markers. Given the heightened metabolic disease and obesity risk faced by Pacific women (Ministry of Health, 2015b), it is likely that even small increases in physical activity might elicit large changes in many body composition and metabolic health markers. In light of the overwhelming evidence for the health benefits of physical activity across all populations (Haskell *et al.*, 2007; World Health Organization, 2010; Brown *et al.*, 2012), Pacific women, especially the 69% who are obese (Ministry of Health, 2015b), must be encouraged towards meeting physical activity guidelines in an effort to improve long-term health. However, the first step for these numerous, highly inactive women is to simply **begin** exercising. Although commencing exercise may be a daunting or seemingly unrealistic prospect for some of these women, national and regional programmes such as Healthy Families (Healthy Families NZ, 2015) and Workplace Health (Auckland Regional Public Health Service, 2018) have been established to provide suggestions for simple and manageable initiatives to easily incorporate even small amounts of physical activity into normal daily life.

Family, church and community are vital components of Pacific people's lives and are closely linked with sport and culture (Gordon *et al.*, 2013; Progressive Training, 2017). Hence, popular group/team activities (e.g. netball) were likely performed in community or church-group settings (Auckland Samoa Netball Association, 2017; Compass Health, 2017). RPAQ data revealed that habitual physical activity was low among many Pacific women, a finding supported by previous reports that a quarter of Pacific adults engage in exercise less than once each week (Sport New Zealand and Auckland Council, 2016). Furthermore, accelerometer data indicated that only 32% of Pacific women in the current study met the physical activity guidelines. Added to these statistics the prevalence of obesity (69% nationally; Ministry of Health, 2015b) and type 2 diabetes (RR 3.48 v non-Pacific women; Ministry of Health, 2015a) among this group, then the objective for many Pacific women should be to simply become physical activity to any extent.

In addition or as an alternative to the initiatives set out in the Healthy Families (Healthy Families NZ, 2015) and Workplace Health (Auckland Regional Public Health Service, 2018) programmes, a range of initiatives aimed at getting Pacific people active are offered by regional sports trusts (e.g. Niu Start (Harbour Sport, 2018)), community (e.g. hula exercise groups (Compass Health, 2017)) and church (e.g. Faith-led Wellness (Logan, 2017)) groups. Furthermore, casual games (e.g. touch football) with family and friends in local parks are also effective avenues to engage Pacific people into exercise (Gordon *et al.*, 2013). Activities in these settings would largely overcome known barriers to exercise participation for Pacific women, specifically child-care and lack of encouragement (Bellows-Riecken and Rhodes, 2008; Schluter *et al.*, 2011), and for some, also the prohibitive cost of gym memberships (Ryan *et al.*, 2012). Ultimately, encouraging more women to be more active more often through any of these culturally appropriate and relevant initiatives would be a very positive step to reducing the alarming rates of obesity and type 2 diabetes faced by many Pacific women.

Interestingly, levels of physical activity achieved by Māori and Pacific women did not differ significantly, yet substantial differences in associations and predictions of physical activity with body composition and metabolic health were revealed. A possible explanation for this discrepancy could be that the activity intensity within the MVPA range may have varied between the two groups, despite similar total time being spent within the MVPA range. For instance, the ~22 min/d spent in MVPA may have averaged an intensity of 5000 cpm among the Māori women, whereas for Pacific women, the same ~22 min/d of MVPA may have averaged only 2500 cpm; both would have been within the MVPA range (≥2020 cpm) but with vastly different total volume and energy expenditure. Further analysis of data in this manner may be warranted to elucidate whether these discrepancies in exercise intensity explain the differences between Māori and Pacific women's interaction with physical activity, or whether other factors such as genetics, diet, socio-economic status are also impactful. Overwhelmingly, women performing any amount of physical activity are at lower risk of metabolic diseases than those who are less active (Sattelmair *et al.*, 2011; Aune *et al.*, 2015). It is therefore imperative that physical activity of any duration or intensity should be promoted as it is likely beneficial to all women, and even more so for overweight/obese women, especially given the findings for this total group in the current study.

Strong recruitment and high accelerometer wear compliance among European women reported in Chapter 3 enabled analysis of accelerometer data for this group to be conducted according to body composition profile groups (Chapter 5). Predictions related to increased physical activity varied by body composition profile group. Among the overweight/obese European women, associations and improvements predicted in Chapters 4 and 5 with increased physical activity were substantially fewer than were found for Māori. In fact, BMI was the only body composition variable predicted to change (a very slight decrease) with increased physical activity. However, potentially important changes were revealed among normal-weight women. For both the normal-weight obese (NH) and the normal-weight (NN) women the higher intensity of vigorous, but not moderate, physical activity was required to predict changes in body composition. For the normal-weight women, lean mass and consequently body mass were predicted to increase with vigorous physical activity. Similar associations for increased lean mass with increasing vigorous physical activity have been reported by others (Drenowatz *et al.*, 2016). Since lean muscle is energetically more expensive to maintain than is adipose tissue, greater lean mass translates to increased energy expenditure both while exercising and at rest (Hall *et al.*, 2011), aiding in the control of energy balance. Among the normal-weight obese women, BF% was predicted to change with only vigorous physical activity. This 13% reduction in BF% with vigorous physical activity was particularly important in terms of long-term health for this group. A decrease in BF% of this magnitude could reduce the BF% of normal-weight obese women to 29.1%; sufficient to bring many of these women within the healthy BF% range of 18.0-29.9% (Romero-Corral, 2008), and potentially decrease the metabolic disease risk posed by their current excessive body fatness (Romero-Corral, 2010). Such substantial reductions in BF% might also improve the metabolic flexibility of these women, resulting in improved substrate utilisation and insulin signalling and sensitivity (Battaglia *et al.*, 2012; Goodpaster and Sparks, 2017). Reduced BF% in exercise intervention studies has also been accompanied by improved lipid profiles and decreased insulin levels (Skrypnik *et al*., 2015; Korshoj *et al.,*2016; Kleist *et al.*, 2017), all of which are key risk factors for cardiovascular disease and type 2 diabetes.

The European women in the current study, even those who were overweight/obese, were relatively more active and had more favourable body composition and metabolic profiles than the other women. Taken together, these data indicate that levels (intensity or duration) of physical activity even greater than those recommended in the basic physical activity guidelines (30 min/d of moderate intensity activity; Ministry of Health, 2015c) might be required to elicit positive changes in body composition and metabolic markers in this relatively healthier group. Therefore, a priority for physical activity promotion among European women should be to add variety to existing activities in order to maintain interest and increase overall physical activity beyond the recommended 30 minutes each day. By simply adjusting existing activities in this way, overall physical activity could be increased without noticeably increasing burden or compromising motivation.

European adults are motivated to exercise for health, fitness and enjoyment and for convenience (Sport New Zealand, 2015). Although not apparent in the RPAQ data (Chapter 6), European adults also spend more recreational time in the outdoors (e.g. bush, beaches) than do others (Sport New Zealand, 2015). RPAQ data from Chapter 6 indicate that European women spent a large portion of recreational time performing gym-type activities. Gym environments can be intimidating for some women, but a place of familiarity and support for others (Arikawa *et al.*, 2011). Therefore, performing many of these existing activities in the environments in which women feel comfortable, and adding variety to avoid boredom, may be sufficient to ensure continuation, or even increases in, exercise participation. Furthermore, encouraging exercise through casual, social activities (e.g. beach cricket, ultimate frisbee) might provide welcoming, supportive environments that encourage more women to take up and continue with regular exercise. In light of the evidence that European women might require levels of physical activity in excess of basic physical activity guidelines (Chapters 4 and 5) the suggestions reported in Chapter 6 provide simple strategies for European women to add variety and interest to existing activities without perceptibly increasing the time commitment or logistical burden of physical activity.

7.3 Concluding remarks

Ethnicity plays a major role in the effects of physical activity on the lives and potential health of New Zealand women, especially some who are at substantially increased risk of metabolic diseases. Distinct ethnic differences were apparent across all aspects of physical activity examined; in the collection of data, in amounts and types of physical activity performed, and in the relationships of physical activity with body composition and markers of metabolic health. Physical activity of any duration, performed at moderate or greater intensity will likely substantially improve the health of all women; overweight/obese Māori women might particularly benefit from this level of activity. European women may require physical activity of even greater intensity or duration to effect body composition and metabolic health marker changes. The goal among Pacific populations should be for more women to become more active, and for some, this means simply becoming active to any extent, with the goal of at least meeting physical activity guidelines. Tailoring physical activity recommendations and promotions to target specific ethnic groups might be more beneficial and efficacious than blanket approaches directed at entire populations. This is the first study to conduct detailed analyse of objectively measured physical activity in relation to obesity-related disease risk markers of New Zealand women across a range of ethnic groups. These data and findings provide a solid foundation on which to base future investigations using physical activity to improve the health outcomes of New Zealand women, some of whom are at substantially increased metabolic disease risk.

This thesis addresses areas of major public health concerns in populations who are particularly vulnerable in terms of metabolic disease risk. This is the first time that ethnic-specific associations between increased physical activity and body composition and metabolic health markers have been reported among New Zealand women. Increased physical activity has the potential to significantly improve the long-term health of New Zealand women through reduced cardiovascular disease, type 2 diabetes and obesity, improving their quality of life and reducing the financial and societal burden of treatment associated with these diseases.

7.4 Strengths of the study

This study contained a number of strengths which must be highlighted. Participants were from three of the major New Zealand ethnic groups and represent a large portion of the New Zealand female population. Two of the groups, Māori and Pacific, are at substantially greater risk of type 2 diabetes and cardiovascular disease, and have higher prevalence of obesity, than other New Zealand population groups. Detailed analysis of physical activity, body composition and metabolic health markers among these particularly vulnerable and at-risk groups provides valuable insight as to how the health of these women might be improved through physical activity.

The study combined the use of both accelerometers and RPAQ to comprehensively assess physical activity among New Zealand women of different ethnicities. Objective physical activity data in relation to physical activity guidelines, and analysed in combination with markers of health, has been lacking among New Zealand women. Valid accelerometer data were obtained from 350 of the 406 women in the EXPLORE study (Kruger *et al.*, 2015) and enabled objective assessment of time spent at different physical activity intensities and the prevalence of meeting physical activity guidelines. The RPAQ includes an extensive list of recreational activities which enabled assessment of the specific types of activities in which women engaged and provision of ethnic-specific suggestions as to the most appropriate types of activities for each ethnic group. Translation of findings into practical and relevant suggestions might encourage more women to engage in physical activity and as a consequence, substantially improve their long-term health.

The 24-h wear protocol strengthened the research design, as it was chosen to improve compliance and to capture the entire 24-h day, including sleep. Few 24-h hip-worn protocols have been reported (Kinder *et al.*, 2012; van Langenberg *et al.*, 2015; McVeigh *et al.*, 2016; Meredith-Jones *et al.*, 2016), however compliance with 24-h protocols does seem to be higher than with waking-wear protocols (Troiano *et al.*, 2014; Tudor-Locke *et al.*, 2015). The Actigraph low-frequency extension was employed as it is designed to lower the band-pass filter threshold of accelerometer movements (Actigraph LLC, 2013) and is recommended for accurately assessing both sleep and physical activity in free-living individuals (Cellini *et al.*, 2016). The low-frequency extension under-estimates sedentary time and over-estimates light physical activity to a similar degree (Cain *et al.*, 2013), but since the main focus of this thesis was moderate and vigorous physical activity, not sedentary behaviour, these slight under/over estimations were unlikely to impact results.

The comprehensive body composition assessment protocol added further strength to the study. The Bodpod was chosen to assess total body fat since very high and very low BF% are more accurately measured with BodPod than with DXA (von Hurst *et al.*, 2015). The DXA provided high quality, accurate and detailed assessment of both total and regional lean and fat mass, and enabled subsequent analysis at these regional levels. Many physical activity studies report simple body composition variables such as BMI and waist circumference. These are useful indicators of obesity status, but they provide no detail on the location of fat, nor the relative amount of lean mass present.

A wide range of metabolic blood markers were collected which enabled detailed analysis of associations between these obesity-related markers and physical activity. Metabolic variables representing central adiposity, dyslipidaemia, hypertension and hyperglycaemia were combined into a cluster score (clustered cardiometabolic risk) indicating cardiometabolic disease risk to enable a comprehensive interpretation of overall risk. Examining the metabolic variables individually and collectively brought simple interpretation but added depth to the study.

A final strength of the study was that data collection was carried out over a 21-month period, likely reducing any seasonal effect in levels and types of physical activities performed (Shephard and Aoyagi, 2009; O'Connell *et al.*, 2014). Although Auckland has a subtropical climate (Chappell, 2013), seasonal variations in physical activity likely still occur.

7.5 Limitations of the study

This study had a number of limitations that must be acknowledged. As with any cross-sectional study, inference of causal relationships between physical activity, body composition and metabolic health markers could not be established. Whether physical activity contributed to improved body composition and metabolic health, or whether more favourable body composition promoted physical activity participation, is unknown and requires further investigation.

Initial power calculations for the women's EXPLORE study (Kruger *et al.*, 2015) were based on pilot data from European women since no body composition data of this nature were available for Māori and Pacific women. However, significant difficulties were experienced recruiting Māori and Pacific women, especially into the NN and NH body composition groups despite active and varied recruitment strategies employed over a 21 month period. Indeed, only 18 Māori and nine Pacific NN women, and nine Māori and two Pacific NH women were recruited (total recruited: Māori, *n* = 84; Pacific, *n* = 89), suggesting that Māori, and particularly Pacific women, of normal BMI, regardless of BF%, make up only a relatively small portion of these ethnic groups. Hence, comparison of the NN and NH groups by ethnicity was not possible. Furthermore, the low number (*n* = 37) of HH Māori women who were recruited and subsequently returned valid data, limited the types of analyses that were possible.

It is difficult to estimate how outcomes might have differed had more evenly sized samples been available. Even if equal numbers (*n* = 225 as proposed for the EXPLORE study; Kruger *et al.*, 2015) of women were recruited for each ethnicity, the valid accelerometer data available for each group would still likely have varied considerably. Using the rates of compliance reported in Chapter 3 valid data may have been: Māori, *n* = 185; Pacific, *n* = 164; European, *n* = 209. Although, data reported in this thesis are from a convenience sample representing a wide range of lifestyles (e.g. university students, stay-at-home mums, corporate employees, factory workers, sportswomen) and socio-economic areas across Auckland city (i.e. North Shore, CBD, West Auckland, South Auckland), different associations and predictions might have been evident had equal samples been available for analysis. Nevertheless, this study did capture good quality objective physical activity data for 350 New Zealand women, and provides valuable evidence on which to base further analysis and research.

Conducting this research in three different ethnic groups posed a number of difficulties. Cultural and demographic influences became evident during the study, especially among the Pacific women, some of whom lacked understanding or engagement with the study and its aims. Understanding and prioritising toward healthy lifestyles (Ministry of Health, 2012) are limited in some Pacific peoples, especially in the absence of apparent symptoms of disease (Bailey *et al.*, 2010). Furthermore, cultural lifestyles and values may influence how Pacific peoples view and prioritise health care and status (Ministry of Health, 2012). Future studies might benefit from having a deeper cultural awareness of target participant groups, and to ensure project teams have appropriate cultural and community connections.

Recruitment strategies used may have attracted a disproportionate number of women who were health conscious and lead healthy lifestyles. A large number of women were drawn from publicity in the *New Zealand Healthy Food Guide*, a monthly magazine promoting healthy eating and lifestyles. The use of email databases from previous Massey University nutrition studies may also have attracted participants who were well-informed on healthy lifestyle choices.

Only limited socio-demographic data were collected in this study. More extensive data of this nature would have contributed to better understanding issues around compliance and engagement in the study (Bauman *et al.*, 2012; Loprinzi *et al.*, 2013; Roth and Mindell, 2013; Ministry of Health, 2016) and may have helped to elucidate factors (e.g. cultural, lifestyle) that pose as barriers to exercise in some portions of the cohort. Socio-demographic status is inversely associated with physical activity participation (Bauman *et al.*, 2012; Ministry of Health, 2016) and is directly associated with obesity and other health outcomes (Ministry of Health, 2016). Some of these socio-demographic factors may have influenced some findings and could have been used as covariates in analysis, had these data been available. Furthermore, although hours of work were recorded, other time commitments such as fulltime childcare, voluntary work and study, were not. Each of these factors may have had an important impact on available time in which to be physically active.

Historical physical activity (past months/year, lifetime) and weight status data could have provided deeper understanding of the snapshot of cross-sectional data obtained in this research. Data detailing previous levels and types of physical activity could provide valuable insight into current habits and might have strengthened the suggestions made in Chapter 6. Knowledge of recently increased physical activity, for example, might have helped to explain apparent discrepancies between levels of physical activity and observed body composition or metabolic health makers that may have confounded some results.

7.6 Recommendations for future research

- When conducting research in groups from different ethnicities, ensure that each ethnicity is represented within the research team or that a liaison person is engaged to bridge the gap between researcher and potential participants. Organising research teams in this way would help to overcome cultural differences leading to difficulties with recruitment, participant engagement and participants' understanding of research objectives, and should ultimately lead to better quality, more representative data.
- Consider the practicality of performing off-site data collection, rather than requiring participants to travel to a specific research facility. Off-site data collection might reduce barriers and make participation more accessible to the target population, but would also compromise methodology (i.e. less than gold-standard equipment would need to be used).
- Design accelerometer-based studies to include two data collection sessions; initially to explain and distribute accelerometers, and later to collect accelerometers and check for completeness of data.
- Conduct intervention studies in all ethnicities to confirm the associations of MVPA and MVPA10 on body composition and metabolic health markers that were identified in Chapter 5.
- Conduct longitudinal studies to follow participants over a number of years to gain a deeper understanding of the interactions between physical activity, body composition and metabolic health markers.
- Conduct qualitative research to investigate reasons for inactivity of both Māori and, particularly, Pacific women. Include in this investigation barriers and enablers to potentially increase accessibility and adherence to physical activity in these groups.
- Further investigate the settings in which women perform particular activities so as to strengthen the suggestions made in Chapter 6. For example, determine whether gym-type activities are predominantly performed in gyms, boot-camps or community exercise classes, and whether settings differ by ethnicity.
- Conduct intervention studies to investigate the effectiveness of the suggestions made in Chapter 6 to determine if the proposed exercises are: a) acceptable and feasible to the specific populations, b) effective in promoting long-term participation in physical

activity, and c) effective in improving health status (body composition and/or metabolic health markers).

- More deeply examine lifestyle factors, other than physical activity, and potential genetic factors among all women, but particularly Pacific women, that might be more influential than physical activity on body composition and markers of metabolic health.

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Appendix 1 Papers (published)

Papers (published as part of thesis)

O'Brien, W. J., Shultz, S. P., Firestone, R. T., George, L., Breier, B. H., Kruger, R. Exploring the challenges in obtaining physical activity data from women using hip-worn accelerometers. *European Journal of Sports Science, 17*(7), 922-30.

Other papers

Casale, M., von Hurst, P. R., Beck, K. L., Shultz, S., Kruger, M. C., **O'Brien, W. J.**, . . . Kruger, R. (2016). Lean mass and body fat percentage are contradictory predictors of bone mineral density in pre-menopausal Pacific Island women. *Nutrients, 8*(8).

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Kruger, R., Shultz, S. P., McNaughton, S. A., Russell, A. P., Firestone, R. T., George, L., . . . Stonehouse, W. (2015). Predictors and risks of body fat profiles in young New Zealand European, Māori and Pacific women: Study protocol for the women's EXPLORE study. *SpringerPlus, 4*(1), 128.

Appendix 2 Conference presentations and abstracts

Papers (published or submitted as part of thesis)

2017

O'Brien WJ, Walsh DCI, Shultz SP, Breier BH, Kruger R. (2017). Replacing sedentary time with active behaviour differentially predicts improved health markers in overweight/obese women, dependent on ethnicity.
Oral presentation at the *Sport and Exercise Science New Zealand Conference*. Cambridge, New Zealand. Oct 2017.

O'Brien WJ, Walsh DCI, Shultz SP, Breier BH, Kruger R. (2017). Isotemporal substitution of physical activity and sedentary behaviours: Predicting effects on body composition and metabolic risk factors.
Oral presentations at the *International Society of Behavioural Nutrition and Physical Activity Annual Meeting*. Victoria, Canada. June 2017.

O'Brien WJ, Shultz SP, Breier BH, Kruger R. (2017). Do New Zealand Women's Age and Ethnicity Contribute to Achieving Physical Activity Guidelines?.
Poster presentation at the *64th Annual Meeting American College of Sports Medicine*. Denver, Colorado, USA. May 2017.

2016

O'Brien WJ, Shultz SP, Firestone RT, George L, Breier BH, Kruger R. (2016). Exploring the challenges of obtaining objectively measured physical activity data from pre-menopausal women.
Oral presentation at the *Sport and Exercise Science New Zealand Conference*. Cambridge, New Zealand. Oct 2016.

O'Brien WJ, Shultz SP, Breier BH, Stonehouse W, Kruger K. (2016). Objectively measured physical activity levels of obese and non-obese pre-menopausal New Zealand women (Women's EXPLORE study).
Oral presentation at *Centre for Metabolic Health Research.* Auckland, New Zealand. April 2016.

2015

O'Brien WJ, Shultz SP, Breier BH, Kruger K. (2015). Objectively measured physical activity levels of obese and non-obese pre-menopausal New Zealand women.
Oral presentation at the *Nutrition Societies of Australian and New Zealand Joint Meeting*. Wellington, New Zealand. Dec 2015.

O'Brien WJ, Shultz SP, Breier BH, Jones B, Stonehouse W, Kruger K. (2015). Physical activity levels of pre-menopausal New Zealand European women differ across age groups.

Poster presentation at the 9^{th} *International Conference on Diet and Activity Methods*. Brisbane, Australia. Sept 2015

2014

O'Brien WJ, Shultz SP, Breier BH, Kruger K. (2014). Exploring the physical activity patterns and micronutrient status of young New Zealand women with different body fat profiles.
Oral presentation at the *Auckland Nutrition Research Network*. Auckland, New Zealand. Dec 2014.

Appendix 3 Contribution of authors (including statements of contributions to doctoral thesis containing publications)

Contribution of authors

Chapter 3: Attrition and challenges paper	Wendy O'Brien	Designed physical activity protocol and telephone interview, co-ordinated and conducted recruitment and data collection, processed and analysed data, interpreted results, main author of manuscript
	Sarah Shultz	Assisted with study design, advised on physical activity protocol, revised and approved manuscript
	Riz Firestone	Advised on and assisted with cultural aspects, revised and approved manuscript
	Lily George	Advised on and assisted with cultural aspects, assisted with recruitment, revised and approved manuscript
	Bernhard Breier	Revised and approved the manuscript
	Rozanne Kruger	Conceptualised and designed the overall EXPLORE study, obtained ethical approval, assisted with data collection, assisted with interpretation of results, revised and approved manuscript
Chapter 4: Associations of physical activity, body composition and metabolic markers among overweight-obese women	Wendy O'Brien	Designed physical activity protocol, co-ordinated and conducted recruitment and data collection, processed and analysed data, interpreted results, main author of manuscript
	Sarah Shultz	Assisted with study design, advised on physical activity protocol, assisted with interpretation of results, revised and approved manuscript
	Sarah McNaughton	Assisted with study design, revised and approved manuscript
	Welma Stonehouse	Assisted with the overall EXPLORE study design, revised and approved manuscript
	Bernhard Breier	Revised and approved the manuscript

	Rozanne Kruger	Conceptualised and designed the overall EXPLORE study, obtained ethical approval, assisted with data collection, assisted with interpretation of results, revised and approved manuscript
Chapter 5: Isotemporal substitution analysis paper	Wendy O'Brien	Designed physical activity protocol, co-ordinated and conducted recruitment and data collection, processed and analysed data, interpreted results, main author of manuscript
	Daniel Walsh	Assisted with statistical analysis, revised and approved manuscript
	Sarah Shultz	Assisted with study design, advised on physical activity protocol, assisted with interpretation of results, revised and approved manuscript
	Bernhard Breier	Revised and approved manuscript
	Rozanne Kruger	Conceptualised and designed the overall EXPLORE study, obtained ethical approval, assisted with data collection, assisted with interpretation of results, revised and approved manuscript
Chapter 6: RPAQ paper	Wendy O'Brien	Designed physical activity protocol, co-ordinated and conducted recruitment and data collection, processed and analysed data, interpreted results, main author of manuscript
	Sarah Shultz	Assisted with study design, revised and approved manuscript
	Riz Firestone	Advised on and assisted with cultural aspects, revised and approved manuscript
	Lily George	Advised on and assisted with cultural aspects, assisted with recruitment, revised and approved manuscript
	Rozanne Kruger	Conceptualised and designed the overall EXPLORE study, obtained ethical approval, assisted with data collection, assisted with interpretation of results, revised and approved manuscript

MASSEY UNIVERSITY
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STATEMENT OF CONTRIBUTION TO DOCTORAL THESIS CONTAINING PUBLICATIONS

(To appear at the end of each thesis chapter/section/appendix submitted as an article/paper or collected as an appendix at the end of the thesis)

We, the candidate and the candidate's Principal Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of Candidate: Wendy O'Brien

Name/Title of Principal Supervisor: Assoc Prof Rozanne Kruger

Name of Published Research Output and full reference:
Exploring the challenges in obtaining physical activity data from women using hip-worn accelerometers.

O'Brien, W. J., Shultz, S. P., Firestone, R. T., George, L., Breier, B. H., & Kruger, R. (2017). European Journal of Sport Science, 17(7), 922-930. doi: 10.1080/17461391.2017.1323952

In which Chapter is the Published Work: Chapter 3

Please indicate either:

- The percentage of the Published Work that was contributed by the candidate:

  and / or

- Describe the contribution that the candidate has made to the Published Work:
  Recruited particpants, conducted research, analysed data, performed statistical analysis, interpreted results, main author of manuscript.

Candidate's Signature — 21/11/2017 (Date)

Principal Supervisor's signature — 21/11/2017 (Date)

Appendix 4 EXPLORE study protocol

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STUDY PROTOCOL Open Access

Predictors and risks of body fat profiles in young New Zealand European, Māori and Pacific women: study protocol for the women's EXPLORE study

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Abstract

Background: Body mass index (BMI) (kg/m^2) is used internationally to assess body mass or adiposity. However, BMI does not discriminate body fat content or distribution and may vary among ethnicities. Many women with normal BMI are considered healthy, but may have an unidentified "hidden fat" profile associated with higher metabolic disease risk. If only BMI is used to indicate healthy body size, it may fail to predict underlying risks of diseases of lifestyle among population subgroups with normal BMI and different adiposity levels or distributions. Higher body fat levels are often attributed to excessive dietary intake and/or inadequate physical activity. These environmental influences regulate genes and proteins that alter energy expenditure/storage. Micro ribonucleic acid (miRNAs) can influence these genes and proteins, are sensitive to diet and exercise and may influence the varied metabolic responses observed between individuals. The study aims are to investigate associations between different body fat profiles and metabolic disease risk; dietary and physical activity patterns as predictors of body fat profiles; and whether these risk factors are associated with the expression of microRNAs related to energy expenditure or fat storage in young New Zealand women. Given the rising prevalence of obesity globally, this research will address a unique gap of knowledge in obesity research.

Methods/Design: A cross-sectional design to investigate 675 NZ European, Māori, and Pacific women aged 16–45 years. Women are classified into three main body fat profiles ($n = 225$ per ethnicity; $n = 75$ per body fat profile): 1) normal BMI, normal body fat percentage (BF%); 2) normal BMI, high BF%; 3) high BMI, high BF%. Regional body composition, biomarkers of metabolic disease risk (i.e. fasting insulin, glucose, HbA1c, lipids), inflammation (i.e. IL-6, TNF-alpha, hs-CRP), associations between lifestyle factors (i.e. dietary intake, physical activity, taste perceptions) and microRNA expression will be investigated.

Discussion: This research targets post-menarcheal, premenopausal women, potentially exhibiting lifestyle behaviours resulting in excess body fat affecting metabolic health. These behaviours may be characterised by specific patterns of microRNA expression that will be explored in terms of tailored solutions specific to body fat profile groups and ethnicities.

Trial registration: ACTRN12613000714785

Keywords: Body fat profile; Predictors; Overweight and obesity; Metabolic disease risk; MicroRNA; Dietary practices; Physical activity; Taste perception; Women

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Background

Obesity has been described as an excess accumulation and storage of fat in the body, typically due to an increase in size and/or number of fat cells. Excess adiposity is generally accepted as an important risk factor for a range of non-communicable diseases; increased fat in the abdominal area compared with fat around the hips poses greater cardiovascular risks and metabolic dysregulation (Huxley et al. 2010; Martinez et al. 2008; Cameron et al. 2009). Yet, there has been no agreement on defining obesity in terms of body fat percentage (BF%) (Oliveros et al. 2014). A wide variety of BF% cut-off points have been used, varying between 20 to 25% for men and 30 to 37% for women (Oliveros et al. 2014). Alternatively, body mass index (BMI) is used worldwide to assess underweight, normal weight, overweight and obesity in adults of both genders (World Health Organisation 2011; Huxley et al. 2010; Gallagher et al. 1996; World Health Organisation 2000). However, BMI does not take into account body fat content or the differential health risks associated with abdominal (central) versus hip (peripheral) fat (Dulloo et al. 2010). There are also concerns regarding the acceptability of BMI as a reference value in varying ethnicities, as overweight and obesity have been defined based on European population data (Deurenberg 2001; World Health Organisation 2011, World Health Organisation 2000). Pacific people, Māori and Asian communities traditionally have larger and smaller body frames, respectively (Swinburn et al. 2004; Huxley et al. 2010; Deurenberg 2001; Rush et al. 2009; Ministry of Health NZ 2009) and subcutaneous fat patterns vary among ethnicities (Deurenberg and Deurenberg-Yap 2003; Okorodudu et al. 2010). Therefore, BMI is unlikely to accurately predict related disease risk profiles among different population subgroups with normal BMI or those that may have different levels of adiposity with a similar BMI (Gallagher et al. 1996; Deurenberg 2001; Ministry of Health NZ 2009).

Adiposity is likely to be overestimated in people with high BMI that have higher lean body mass (e.g. athletes), whilst underestimation is likely in those with lower BMI and less lean body mass (Oliveros et al. 2014; Romero-Corral et al. 2010; Okorodudu et al. 2010). The concept of metabolically obese normal weight individuals has been previously described (Karelis et al. 2004; De Lorenzo et al. 2006), and is associated with increased metabolic dysregulation. This has been referred to as "Normal Weight Obesity" (De Lorenzo et al. 2006) or as will be used in this study, a hidden body fat profile. However, not all individuals with the "hidden fat" profile may be at risk of metabolic disease, and it is unclear from previous studies whether metabolic dysregulation can be explained by high total fat mass, high BF% or high visceral fat (Oliveros et al. 2014).

During the transition from adolescence to adulthood (15–35 years), women experience larger weight gain than men (Jasik and Lustig 2008). Younger women often practice risky eating (e.g. dieting, fast foods) or lifestyle (e.g. physical inactivity) behaviours and work and environmental pressures may lead to altered food habits resulting in higher BF% that may negatively affect their metabolic profiles (Haslam and James 2005; Keskitalo et al. 2008). Furthermore, different taste sensitivities have been shown to influence dietary habits and metabolic health. A higher preference for sweet taste is associated with increased sugary food consumption (Drewnowski et al. 2012), whilst those who are hypersensitive to fatty acids consume less total fat (Stewart et al. 2010). Specific taste perception profiles may therefore lead to increased adiposity and ultimately reduced metabolic and cardiovascular health (Mendoza et al. 2007; Duffey and Popkin 2008). Gene-environment interactions may also increase the susceptibility of overweight individuals to develop hyperlipidemia, hypertension or diabetes (Martinez et al. 2008; Arkadianos et al. 2007). Excess body fat accumulation is mostly the result of a polygenic syndrome interacting with both dietary and physical activity components of lifestyle (Martinez et al. 2008). The signals delivered by food intake and physical activity regulate genes and proteins that alter energy expenditure/storage (Buttriss 2006). Gene/protein responses to food intake and physical activity vary between individuals; however, the cause is unknown (Martinez et al. 2008). MiRNAs are recently discovered molecules that act as "switches" to "turn on" or "turn off" genes and proteins. They are sensitive to diet and exercise (Güller and Russell 2010) and may influence the varied metabolic response seen between individuals (Davidsen et al. 2011). Recently, specific miRNAs have been suggested as biomarkers for metabolic disease (Heneghan et al. 2011). This unique gene-diet-physical activity relationship might impact on the development of hidden or apparent body fat, with different consequences across ethnic groups and thus requires further investigation (Swinburn et al. 2004; Arkadianos et al. 2007; Deurenberg and Deurenberg-Yap 2003; Di Renzo et al. 2007).

This study will be conducted as a cross-sectional comparative designed study. The primary aim of this study is to explore the metabolic risks and predictive factors associated with the hidden and apparent body fat profiles in 16 to 45 year old (post-menarcheal and premenopausal) NZ European, Māori and Pacific women. The primary outcomes are:

- Investigating the association between body composition profiles and markers of metabolic disease risk, including glucose, lipid and inflammatory marker profiles;
- Investigating dietary and physical activity patterns as predictive factors associated with body composition profiles;

- Investigating miRNA expression related to energy expenditure/storage as a predictive factor associated with body composition profiles.

The secondary outcomes are:

- Investigating associations/interactions between dietary and physical activity patterns and miRNA expression and how this may modulate the odds of having a specific body composition profile;
- Investigating taste perceptions as a predictive factor associated with the different body composition profiles;
- Investigating eating behaviour and habits as predictive factors associated with the different body composition profiles;
- Investigating nutrient intake as a predictive factor associated with the different body composition profiles.

We hypothesise that the "hidden fat" profile is associated with increased metabolic disease risk in NZ European, Māori, and Pacific women aged 16 to 45 years. We further hypothesise that for all women, dietary and physical activity patterns are predictors of a particular body composition profile by modulating miRNAs associated with energy expenditure/storage.

Methods/Design

Study design

The Women's EXPLORE ("EXamining Predictors Linking Obesity Related Elements") is a cross-sectional study targeting post-menarcheal, premenopausal NZ women to examine predictors of body composition profiles. Three body composition profile groups will be explored, namely:

"Normal Fat" group – normal BMI (<25 kg/m^2), normal BF% (≥22%,<30%);

"Hidden Fat" profile group – normal BMI (<25 kg/m^2), high BF% (≥30%);

"Apparent Fat" profile group – high BMI (≥25 kg/m^2), high BF% (≥30%) (Oliveros et al. 2014; Okorodudu et al. 2010; NHLBI Obesity Education Initiative Expert Panel on the Identification Evaluation and Treatment of Overweight and Obesity in Adults 1998).

Participants and sample size

Study participants are adult NZ women from three ethnic groups (NZ European, Māori, and Pacific Island). A total sample size of 225 women per ethnic group, consisting of 75 per profile group, will provide 80% power at significance levels of $p < 0.05$ to detect a medium effect size *f* of 0.25 (G*Power 3.1.2) for comparing the "hidden fat" profile with the other two body composition profiles ("normal fat" and "apparent fat") regarding metabolic disease risk markers, dietary and physical activity patterns, and miRNA expression levels.

The medium effect size is relevant to all variables, and encompasses a variety of scenarios, as we wish to be able to explore how metabolic profile changes with body composition. For example, if the three groups have equally spaced means ($\mu - \Delta$, μ, $\mu + \Delta$), the difference in means will be detected with 80% power when $\Delta = 0.31 \times \sigma$, where σ is the within group standard deviation. For cholesterol, where preliminary data suggests $\sigma = 0.98$ mmol/L, we have 80% power to detect the difference when $\Delta = 0.30$ mmol/L. Alternately, if two groups have the same mean μ and the third has mean $\mu + \Delta$, 80% power is achieved when $\Delta > 0.53 \times \sigma$, or 0.52 mmol/L in the case of cholesterol. A $\Delta = 0.30 – 0.52$ mmol/L is estimated to be associated with a 9 – 15% lower relative risk of coronary heart disease (CHD)-related mortality (Gould et al. 2007). For HDL-C where preliminary data suggests $\sigma = 0.38$ mmol/L we have 80% power to detect a difference when $\Delta = 0.12 – 0.20$ mmol/L. Every 0.1 mmol/L increase in HDL-C has been suggested to reduce CHD risk by between 8 – 15% (Gordon et al. 1989; Turner et al. 1998). For TG where preliminary data suggests $\sigma = 0.45$ mmol/L we have 80% power to detect a difference when $\Delta = 0.14 – 0.24$ mmol/L. Studies in women showed a 1 mmol/L increase in TG was associated with 37% increase in risk of CVD (after adjustment for HDL-C and other risk factors)(Austin et al. 1998); Δ of 0.14 – 0.24 is thus estimated to be associated with 5.2 – 9% difference in CVD risk.

The power for simple (one variable) logistic regression for the risk of having a "hidden fat" profile among people of normal BMI is equivalent to the power of the independent sample t-test (Vaeth and Skovlund 2004) for comparing the predictor variable mean between the hidden fat and normal fat profiles. With a sample size of 75 per group and equal variance within groups, 80% power is achieved for differences of 0.46 σ. For instance, preliminary data on total energy expenditure assessed using the Recent Physical Activity Questionnaire (RPAQ) estimates the standard deviation at 5.36 METs-h/day; if the true difference means between the body composition groups is 2.47 METs-h/day, the logistic regression coefficient will be significantly nonzero 80% of the time. Clinically, the difference of 2.47 METs-h/day equates to ~684 kJ/day (164 kcal/day)(Besson et al. 2010), which is considered within the target range of recommended energy expended each day in physical activity and/or exercise (Pescatello and American College of Sports Medicine 2014). We will consider logistic regression predictors from the dietary and activity pattern data, and separately for the miRNA measurements.

Based on our pilot study that showed a prevalence of 21% of NZ European women having a "hidden fat" profile, (Kruger et al. 2010b) a sample of ~1140 women will need to be screened (380 per ethnicity) to find ~75 women per profile group; or to explore new profiles. The study design and study procedures are illustrated in Figure 1.

Inclusion criteria for women are:

- age (16 to 45 years),
- being post-menarcheal or pre-menopausal (as defined by a continuous regular menstrual cycle for the past one complete year),
- ethnicity (being of NZ European, Māori, or Pacific ethnicity as defined by self-identification and having at least one parent from the same ethnicity).

Exclusion criteria for women are:

- pregnancy and lactation,
- presence of any diagnosed chronic illness particularly affecting metabolic health (e.g. T2DM),

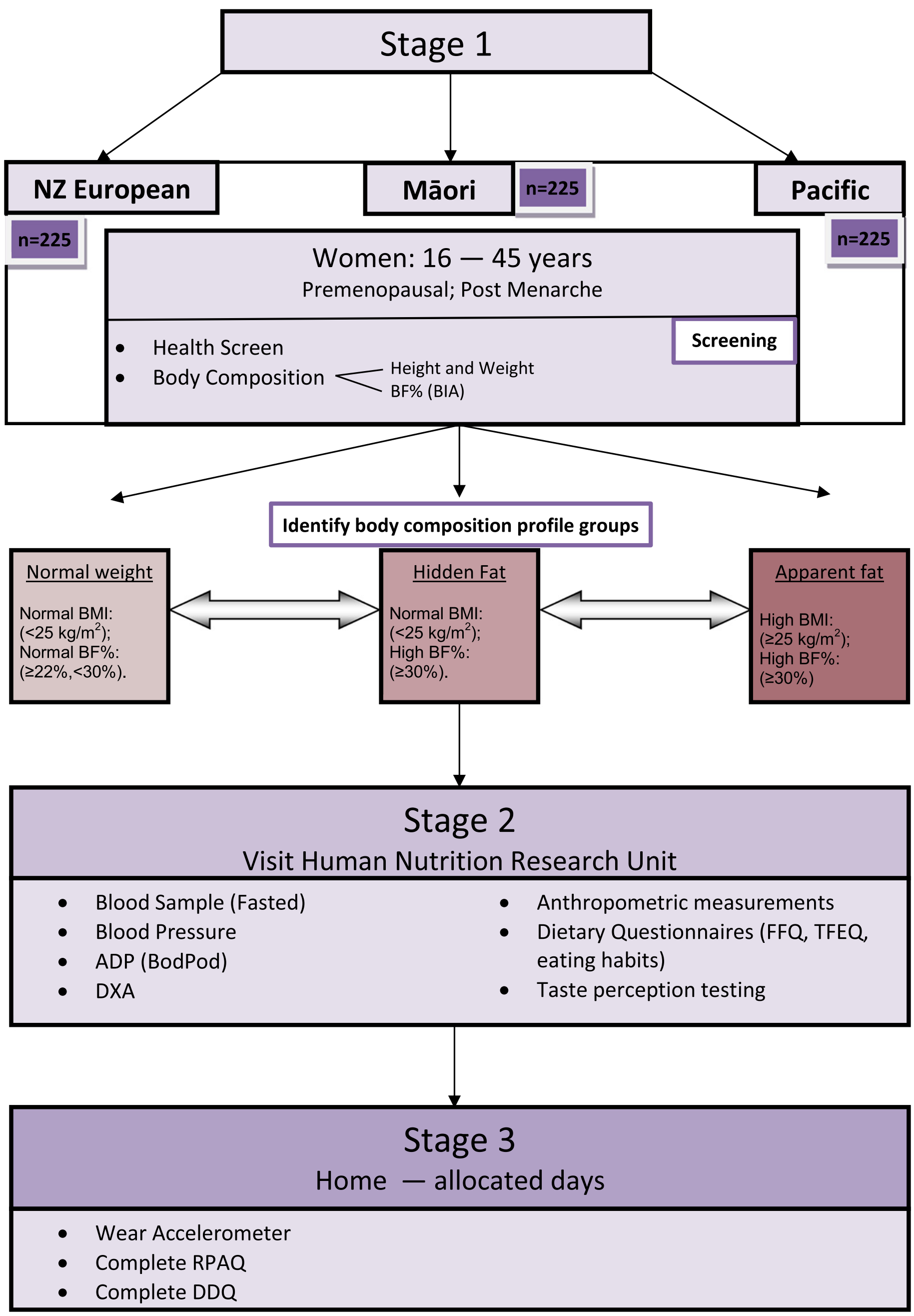

Figure 1 Study design and procedures.

- presence of dairy allergy as the taste solution is dairy based.

Setting and recruitment

Women are recruited in Auckland, NZ using media articles and advertising (e.g. in newspapers, magazines, on websites and radio interviews). Posters and flyers are used in a variety of venues including local crèches, primary schools, secondary schools, local businesses and events (e.g. gym's, libraries, and sport events). The study is also advertised using social media (e.g. Facebook, twitter) and via emailing lists (e.g. Massey University staff, student, and previous research participant databases). Potential participants are directed to a study website for further information and to register their interest in the study. For the Māori and Pacific cohorts, recruitment strategies were adapted to be culturally appropriate. A more personal approach with face-to-face contact by community liaisons, were used to recruit women. Screening (see Stage 1 under procedures) was conducted within the respective communities and special assistance was provided for participants to travel to Massey University for further data collection (Stage 2).

Procedures

The study follows a three-staged approach that involves screening (Stage 1), on-site assessments (Stage 2), and at-home assessments (Stage 3) (Figure 1).

Screening (stage 1)

Women who register interest are provided with an information sheet and asked to complete a consent form and the screening questionnaire. If all the inclusion and exclusion criteria assessed using the screening questionnaire is met, BMI (calculated using height and weight) and BF% (assessed using bioelectrical impedance (BIA)) are used for preliminary categorisation into the body composition profile groups (described above). The body composition screening is done in person and either at the Human Nutrition Research Unit, Albany campus, Massey University, or off-site.

Assessments (stages 2 and 3)

Participants recruited in stage 1 are invited to the research unit within 14 days of the start of their last menstrual period (the follicular phase) for testing to avoid the confounding effect of menstrual cycle hormones on taste perception, energy intake and energy expenditure (Davidsen et al. 2007).

Stage 2 of testing involves measurements of anthropometry, body composition, metabolic health, dietary intake, taste perception, and eating behaviour, which are described in detail below.

Stage 3 of assessment is completed at home over a seven day period. Participants wear accelerometers and keep a physical activity diary to assess physical and sedentary activity objectively in real life. At the end of the seven days, participants complete the RPAQ and the dietary diversity questionnaire (DDQ) (see Figure 1).

Measures

The chosen measures and/or methods used for the various assessments in stages 1, 2 and 3 are listed in Table 1.

Body composition assessment

Anthropometric measurements include weight, height, waist and hip circumferences using the International Society for the Advancement of Kinanthropometry (ISAK) protocol (Marfell-Jones et al. 2006). Waist-to-hip ratio, waist-to-height ratio and BMI will be derived from these measures and will be used to assess body composition in terms of obesity along with associated disease risk (NHLBI Obesity Education Initiative Expert Panel on the Identification Evaluation and Treatment of Overweight and Obesity in Adults 1998). Fat and lean mass are assessed using BIA (Boneva-Asiova and Boyanov 2008; Ling et al. 2011) for screening and preliminary categorisation into profile groups, and air displacement plethysmography (ADP) (using thoracic gas volume method) for final categorisation (Wingfield et al. 2014; Noreen and Lemon 2006), as well as DXA measurements for regional body composition (Boneva-Asiova and Boyanov 2008).

Metabolic health assessment

After an overnight fast (no food or beverages, excluding water for 12 hours prior to phlebotomy), blood samples are obtained by registered phlebotomists between 7.00 and 10.00 am and prior to sensory testing. Serum and plasma samples (ethylene diamine tetraacetic acid (EDTA) and heparin) are collected and processed in accordance with pathology laboratory protocols. All samples are frozen in separate aliquots in Eppendorf tubes and stored at −80°C until analysis. Analysis will be carried out by a fully accredited (with IANZ to the ISO 15189) laboratory or by qualified laboratory technicians upon completion of data collection. Biomarkers that will be analysed include plasma levels of glucose, total cholesterol, triglycerides, HDL-C, LDL-C, insulin, leptin, serum hs-CRP, Il-6 and TNF-alpha using commercially available kits or using routine enzymatic assays as published by our team (van Langenberg et al. 2014; Smith et al. 2012). The analyses will be performed using either a Biotek Synergy 2 Plate Reader (Millennium Science, Balwyn, Vic) or a Bioplex 200 plate reader (BioRad Hercules CA) depending on the required assay.

Selected miRNA species to assess metabolic disease risk and to explore energy expenditure and storage will be measured as published by our group (Russell et al. 2012; Güller and Russell 2010; Russell et al. 2013; Zacharewicz et al.

Table 1 Measures and methods

Domain	Measures / methods	Reference	Equipment	Concept captured
Body composition: anthropometry.	Anthropometric measurements (height, weight, circumferences) using ISAK protocol and standards.	(NHLBI Obesity Education Initiative Expert Panel on the Identification Evaluation and Treatment of Overweight and Obesity in Adults 1998)	Stadiometer, Lufkin tape.	Body composition. - Profile in terms of BMI (weight, height) - Risk in terms of circumferences and ratios (waist, hip, height).
Body composition profile – fat and lean mass.	-	(Ling et al. 2011)	Bioelectrical Impedance (BIA) (InBody230, Biospace Co. Ltd, Seoul).	Body composition - (fat and lean mass). - total
	-	(Noreen and Lemon 2006; Wingfield et al. 2014)	Air displacement Plethysmography (BodPod) (2007A, Life Measurement Inc, Concord, Ca., using software V4.2+ as supplied by the manufacturer).	Body composition - (fat and lean mass). - total
	-	(Boneva-Asiova and Boyanov 2008)	Dual XRay Absorptiometry (DXA) (Hologic QDR Discovery A, Hologic Inc, Bedford, MA. with APEX V. 3.2 software.	Body composition - (fat and lean mass). - total - regional
Metabolic health – biomarkers.	Analysis will be conducted by fully accredited laboratory with IANZ to the ISO 15189.	-	Blood sampling to capture plasma glucose, total cholesterol, triacylglyceride, HDL-cholesterol, LDL-cholesterol, insulin, serum hs-CRP, Il6, TNF-alpha, HbA1C, Leptin, Ghrelin.	Biomarkers related to metabolic health (lipid profile, glucose control, inflammation, hormonal control).
Metabolic health – blood pressure.	-	(Ogedegbe and Pickering 2010)	Blood pressure measurement Riester Ri-Chamion N digital blood pressure monitor, using one of two arm cuff sizes (22-32 cm or 32-48 cm).	Blood pressure related to metabolic health.
Metabolic health – gene expression	-	(Russell et al. 2012; Zacharewicz et al. 2014)	miRNA - use specific primer and probes sets as per the manufacturer's instructions (Applied Biosystems, Carlsbad, USA) using an MX3000p thermal cycler system. miRNA species will be measured using published techniques.	MiRNA related to energy expenditure.
Diet Quality	Food Frequency Questionnaire (FFQ)	(Ministry of Health NZ 1997; McNaughton 2011; Mishra et al. 2010)	Analysis using Foodworks7 2010 (Xyris Software (Australia) Pty Ltd, Queensland, Australia).	Dietary adequacy - energy intake - nutrient intake Patterns of food and nutrient intake.
Diet Quality	Eating Habits Questionnaire	Developed in this study	-	Dietary habits - eating habits - meal distribution - food choices.

Table 1 Measures and methods *(Continued)*

Dietary Variety	Dietary Diversity Questionnaire (DDQ)	Developed in this study; mostly based on foods in the FFQ	-	Dietary diversity Food variety.
Dietary Behaviour	Three Factor Eating Questionnaire (TFEQ)	(Stunkard and Messick 1985)	-	Dietary behaviour - Restraint, - Disinhibition, - Hunger.
Physical Activity patterns	-	(Pescatello and American College of Sports Medicine 2014)	WGT3X Actigraph	Objective real life physical activity Physical activity expenditure - sedentary activities - intensity of activity.
	Physical Activity diary	-	-	Self-reported accelerometer non-wear time Self-reported intentional exercise – time - duration - type - intensity.
Physical Activity behaviour	Recent Physical Activity Questionnaire (RPAQ)	(Besson et al. 2010)	-	Self-reported physical activities - sedentary activities - time - intensity.
Taste perception, intensity, and hedonic preference	-	(Lim et al. 2008; Bartoshuk et al. 2004)	Rate intensity and hedonic preference of sweet and fat taste on a gLMS.	Sweet and fat taste sensitivity and preference.

2014). For miRNA analysis, extracted RNA will be reverse transcribed using target specific primers followed by qPCR using target specific probes as published routinely by our group. All qPCR analysis will be performed using the Stratagene MX3000p thermocycler (Stratagene, La Jolla, CA); miRNA results will be normalized to RNA input and log transformed if not normally distributed.

Resting blood pressure measurements are taken whilst sitting, following a 10 minute resting period after taste perception assessments. For blood pressure measurements, an arm cuff is attached to the arm that has not been used for the venepuncture and three measurements are taken consecutively in one minute intervals (Ogedegbe and Pickering 2010).

Dietary intake data

A 220-item self-administered semi-quantitative food frequency questionnaire (FFQ) is used. The FFQ was adapted from the validated FFQ used in the Adult National Nutrition survey in NZ (Ministry of Health NZ 1997). Changes include an expanded food list to include currently consumed/available foods, additional questions relating specifically to fast food and snack food intakes, changes to the order of questions to improve continuity between questions. The food intake data will be processed using the Foodworks7 (Xyris Software (Australia) Pty Ltd, Queensland, Australia) dietary analysis database utilising FOODfiles 2010 (developed by the NZ Institute for Plant & Food Research and the NZ Ministry of Health) as the reference food composition table for NZ. Dietary quality and variety of the whole diet will be assessed, including nutritional adequacy and usual intake patterns and adherence to NZ dietary guidelines (Wirt and Collins 2009; Kant and Graubard 2005; Ibiebele et al. 2009). The frequency and patterns of intake of various nutrient-rich/poor dietary components and dietary factors that may affect fat deposition/obesity (e.g. sugar/fat-rich foods, fast foods, etc.) and related habits will be investigated. Foods from the FFQ will be grouped accordingly and factor analysis will be used to determine dietary pattern scores (McNaughton 2011; Mishra et al. 2010). Dietary variety will be assessed using dietary diversity scores and food variety scores to explore the variety of nutritious and non-nutritious foods (Ruel 2003; Murphy et al. 2006). Eating habits, meal patterns and food choices are explored using a self-developed and validated (during the current study) questionnaire, providing descriptive data of the women's dietary practices.

Dietary behaviour is assessed using the validated TFEQ (Stunkard and Messick 1985; Bond et al. 2001) to measure three eating behaviour traits. The three factors are cognitive dietary restraint (Restraint), disinhibition of control (Disinhibition) and susceptibility to hunger (Hunger) by calculating scores for the dimensions and their sub-categories.

Sensory testing

Sensitivity and preferences of sweet and fat taste are assessed. Participants rate the intensity and hedonic preference of five sucrose and dairy samples on a general labelled magnitude scale (gLMS) (Bartoshuk et al. 2004; Lim et al. 2008).

Physical activity

A w-GT3X triaxial accelerometer (Actigraph, Pensacola, FL) secured to a waist belt, is worn for seven days, with a minimum of 10 h per day, to measure all components of physical activity and energy expenditure. Participants maintain their regular physical activity, whilst keeping a diary of times when the device is not worn. At least three full week and two weekend days is required for analysis. Physical activity counts will be calculated from raw data as the square root of the sum squared of activity counts, and will be categorized using metabolic equivalents (METs), as defined by the American College of Sports Medicine guidelines (Pescatello and American College of Sports Medicine 2014). Activities will be classified as light or sedentary (1.1-2.9 METs), moderate (3.0-6.0 METs), or vigorous (>6.0 METs). A physical activity diary is kept to record periods of non-wear and of intentional exercise. A self-reported RPAQ (Besson et al. 2010) is completed at the end of seven days with reference to the previous four weeks, allowing, together with the diary, a specific interpretation of the accelerometry counts.

Data handling and statistical analysis

Statistical analysis will be performed using IBM SPSS statistics (IBM Corporation, New York, USA). Descriptive statistics will be used to describe the baseline population using mean (standard deviation), median (25, 75 percentile) or frequencies summary statistics. Normality of distribution will be evaluated using the Kolmogorov-Smirnov test and examining normality plots. Non-normally distributed variables will be transformed into approximately normal distributions by logarithmic transformations and again tested for normality. Primary statistical analyses will involve ANOVA tests with post-hoc analysis and Bonferoni adjustments comparing body composition profile groups regarding metabolic disease risk markers and dietary and physical activity patterns and miRNA levels; multiple logistic regression analysis to determine odds ratios of having a "hidden body fat" profile based on dietary and physical activity patterns; and, separately, miRNA expression levels. Principal components analysis will be performed on the miRNA data using the PCP directive in GenStat to identify linear combinations of the miRNAs that account for most of the variation between individuals (Zacharewicz et al. 2014); and Pearson correlations to determine correlation coefficients between dietary and physical activity patterns and miRNA expression profiles. A p-value of <0.05 will be considered significant.

Ethics
Ethical approval was obtained from the Massey University Human Ethics Committee: (Southern A), Reference No.13/13.

Discussion
An ethnic-specific focus aimed at weight maintenance has been recommended from previous NZ research (Metcalf et al. 2000). Overweight or obesity is a continual process and the effects of inappropriate lifestyle behaviour may often be missed when strictly assessing BMI as an indicator of over-nutrition. BMI provides only a crude measure of body fatness as it does not distinguish between weight associated with muscle or with fat. However, it appears to remain a useful estimate of the proportion of the population with increased risk of health conditions associated with obesity (World Health Organisation 2000), but may not be able to predict disease risk in those with normal BMI and varying adiposity.

Previous research has shown that a significant proportion of individuals with normal weight and subsequent normal BMI values had excessive body fat or "hidden" fat (Kruger et al. 2010a; De Lorenzo et al. 2006; Romero-Corral et al. 2010; Kruger et al. 2010b). This "hidden fat" profile may be linked with early inflammation and may be a key factor in the emerging epidemic of obesity and related disease risk (De Lorenzo et al. 2006; De Lorenzo et al. 2007). Pilot study data from our laboratory (Kruger et al. 2010a; Kruger et al. 2010b) revealed that in a free-living population (N = 116) of 18 to 44 year old NZ European women, 21.4% had a "hidden fat" profile and subsequent increased metabolic disease risk (identified through elevated fasting plasma leptin and insulin concentrations) and higher levels of sedentary lifestyle parameters.

Although a few studies have explored normal weight obesity (Marques-Vidal et al. 2008; Di Renzo et al. 2010; Romero-Corral et al. 2010; Karelis et al. 2004), not many studies have been specifically conducted to explore metabolic disease risk associated with high body fat (hidden or apparent), in premenopausal women. The typical central fat deposition following menopause and/or ageing may be absent in premenopausal women, despite the fact that women steadily gain weight from menarche to adulthood. It is therefore unclear where the hidden fat is situated in these women, especially if they are slender. It may be that excess fat in a lean person is hidden in the abdomen or elsewhere where it could pose health risks and cause metabolic dysregulation (Di Renzo et al. 2006; Huxley et al. 2010; Martinez et al. 2008; Cameron et al. 2009).

Implications
The presence of normal weight obesity varies between 2 to 28% in women (Oliveros et al. 2014). The origins are unclear and may be due to environmental as well as genetic factors (Oliveros et al. 2014; Karelis et al. 2004). Common recommendations for appropriate dietary or lifestyle behaviours may be ineffective due to individual genetic variation. Dietary or physical activity behaviours may influence molecular mechanisms controlling metabolic activity and gene expression. MiRNAs can regulate the gene and protein networks that control substrate utilization and storage. Differences in behaviour that impact on miRNA expression need to be identified in different body composition profiles. Identifying these differences may assist in developing preventive recommendations (Arkadianos et al. 2007), and need to be specific to the locality and culture of the target population (Swinburn et al. 2004).

Because we do not know if and where slender women of different ethnicities with a normal BMI store hidden fat, it is important to identify this and its possible impact on women's health. It is equally important to consider these issues in women with apparent fat and normal BF% to be able to make comparisons and explore tailored solutions. Our study will address a unique gap in health research knowledge by investigating multi-ethnic populations in NZ, identifying important physiological and behavioural predictors of metabolic disease risk. This research will assist in providing an important piece of the metabolic health versus body composition puzzle to fall into place and generate new pathways for treatment or early intervention.

Abbreviations
ADP: Air displacement plethysmography; BF%: Body fat percentage; BIA: Bioelectrical impedance analysis; BMI: Body mass index; CVD: Cardiovascular disease; DDQ: Dietary diversity questionnaire; EDTA: Ethylene diamine tetra acetic acid; FFQ: Food frequency questionnaire; gLMS: General labelled magnitude scale; ISAK: International society for the advancement of kinanthropometry; miRNA: micro ribonucleic acid; METs: Metabolic equivalents; NZ: New Zealand; RPAQ: Recent Physical Activity Questionnaire; T2DM: Type two diabetes mellitus; TFEQ: Three factor eating questionnaire.

Competing interests
The authors declare that they have no competing interests.

Authors' contributions
RK conceptualised the study. RK and WS designed the overall research study and obtained ethical approval. RK, SM and KB advise on the dietary measures, BHB and SJ advise on the taste perception assessment and metabolic health measures, AR advises on the miRNA protocols and analysis, SS and WO'B advise on the physical activity section, BJ and WS advise on statistical analysis, RF and LG advise on and assist with cultural aspects and recruitment; RK, SJ, WO'B, KB, CC, PvH conduct the study including recruitment and data collection. RK drafted the manuscript. All authors were involved in revising the manuscript and all read and approved the final manuscript.

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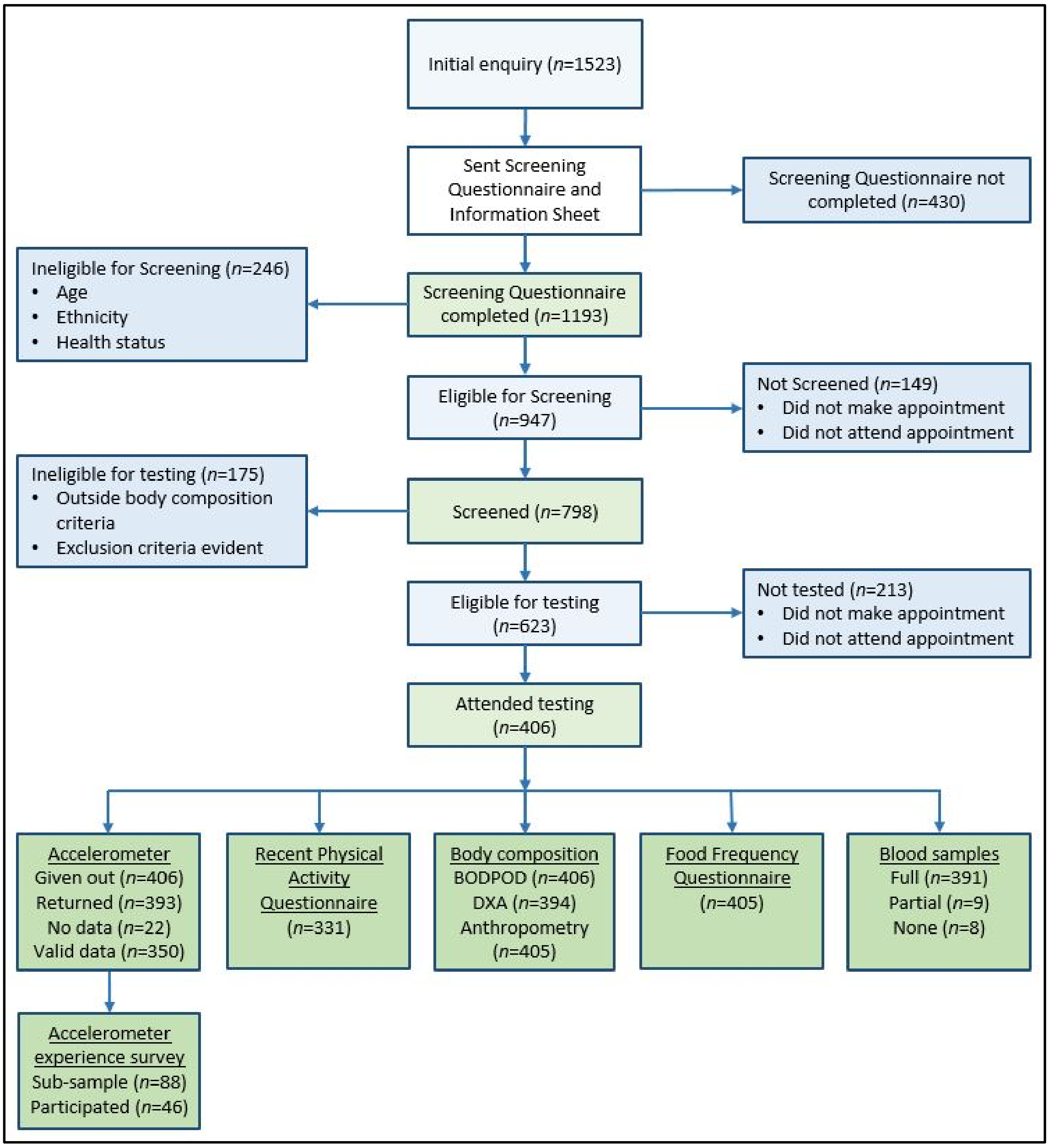
Appendix 5 Consort diagram for EXPLORE study



Consort diagram of EXPLORE study: numbers of participants from initial enquiry through each stage of data collection.

Appendix 6 Demographic questionnaire

Subject Number:

MASSEY UNIVERSITY
COLLEGE OF HEALTH
TE KURA HAUORA TANGATA

Women's EXPLORE study

Personal Information, Health and Demographics Questionnaire

First name: ____

Family name: ____

Name you would like to be called by: _______________________________________

Medical Practitioner: ____

Address: ____

Phone: ____

What is your first language?

English ☐

Other ☐

If other, please state: _______________________________

I would like to receive a brief report summarizing the main findings of the project:

Yes ☐ No ☐

I am willing to be contacted in future research projects within the Institute of Food, Nutrition and Human Health:

Yes ☐ No ☐

Health and Demographic information

Do you have children? Yes ☐ No ☐

- How many children do you have? ______________________

- When was your youngest child born? __ / __ / ____ (DD/MM/YYYY)

When did your last period start? (Day / month / year) ____________________

Are you pregnant? Yes □ No □

Do you have any surgical or cosmetic implants? Yes □ No □

Are you currently in paid employment? Yes □ No □

If yes,

Full time Yes □ No □

Part time Yes □ No □

If yes, specify hours per week:________________________

Describe your job or paid employment or work:

TITLE / DESCRIBE HOURS PER WEEK

____

____

Do you follow a specific diet for health reasons? Yes □ No □

Please explain

____

____

Do you follow any diet for cultural or religious reasons? Yes □ No □

If yes, what type of diet do you follow?

____

____

Are you taking any form of medication, including traditional or homeopathic medicine and contraception?

Yes □ No □

Please specify the condition, the medication and the dosage in the table provided.

Condition	Medication	Dosage	Frequency

Are you taking any form of supplements, including tablets or drinks? Yes □ No □
If yes, what are the name, brand and dosage of the supplements you are taking?
(Will send details by email Yes □ No □)

Supplement	Brand	Dosage	Frequency

Do you smoke cigarettes? Yes □ No □
If yes, approximately how many cigarettes per day:______________________________
____

Do you drink alcohol? Yes □ No □
If yes, approximately how many standard drinks per week:__________ ____ ________
[1 standard drink = a glass of wine (120ml), 1 bottle/can of beer, I tot of spirits (45mL)]

Do you have any allergies? Yes □ No □
Please specify ____
____

Please tell us how you found out about the Women's EXPLORE study. Did you found out from:

- A friend?
  - If yes, what is him/her name?...
- An email list?
  - If yes, what is the name of the email list?..
- At an event?
  - If yes, which event?..
    ....
- Flyer on noticeboard?
  - If yes, where was the noticeboard?
    ………………………………………………………………………………
- Other………………………………………………………………………………..
  ………..……………………………………………………………………………..
  ………………………………………………………………………………………

Appendix 7 Accelerometer information sheet

MASSEY UNIVERSITY

COLLEGE OF HEALTH
TE KURA HAUORA TANGATA

Women's EXPLORE Study

What is an ActiGraph device?

- An ActiGraph device is a motion sensor which measures your movement. It is an expensive piece of equipment so it is important you take good care of it and wear it only as instructed!
- Your ActiGraph device is threaded onto an elastic belt on which it must remain.

How do I wear the ActiGraph device?

- The elastic belt with the ActiGraph device on it should fit firmly around your hips (under your clothes).
- The ActiGraph device can be taken on and off using the clip fastener on the elastic belt.
- The ActiGraph device must be positioned on the **right hand side of your hip**, just above your hip bone and in line with your armpit as shown in Fig 1 and 2.

Correct

Fig 1

Correct

Fig 2

- The ActiGraph device must be worn on the **right hip**, not in the centre of your body as in Fig 3.
- The elastic belt must **not sag or twist** (Fig 2) and must be **FIRM** around your hips (Fig 1).
- Make sure the ActiGraph device is in an upright position and is not tilted as in Fig 4.

Incorrect

Fig 3

In centre of body

Incorrect

Fig 4

Belt too lose and twisted
Device tilted

Incorrect

Fig 5

Too high on waist

Please DO NOT wear the ActiGraph device in an incorrect place or position.
ActiGraph devices worn incorrectly (as in Fig 3, 4 or 5) will NOT work properly.

When do I wear the ActiGraph device?

You need to wear your ActiGraph device for **8 days** ……..

Starting today when you receive the device

Finishing any time after midday on ____

- Please wear the ActiGraph device **ALL THE TIME** (including to bed), except for water based activities like showering or swimming.

- Reposition the ActiGraph device above your right hip first thing in the morning as soon as you wake up and any time during the day when it slips or moves.

- The ActiGraph device may be taken off **ONLY** when doing **water based activities** where it would get completely wet or submerged (e.g., swimming or showering). The device should be worn for other water activities such as kayaking where it won't get completely wet.

- **Remember,** if the ActiGraph device is removed at any time (e.g. swimming, showering):

    - Put it back on as soon as you have finished.
    - Be sure to record in your activity diary when the ActiGraph device was removed and put back on.

- If possible, wear the ActiGraph device under clothing at all times.

- The ActiGraph device must remain on the elastic belt at all times and should be put on and taken off using the clip fastener.

What information do I need to record in the Activity Log?

- We need to know when the ActiGraph was worn and not worn during each day (e.g., taken off for a shower).

- **If the ActiGraph device is taken off,** please note the time when it was removed and replaced and what activity you were doing during that time.

- If you find at any time that the device has moved from its position on your right hip, note the time you corrected it and about when it might have moved (if you have some idea).

- We'd also like to know about any activities you do with the aim of improving your health, fitness or for sport, e.g. if you go for a walk, or to the gym or bike riding. For these activities, record for each day, the time, length of time you did the activity, and the intensity.

If you have any queries, questions or concerns whilst wearing the ActiGraph, please don't hesitate to contact: Wendy O'Brien on 027 276 7796 or w.j.obrien@massey.ac.nz

Appendix 8 Recent Physical Activity Questionnaire

EXPLORE Recent Physical Activity Questionnaire (RPAQ)

1. Introduction

This questionnaire is designed to find out about your physical activity in your everyday life in the past 4 weeks.

The questionnaire is divided into 3 sections.

Please answer every question.

Section A asks about your physical activity patterns in and around the house.
Section B is about travel to work and your activity at work.
Section C asks about recreations that you may have engaged in during the last 4 weeks.

Your answers will be treated as strictly confidential and will be used only for the Massey University Women's EXPLORE study.

*** 1. Please enter your ID number (this is on the front of your Physical Acitivity Diary).**

*** 2. Please enter your name.**

*** 3. Please enter your date of birth.**

	DD		MM		YYYY
Date/Month/Year		/		/	

2. Section A - Home Activities

Getting about

*** 1. Which form of transport have you MOST OFTEN used in the last 4 weeks APART from your journey to and from work?**

- Car/motor vehicle
- Walk
- Public transport
- Cycle

TV, DVD or Video Viewing

*** 2. On average over the last 4 weeks, how many hours per day have you watched TV, DVD or video?**

	None	Less than 1 hour per day	1 to 2 hours per day	2 to 3 hours per day	3 to 4 hours per day	More than 4 hours per day
On a weekday before 6pm						
On a weekday after 6pm						
On a weekend day before 6pm						
On a weekend day after 6pm						

Computer use at HOME but NOT AT WORK (e.g. internet, email, Playstation, Xbox, Gameboy, etc)

EXPLORE Recent Physical Activity Questionnaire (RPAQ)

*** 3. On average over the last 4 weeks, how many hours per day have you used a computer at home?**

	None	Less than 1 hour per day	1 to 2 hours per day	2 to 3 hours per day	3 to 4 hours per day	More than 4 hours per day
On a weekday before 6pm	○	○	○	○	○	○
On a weekday after 6pm	○	○	○	○	○	○
On a weekend day before 6pm	○	○	○	○	○	○
On a weekend day after 6pm	○	○	○	○	○	○

Stair Climbing at home

*** 4. On average over the last 4 weeks, how many times each day have you climbed up a flight of stairs (approx. 10 steps) at home?**

	None	1 to 5 times per day	6 to 10 times per day	11 to 15 times per day	16 to 20 times per day	More than 20 times per day
On a weekday	○	○	○	○	○	○
On a weekend day	○	○	○	○	○	○

3. Section B - Activity at Work

Please answer this section to describe if you have been in paid employment at any time during the last 4 weeks or you have done regular, organised voluntary work.
If you answer 'no' - you will move onto the recreation section.

*** 1. Have you been in employment during the past 4 weeks?**

○ Yes

○ No

4. Section B - Activity at Work (continued)

*** 1. During the last 4 weeks, how many TOTAL hours of work did you do per week (excluding travel)?**

4 weeks ago	
3 weeks ago	
2 weeks ago	
1 week ago	

Type of work
We would like to know the type and amount of physical activity involved in your work.

EXPLORE Recent Physical Activity Questionnaire (RPAQ)

***2. Please choose the option that BEST corresponds with your occupation(s) in the last 4 weeks from the following four possiblities:**

- Sedentary occupation: you spend most of your time sitting (such as in an office)
- Standing occupation: you spend most of your time standing or walking. However, your work does not require intense physical effort. (e.g. shop assistant, hairdresser, guard)
- Manual work: this involves some physical effort including handling heavy objects and use of tools (e.g. plumber, electrician, carpenter)
- Heavy manual work: this implies very vigorous physical activity including handling of very heavy objects (e.g. dock worker, miner, bricklayer, construction worker)

Travel to and from work in the last 4 weeks

***3. What is the approximate distance from your home to your work in kilometres? (e.g. 10.5)**

***4. How many times a week did you travel from home to your main work? (Count outward journeys only)**

***5. How did you normally travel to work?**

	Always	Usually	Occassionally	Never or rarely
By car/motor vehicle				
By works or public transport				
By bicycle				
Walking				

6. Please enter the postcode for your main place of work during the last 4 weeks. If you don't know your post code please go to question 7, otherwise skip to question 8.

7. If you didn't know your work post code, please enter your work address.

***8. What is the postcode of your home address?**

5. Section C - Recreation

The following questions ask about how you spent your leisure time.

Please indicate how often you did each activity on average over the last 4 weeks.

Please indicate the average length of time that you spent doing the activity on each occasion.

EXPLORE Recent Physical Activity Questionnaire (RPAQ)

1. Please indicate the NUMBER OF TIMES you did each activity in the past 4 weeks and the AVERAGE LENGTH OF TIME you spent doing that activity on each of those occasions.

Note: We want to know the AVERAGE TIME you spent doing the activity on EACH OCCASION, not the total time per week, e.g., if you did weeding for 1.5 hours twice a week, you would select '2 to 3 times per week' for the number of times, then '1' for hours and '30' for minutes.

Please answer for EVERY activity. If you DID NOT do an activity, choose 'None' for the number of times.
If you did an activity which doesn't fit into any of those listed below, please list them under the "Other" options and state what they were.

	Number of times in last 4 weeks	Average time per session (hours)	(minutes)
Swimming competitively			
Swimming leisurely			
Hiking or mountain climbing			
Walking for pleasure (not as a means of transport)			
Racing or rough terrain cycling			
Cycling for pleasure (not as a means of transport)			
Mowing the lawn			
Watering the lawn or garden			
Digging, shovelling or chopping wood			
Weeding or pruning			
DIY e.g. carpentry, home or car maintenance			
High impact aerobics or step aerobics			
Other types of aerobics			
Exercise with weights			
Conditioning exercises e.g. using an exercise bike or rowing machine			
Floor exercises e.g. stretching, bending, keep fit or yoga			
Dancing e.g. kapa haka, waiata-a-ringa, lakalaka, hip hop			
Competitive running			
Jogging			
Bowling - indoor, lawn or 10 pin			
Tennis or badminton			
Squash			
Table tennis			
Golf			

EXPLORE Recent Physical Activity Questionnaire (RPAQ)

Football, rugby, hockey, touch			
Cricket or softball/baseball			
Rowing			
Netball, volleyball or basketball			
Fishing			
Horse-riding			
Snooker, billiards or darts			
Musical instrument playing or singing			
Ice skating			
Sailing, wind-surfing or boating			
Martial arts, boxing or wrestling			
Other 1			
Other 2			
Other 3			
Other 4			
Other 5			

2. If you selected "Other" activities above please state what each one was.

Other 1

Other 2

Other 3

Other 4

Other 5