SEDENTARY BEHAVIOUR AND HEATH RISK: IS EXCESSIVE "SCREEN TIME" THE REAL CULPRIT?

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SEDENTARY BEHAVIOUR AND HEALTH RISK: IS EXCESSIVE "SCREEN TIME" THE REAL CULPRIT?

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DEDICATION

This thesis is dedicated to Dr. Jennifer Copeland, whose support and guidance has shaped this thesis (and my academic career) into what it is today.

ABSTRACT

Excessive sedentary behaviour is associated with poor cardiometabolic health and leisure sedentary screen time may pose greater health risk than other sedentary activities. The purpose of this research was to develop a method for quantifying sedentary behaviour that combines device-measured total sedentary time and self-reported sedentary screen time to create the Index of Sedentary Screen Time (ISST). Ninety-one healthy adult volunteers (19-71 years) wore an ActivPAL4^{TM} inclinometer and completed a screen time questionnaire for two separate weeks. Health risk was assessed using 11 different biomarkers of cardiometabolic health. Three different ISST calculation methods were tested, and all showed acceptable test-retest reliability across two weeks. The continuous ISST score was significantly associated with cardiometabolic health risk in this group of healthy adults. This exploratory study demonstrated that the ISST could be useful for identifying individuals at greater cardiometabolic health risk based on their movement behaviours.

PREFACE

H. Dennis and J.L. Copeland conceived and designed the study, and J.L. Copeland provided funding. H. Dennis recruited all participants, as well as collected and analyzed all data. H. Dennis wrote all thesis chapters with editing by J.L. Copeland. N. Patel gave advice on the statistical analyses. All members of the supervisory committee (N. Patel, J.P. Pope, and R. Larouche) gave feedback on the proposal and the thesis.

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LIST OF ABBREVIATIONS

CRP	C-reactive protein
HDL	High-density lipoprotein
HOMA-B	Homeostatic model assessment of β-cell functioning
HOMA-IR	Homeostatic model assessment of insulin resistance
HOMA-S	Homeostatic model assessment of insulin sensitivity
ICC	Intraclass correlation coefficient
ISST	Index of Sedentary Screen Time
LDL	Low-density lipoprotein
TV	Television

CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW

Introduction

Our habitual daily movement behaviours can have a profound impact on long-term health and quality of life. According to the World Health Organization (2020a), an estimated five million deaths worldwide could be prevented annually if people were more physically active. A substantial amount of research has demonstrated the importance of regularly engaging in physical activity to promote optimal health and reduce the risk of certain chronic diseases (Warburton et al., 2006). Additionally, sedentary behaviour has been identified as an important movement behaviour that can pose health risks, even independent of participation in physical activity (Owen et al., 2010). Recent movement behaviour guidelines have recommended limiting time spent in sedentary behaviours in an attempt to minimize this health risk (Canadian Society for Exercise Physiology, 2020; World Health Organization, 2020a).

Sedentary behaviour is defined as any waking activity in a seated or reclined position with low energy expenditure (Tremblay et al., 2017), and includes activities such as reclining on a sofa, driving a car, and sitting while eating a meal. Sedentary behaviour is typically quantified as the number of minutes or hours that an individual spends sedentary, which is called sedentary time (Tremblay et al., 2010). Another aspect of sedentary behaviour that is commonly measured is the number of bouts and frequency of breaks in sedentary time. One sedentary bout is an amount of time that an individual spends continuously in a sedentary posture, and a sedentary break occurs when that individual stands up or ambulates (Tremblay et al., 2010).

Accumulating high amounts of sedentary time is associated with an increased risk of numerous adverse health outcomes in adults, such as cardiovascular disease (Dickins et

al., 2018), metabolic syndrome (Edwardson et al., 2012; Powell et al., 2017), type II diabetes (Patterson et al., 2018), certain types of cancer (Berger et al., 2019; Biswas et al., 2015; Owen et al., 2010), all-cause mortality (Patterson et al., 2018; Zhao et al., 2020), poor mental health (Tully et al., 2020), and poor cognitive functioning (Copeland et al., 2017; Olanrewaju et al., 2020). Additionally, some research suggests that long, uninterrupted bouts of sedentary behaviour may be more detrimental for health than shorter bouts (Owen et al., 2010). Many people in Western society are highly sedentary, therefore understanding and targeting sedentary behaviour as a risk factor for poor health could decrease chronic disease risk and increase health-related quality of life for many people (World Health Organization, 2020a).

Sedentary Behaviour and Cardiometabolic Health Risk

Accumulating high amounts of sedentary time is associated with an increased risk of many adverse health outcomes in adults (Owen et al., 2010), and high sedentary time is specifically associated with an increased risk of poor cardiometabolic health outcomes (Dickins et al., 2018; Edwardson et al., 2012; Patterson et al., 2018; Wilmot et al., 2012; Zhao et al., 2020). Sedentary behaviour has also been found to be detrimentally associated with various biomarkers indicative of cardiometabolic health risk (Brocklebank et al., 2015; Buman et al., 2014; de Rezende et al., 2014; Healy et al., 2011; Powell et al., 2017; Vella et al., 2020; Wirth et al., 2016), and understanding the relationships between sedentary behaviour and cardiometabolic health risk could assist in the development and modification of sedentary behaviour guidelines to promote cardiometabolic health (Canadian Society for Exercise Physiology, 2020; World Health Organization, 2020a). A summary of the identified studies examining sedentary behaviour and cardiometabolic health is shown in Table 1.

Sedentary Time and Chronic Disease Risk

Numerous systematic reviews and meta-analyses have found that accumulating high amounts of sedentary time is positively associated with poor cardiometabolic health. Specifically, sedentary time is associated with the incidence of metabolic syndrome (de Rezende et al., 2014; Edwardson et al., 2012; Marin et al., 2020; Powell et al., 2017), type II diabetes (Biswas et al., 2015; Grøntved & Hu, 2011; Patterson et al., 2018; Wilmot et al., 2012), cardiovascular disease (Dickins et al., 2018; Pandey et al., 2016; Wilmot et al., 2012), and certain types of cancer (Berger et al., 2019; Biswas et al., 2015). Furthermore, high sedentary time is associated with both cause-specific mortality (Biswas et al., 2015; Dickins et al., 2018; Grøntved & Hu, 2011; Patterson et al., 2018; Wilmot et al., 2012; Zhao et al., 2020) and all-cause mortality (Biswas et al., 2015; de Rezende et al., 2014; Grøntved & Hu, 2011; Patterson et al., 2018; Wilmot et al., 2012; Zhao et al., 2020).

Metabolic syndrome is a condition in which an individual exhibits numerous metabolic risk factors, and the requirements for diagnosis include central obesity (high waist circumference) and any two of the following: elevated blood pressure, elevated triglycerides, elevated fasting plasma glucose, or reduced high-density lipoprotein (HDL) cholesterol (Bankoski et al., 2011; Edwardson et al., 2012). Previous research has shown that individuals with metabolic syndrome are at a greater risk of experiencing other adverse health outcomes, such as cardiovascular disease, cardiovascular mortality, type II diabetes, and all-cause mortality (Bankoski et al., 2011; Edwardson et al., 2012). Edwardson et al. (2012) completed a systematic review and a meta-analysis regarding the association between sedentary behaviour and metabolic syndrome in cross-sectional papers, and found that higher sedentary time was associated with a 73% increased risk of metabolic syndrome (Odds Ratio 1.73, 95% Confidence Interval 1.55-1.94) in a large

sample of adults (n = 21,393) between the ages of 18 and 65 years old. The authors noted that sedentary time was self-reported as either television (TV) time, screen time, or sitting time in nine of the 10 included studies, and one study used accelerometer-measured sedentary time (Edwardson et al., 2012). Based on their results, the authors noted that reductions in sitting time could reduce the risk of metabolic syndrome independently of changes in physical activity (Edwardson et al., 2012).

Powell et al. (2017) also completed a systematic review including sedentary behaviour and metabolic syndrome in cross-sectional and prospective papers, and found that objectively measured sedentary behaviour was cross-sectionally associated with an increased risk of metabolic syndrome in a large sample of apparently healthy adults between the ages of 18 and 87 years old. However, the authors noted that the small number of identified prospective studies reported no association between baseline sedentary behaviour and the development of metabolic syndrome at follow-up (Powell et al., 2017). This finding could reflect the different devices used to measure sedentary behaviour, or the various sedentary behaviour accumulation patterns that the participants engaged in such as prolonged bouts (Farrahi et al., 2021) or different types of activities completed while sedentary. Additionally, de Rezende et al. (2014) completed a systematic review involving sedentary behaviour and metabolic syndrome in cross-sectional, prospective cohort, and case-control papers, and found that self-reported sedentary time was detrimentally associated with metabolic syndrome in older adults (above the age of 60 years). Overall, sedentary time appears to be positively associated with the incidence of metabolic syndrome in adults of all ages, especially in older adults.

Type II diabetes is a condition in which the body's ability to manage blood glucose levels is compromised due to the body's muscle and liver cells developing a

resistance to insulin, which can lead to subsequent liver fat accumulation and pancreatic β-cell dysfunction (Taylor, 2013). Chronically elevated blood glucose levels (hyperglycemia) results in an increased risk of developing other health complications, such as cardiovascular disease (Imazu et al., 2002), chronic kidney disease (Adua et al., 2018), and diabetic neuropathy (Feldman et al., 2019). Wilmot et al. (2012) completed a systematic review and meta-analysis involving sedentary time and type II diabetes, cardiovascular disease, and death, and found that greater self-reported sedentary time was associated with a 112% increase (Risk Ratio 2.12; 95% Confidence Interval 1.61-2.78) in the incidence of type II diabetes in a large sample (n = 70,576) of apparently healthy adults (over the age of 18 years). The authors noted that this relationship was found in both cross-sectional and prospective papers, and that the association between sedentary time and type II diabetes had a significant Bayesian predictive effect and interval (Wilmot et al., 2012). This means that this association was not only stronger than the association between sedentary behaviour and mortality outcomes in this study, but that these findings are predictive of future events as well (Wilmot et al., 2012). Patterson et al. (2018) completed a similar systematic review and meta-analysis of prospective studies, and found that both total sedentary time and TV viewing time were associated with an increased risk of type II diabetes in a large sample (n = 1,331,468) of adults. The authors noted that all of the included studies used self-reported measures of sedentary time or TV viewing time except for Ensrud et al. (2014), Fox et al. (2015), and Schmid et al. (2015). Ensrud et al. (2014) and Schmid et al. (2015) did not directly examine incidence of type II diabetes, but Fox et al. (2015) examined the association between accelerometer-measured sedentary time and type II diabetes and found that this relationship was statistically

significant in older adults (Fox et al., 2015). Overall, sedentary time appears to be positively associated with the incidence of type II diabetes in adults.

Cardiovascular disease is a broad category that encompasses numerous specific events or diagnoses, such as coronary artery disease, cerebrovascular disease, and myocardial infarction (Pandey et al., 2016; World Health Organization, 2017). Cardiovascular disease is currently one of the leading causes of mortality worldwide (Dickins et al., 2018; World Health Organization, 2017), and cardiovascular events that are non-fatal can result in substantial health consequences (World Health Organization, 2017) and reduced health-related quality of life (Ski & Thompson, 2010). Dickins et al. (2018) completed a review of reviews and found that sedentary time was positively associated with cardiovascular events, cardiovascular disease incidence, and cardiovascular mortality in adults. More specifically, Biswas et al. (2015) completed a systematic review and meta-analysis of prospective, cross-sectional, and case-control studies, and found that self-reported sedentary time was associated with a 14.3% increased risk of cardiovascular disease (Hazard Ratio 1.143, 95% Confidence Interval 1.002-1.729) and a 17.9% increased risk of cardiovascular mortality (Hazard Ratio 1.179, 95% Confidence Interval 1.106-1.257) in adults independently of the amount of physical activity they completed. Pandey et al. (2016) also completed a meta-analysis involving prospective studies, and found that high self-reported sedentary time increased the risk of adverse cardiovascular events by 14% (Hazard Ratio 1.14, 95% Confidence Interval 1.09-1.19) in a large sample of adults (n = 720,425) independently of physical activity participation, but that the observed relationship was not linear. Overall, high amounts of sedentary time appear to be detrimentally associated with the risk of cardiovascular disease and cardiovascular mortality in adults.

Cancer is characterized by certain cells growing and dividing at an abnormal rate, which can result in a localized tumor and in the spreading of cancer cells to other areas of the body (World Health Organization, 2021). Cancer is one of the leading causes of mortality worldwide (Barros et al., 2016; World Health Organization, 2021), and some research suggests that up to half of all cancer deaths are related to unhealthy lifestyle factors such as insufficient physical activity, smoking, and poor dietary habits (Barros et al., 2016). Recent research has also shown a detrimental association between high amounts of sedentary time and certain types of cancer, such that sedentary time is positively associated with the incidence of colon, colorectal, endometrial, breast, and epithelial ovarian cancer (Biswas et al., 2015) and with cancer mortality (Biswas et al., 2015; Patterson et al., 2018; Zhao et al., 2020). Biswas et al. (2015) completed a systematic review and meta-analysis of prospective, cross-sectional, and case-control papers, and found that high amounts of self-reported sedentary time was associated with a 13% increase in risk of cancer incidence (Hazard Ratio 1.130, 95% Confidence Interval 1.052-1.213) and a 17.3% increase in risk of cancer mortality (Hazard Ratio 1.173, 95% Confidence Interval 1.108-1.242) in adults. In contrast, Berger et al. (2019) completed a systematic review and meta-analysis of prospective cohort papers examining prostate cancer incidence, and found that self-reported sedentary time was not significantly associated with prostate cancer in a large sample of male adults. However, overall cancer risk and cancer mortality appears to be increased in individuals who accumulate excessive amounts of sedentary time.

Similarly to the increased risk of cause-specific mortality associated with high amounts of sedentary time, all-cause mortality also appears to be detrimentally associated with excessive sedentary behaviour. Biswas et al. (2015) reported that all-cause mortality

risk was 24% higher in adult participants with higher self-reported sedentary time in their meta-analysis of 13 studies (Hazard Ratio 1.240, 95% Confidence Interval 1.090-1.410), and de Rezende et al. (2014) reported that all-cause mortality was positively associated with self-reported sedentary time in older adults specifically (over the age of 60 years) in their systematic review of 24 articles. Patterson et al. (2018) reported that both device-measured and self-reported sedentary time were significantly detrimentally associated with all-cause mortality in a large prospective sample of adults (n = 1,331,468), and Wilmot et al. (2012) reported that self-reported sedentary time was positively associated with all-cause mortality in adults. Furthermore, in addition to the relationships between sedentary time and individual chronic diseases or mortality risk, the combination of high sedentary time and pre-existing chronic diseases may be more detrimental for future mortality risk than high sedentary time alone (Zhao et al., 2020). Zhao et al. (2020) completed a systematic review and meta-analysis of prospective cohort papers, and found that the combination of high amounts of self-reported sedentary time with the pre-existing chronic conditions of diabetes, hypertension, or a high body mass index appeared to be more detrimental for all-cause mortality risk than high amounts of sedentary behaviour alone.

Although high sedentary time is associated with an increased risk of numerous cardiometabolic diseases and all-cause mortality, the authors of many of these reviews noted that most or all of the articles that met the inclusion criteria for their reviews used self-reported measures of total sedentary time, TV viewing time, sitting time, or leisure-time sedentary time, which are vulnerable to biases such as recall and social desirability biases and therefore may be less accurate than device-measured sedentary time (Berger et al., 2019; Biswas et al., 2015; de Rezende et al., 2014; Dickins et al., 2018; Edwardson et

al., 2012; Grøntved & Hu, 2011; Patterson et al., 2018; Wilmot et al., 2012; Zhao et al., 2020). Thus, future research using device-based measures of sedentary time is needed to confirm these findings in large samples of adults of all ages.

Sedentary Time and Cardiometabolic Risk Biomarkers

In addition to associations with numerous chronic diseases, excessive amounts of time spent engaging in sedentary behaviours is detrimentally associated with several biomarkers indicative of cardiometabolic health risk (Biswas et al., 2015; Brocklebank et al., 2015; Buman et al., 2014; de Rezende et al., 2014; Healy et al., 2011; Powell et al., 2017; Wirth et al., 2016). Specifically, numerous systematic reviews and meta-analyses have found that sedentary time is detrimentally associated with C-reactive protein (CRP) concentrations (Chastin et al., 2015; de Rezende et al., 2014; Healy et al., 2011), HDL cholesterol (Healy et al., 2011; Powell et al., 2017), triglycerides (Brocklebank et al., 2015; Powell et al., 2017), glycosylated hemoglobin (Wirth et al., 2016), fasting blood insulin (Brocklebank et al., 2015; Buman et al., 2014; Healy et al., 2011; Powell et al., 2017), homeostatic models of insulin sensitivity (Brocklebank et al., 2015; Buman et al., 2014; Healy et al., 2011; Wirth et al., 2016), and waist circumference (de Rezende et al., 2014; Healy et al., 2011; Powell et al., 2017; Wirth et al., 2016). Additionally, sedentary time was found to be detrimentally associated with postprandial blood glucose in a recent randomized controlled trial (Yates et al., 2020). In contrast, the biomarkers of body mass index (Biddle et al., 2017), resting blood pressure (de Rezende et al., 2014; Healy et al., 2011; Powell et al., 2017; Wirth et al., 2016), and fasting blood glucose (Brocklebank et al., 2015; Buman et al., 2014; Wirth et al., 2016) were not consistently associated with sedentary time according to the current literature.

CRP is a plasma protein that is part of the inane immune system, and can be used as an indicator of systemic inflammation (Beavers et al., 2010; Pepys & Hirschfield, 2003; Truba et al., 2018). Prolonged low-grade inflammation is associated with an increased risk of diabetes, cardiovascular disease, atherosclerosis, osteoarthritis, and dementia (Beavers et al., 2010; Palmefors et al., 2014), and higher CRP concentrations have been specifically linked with cardiovascular disease incidence and severity (Pepys & Hirschfield, 2003). Sedentary time has been shown to be positively associated with CRP concentrations in adults in most studies (Chastin et al., 2015; de Rezende et al., 2014; Healy et al., 2011), but not in all studies (Buman et al., 2014; Wirth et al., 2016). Additionally, even short-term changes in sedentary behaviour appear to be detrimentally associated with changes in CRP concentrations, such that increasing sedentary time for 10 days was associated with a 31% average increase in salivary CRP concentrations in healthy middle-aged women (Truba et al., 2018). Thus, this association between sedentary time and CRP concentrations could contribute to the association between sedentary time and cardiovascular disease risk.

Cholesterol is typically measured as the concentration of HDL cholesterol, low-density lipoprotein (LDL) cholesterol, or total cholesterol in the blood, and is involved in the body's delivery of lipids (Heart and Stroke Foundation of Canada, n.d.). Having low HDL cholesterol or high LDL cholesterol is associated with an increased risk of cardiovascular disease, and specifically associated with an increased risk of coronary artery disease and atherosclerosis (Bastianelli et al., 2017; He et al., 2013; Sirtori & Fumagalli, 2006). Several studies have reported significant detrimental associations between sedentary behaviour and HDL concentrations in adults of all ages, such that higher sedentary time was associated with lower HDL concentrations (Healy et al., 2011;

Powell et al., 2017). However, other studies have reported no consistent association between sedentary behaviour and HDL concentrations in adults of all ages (Brocklebank et al., 2015; Buman et al., 2014) and older adults (de Rezende et al., 2014; Wirth et al., 2016), no consistent association with LDL concentrations in adults of all ages (Brocklebank et al., 2015; Buman et al., 2014; Powell et al., 2017), and no consistent association with total cholesterol concentrations in adults of all ages (Brocklebank et al., 2015; Powell et al., 2017) and older adults (de Rezende et al., 2014; Wirth et al., 2016). Thus, there may not be a relationship between sedentary behaviour and LDL or total cholesterol concentrations in adults, but sedentary behaviour may have a relationship with HDL cholesterol concentrations in adults.

Triglycerides are another type of circulating lipid found in the blood, and triglycerides function as a substrate for energy production inside the body's cells through the process of β-oxidation (Bastin, 2014). High concentrations of blood triglycerides are detrimental for cardiometabolic health, such that high blood triglycerides are associated with an increased incidence of cardiovascular disease, coronary artery disease, cerebrovascular disease, myocardial infarction, and atherosclerosis (Peng et al., 2017). Numerous studies have found that high accelerometer-measured sedentary time is associated with high blood triglycerides in adults (Brocklebank et al., 2015; Buman et al., 2014; Healy et al., 2011), and one systematic review found that high sedentary time measured using accelerometers, inclinometers, or sitting pads was also associated with high blood triglycerides in adults (Powell et al., 2017). In contrast, de Rezende et al. (2014) completed a systematic review of cross-sectional, prospective cohort, and case-control papers, and found that self-reported sedentary time was not significantly associated with blood triglycerides in older adults (over the age of 60 years). Overall,

sedentary time appears to be associated with blood triglycerides in young and middle-aged adults, but this association may not be present in older adults. However, it is possible that the apparent difference in findings between these age groups is due to the use of self-reported sedentary time instead of device-measured sedentary time in older adults.

In addition to triglycerides, glucose is the other main source of energy in the body and is primarily converted into energy through the process of cellular respiration, which begins with aerobic glycolysis (Feldman et al., 2019). Individuals with fasting blood glucose concentrations between 6.1 mmol/L and 6.9 mmol/L are classified as having prediabetes, and with fasting blood glucose concentrations above 7.0 mmol/L as having type I or type II diabetes (Punthakee et al., 2018). Although sedentary time appears to be positively associated with the incidence of type II diabetes (as previously mentioned), numerous studies have found that device-measured sedentary time is not associated with blood glucose concentrations in adults (Brocklebank et al., 2015; Buman et al., 2014; Cooper et al., 2011; Healy et al., 2011; Vella et al., 2020) or in community-dwelling older adults (Wirth et al., 2016). In contrast, Powell et al. (2017) found that device-measured sedentary time was significantly detrimentally associated with fasting blood glucose in a large sample of adults of all ages (n = 70,576), and Whitaker et al. (2018) found that accelerometer-measured sedentary time was detrimentally associated with fasting blood glucose in adults aged 18-30 years at baseline. Similarly, Marin et al. (2020) found that self-reported or device-measured sedentary time was detrimentally associated with fasting blood glucose in South American adults.

Several randomized controlled trials have also been completed investigating the effects of sedentary behaviour on postprandial blood glucose concentrations, and Yates et

al. (2020) found that sitting with regular walking breaks was beneficially associated with postprandial blood glucose concentrations in older adults compared to prolonged sitting or sitting with regular standing breaks. In contrast, Hawari et al. (2016) found that there were no significant differences in postprandial blood glucose concentrations when adult overweight normoglycemic men participated in prolonged sitting, prolonged standing, or intermittent standing conditions. Based on these two studies, movement might be needed in order to reduce the acute effects of sedentary time on postprandial blood glucose concentrations, as only standing does not appear to be sufficient. Overall, the current literature is unclear regarding the potential association between sedentary time and blood glucose concentrations.

Although many studies measure instantaneous blood glucose concentrations, a way to retrospectively measure the body's blood glucose control is by measuring the percentage of glycosylated hemoglobin present. Glycosylated hemoglobin is formed non-enzymatically in the blood when glucose molecules are slowly and irreversibly bonded to hemoglobin molecules (O'Sullivan et al., 2006), and the percentage of glycosylated hemoglobin present is an indication of that individual's mean blood glucose concentrations over the previous two to three months (O'Sullivan et al., 2006; Strauss et al., 2014). A glycosylated hemoglobin value greater than 6% for non-diabetic individuals or greater than 7% for diabetic individuals is considered a reflection of poor glycaemic control in the recent past (Cavero-Redondo et al., 2018; O'Sullivan et al., 2006). While poor glycaemic control is generally a risk factor for adverse health outcomes, glycosylated hemoglobin specifically is associated with cardiovascular events, atherosclerosis (O'Sullivan et al., 2006), cardiovascular mortality, and all-cause mortality in non-diabetic populations (Cavero-Redondo et al., 2018), and is associated with

microvascular and macrovascular complications in diabetic populations (Cavero-Redondo et al., 2018; O'Sullivan et al., 2006). Furthermore, glycosylated hemoglobin has been shown to predict cardiovascular events better than some measures of instantaneous blood glucose (Punthakee et al., 2018). Regarding sedentary time, Wirth et al. (2016) found that there was a significant association between device-measured or self-reported sedentary time and glycosylated hemoglobin in community-dwelling older adults, but de Rezende et al. (2014) found that there was no association between device-measured or self-reported sedentary time and glycosylated hemoglobin in a general sample of older adults (over the age of 60 years). Similarly, Powell et al. (2017) found no association between device-measured sedentary time and glycosylated hemoglobin in a large sample of apparently healthy adults aged 18-87 years, and Marin et al. (2020) found that there was no association between device-measured or self-reported sedentary time and glycosylated hemoglobin in South American adults. Thus, it appears that glycosylated hemoglobin may not be associated with sedentary time in adults with the exception of community-dwelling older adults.

Insulin is a hormone secreted into the blood by β-cells in the pancreas in response to high blood glucose concentrations, and causes the uptake of glucose into the body's skeletal muscle and liver cells (Taylor, 2013). Thus, blood insulin concentrations and homeostatic models of insulin sensitivity are measures of the body's response to changes in blood glucose concentrations, and can indicate how effectively and efficiently the body is able to manage blood glucose concentrations (Taylor, 2013). Taylor (2013) noted that high fasting blood insulin concentrations precede the development of type II diabetes, even when simultaneous fasting blood glucose levels are still within the normal range. Wilmot et al. (2012) noted that postprandial insulin and glucose can be negatively

impacted by as little as one day of prolonged sitting, but that periodically interrupting sitting with light-intensity physical activity can reduce this harmful effect in overweight or obese adults. Furthermore, numerous studies have found that device-measured sedentary time is detrimentally associated with blood insulin concentrations in adults (Brocklebank et al., 2015; Buman et al., 2014; Healy et al., 2011; Powell et al., 2017). However, Wirth et al. (2016) found that there was no significant association between self-reported or device-measured sedentary time and blood insulin concentrations in community-dwelling older adults. In addition to measuring blood insulin concentrations, several models have been developed to assess aspects of glucose homeostasis (Taylor, 2013). These models include the homeostatic model assessment of β-cell functioning (HOMA-B), the homeostatic model assessment of insulin resistance (HOMA-IR), and the homeostatic model assessment of insulin sensitivity (HOMA-S). Numerous studies have found that device-measured sedentary time is detrimentally associated with HOMA-B (Buman et al., 2014; Healy et al., 2011), HOMA-IR (Brocklebank et al., 2015; Cooper et al., 2011; Marin et al., 2020; Wirth et al., 2016), and HOMA-S (Buman et al., 2014; Healy et al., 2011) in adults of all ages. Overall, sedentary time appears to be adversely associated with blood insulin concentrations and with models of β-cell functioning, insulin resistance, and insulin sensitivity.

Waist circumference is typically used in research and health screening as an indication of abdominal adiposity, and is a better predictor of chronic disease risk than body mass index (Seo et al., 2016). Numerous systematic reviews and meta-analyses have found that sedentary time is positively correlated with waist circumference in adults of all ages and specifically in older adults, such that individuals who engaged in higher amounts of self-reported or device-measured sedentary time also had higher waist circumferences

(de Rezende et al., 2014; Healy et al., 2011; Powell et al., 2017; Wirth et al., 2016). In contrast, Buman et al. (2014) found that device-measured sedentary time was not associated with waist circumference in a sample of 923 adults over the age of 19 years from the National Health and Nutrition Examination Survey (NHANES). However, this conflicting result could be partly due to differences in sample populations between studies. Specifically, while Healy et al. (2011) and Powell et al. (2017) examined young and middle-aged adults, de Rezende et al. (2014) and Wirth et al. (2016) examined sedentary time and waist circumference in older adults. These differences in the literature show that the potential relationship between waist circumference and sedentary time is not fully clear at this time, but that waist circumference and sedentary time may be correlated.

In addition to waist circumference, higher body mass index values are commonly used as a measure of excess adiposity which can lead to greater health risk (Seo et al., 2016). Body mass index is calculated using a person's weight and height, and while it would be expected that a high body mass index would be associated with engaging in high amounts of sedentary behaviour, some research suggests that this may not be accurate. Biddle et al. (2017) completed a review of reviews regarding sedentary time and measures of adiposity or weight status, and found that self-reported sedentary time was not consistently associated with obesity, high body mass index, or other measures of excess adiposity in adults over the age of 18 years. Similarly, other systematic reviews have found that device-measured or self-reported sedentary time is not consistently associated with body mass index in adults of all ages (Powell et al., 2017) or in community-dwelling older adults (Wirth et al., 2016). In contrast, de Rezende et al. (2014) found that sedentary time was positively associated with body mass index in older

adults, and Vella et al. (2020) found that higher sedentary time was associated with higher body mass index in college students (aged 18-25 years). However, much of the current research regarding the association between sedentary time and body mass index is cross-sectional, therefore the directionality of this association has been debated (Rhodes et al., 2012). Berger et al. (2019) noted that obesity in adulthood predicted future sedentary behaviour, but that accumulating excessive amounts of sedentary behaviour in childhood or adolescence predicted excess adiposity and obesity in adulthood. Similarly, Rhodes et al. (2012) noted that a previous study reported that variables related to body weight were associated with future sedentary behaviour, but that past sedentary behaviour was not associated with future changes to body weight.

Body mass index may also play an important mediating role in the relationship between sedentary time and the development of certain chronic diseases. Zhao et al. (2020) found that the combination of high self-reported sedentary time and a high body mass index was more strongly associated with all-cause and cause-specific mortality risk in adults of all ages compared to sedentary time alone. Similarly, Berger et al. (2019) found that high self-reported sedentary time and a high body mass index was significantly associated with an increased risk of aggressive prostate cancer in numerous prospective cohort studies, even though sedentary time alone was not significantly associated with prostate cancer risk. Thus, while body mass index may or may not be directly associated with sedentary time, it appears to have an important role in the relationship between sedentary behaviour and health risk.

Hypertension is categorized as a resting systolic blood pressure greater than 140 mmHg or a resting diastolic blood pressure greater than 90 mmHg (Poulter et al., 2015). Untreated hypertension is associated with an increased risk of adverse health

consequences, such as chronic kidney disease, coronary artery disease, and cerebrovascular disease (Adua et al., 2018; Poulter et al., 2015). Additionally, blood pressure has consistently been found to be linearly associated with the risk of cardiovascular events, even at prehypertensive levels (Chobanian et al., 2003). Wirth et al. (2016) and de Rezende et al. (2014) found that sedentary time was not significantly associated with resting systolic or diastolic blood pressure in older adults, and both Healy et al. (2011) and Powell et al. (2017) found a similar lack of association between device-measured sedentary time and resting blood pressure in adults of all ages. Surprisingly, Buman et al. (2014) found that replacing 30 minutes per day of sedentary time with light-intensity physical activity (using isotemporal substitution modelling) was associated with an increase in both resting systolic and diastolic blood pressure in adults of all ages, which would be considered harmful to health. While there does not appear to be a cross-sectional association between sedentary behaviour and resting blood pressure, Yates et al. (2020) found that walking breaks were beneficial for postprandial systolic and diastolic blood pressures in older adults when compared to prolonged sitting. Thus, there may not be a straightforward relationship between sedentary behaviour and resting blood pressure.

Overall, sedentary time appears to be detrimentally associated with numerous key risk factors for poor cardiometabolic health, and there are some key areas that require additional research. Further research is needed to confirm the preliminary findings of the detrimental association between HDL cholesterol and sedentary behaviour in adults (ages 18-65 years), and to determine if there is a relationship between sedentary behaviour and HDL cholesterol concentrations in older adults. Studies examining the use of device-measured sedentary time and blood triglycerides in older adults specifically are needed to determine possible reasons (such as measurement method) for the lack of association in

this specific population but not other similar populations. While the current literature is mixed regarding the potential associations between sedentary time, blood glucose concentrations, and glycosylated hemoglobin, further cross-sectional, prospective, and randomized control trial studies are needed to confirm these findings. However, as previously stated, blood glucose measures can appear normal in the presence of elevated fasting blood insulin levels (which precedes the development of type II diabetes), therefore future studies could focus on measuring fasting insulin concentrations instead of only including measures of blood glucose control. Given the conflicting results for the potential association between waist circumference and sedentary time, further research is needed to determine if waist circumference is consistently associated with sedentary time in young and middle-aged adults. Similarly, body mass index may or may not be directly associated with sedentary time, but current findings necessitate further research in this area to examine the role of body mass index in the relationship between health risk and sedentary behaviour. Resting blood pressure and sedentary behaviour may not exhibit a straightforward relationship, and more research is needed to confirm these findings.

In addition to clarifying the findings of previous research, further research exploring the relationships between sedentary time and the cardiometabolic risk factors of circulating CRP concentrations, cholesterol, triglycerides, glucose, glycosylated hemoglobin, and insulin, as well as waist circumference, body mass index, and blood pressure, could provide valuable insights into the pathways by which accumulating high amounts of sedentary time throughout the lifespan affects cardiometabolic disease incidence. This knowledge could be used to inform future public policy decisions regarding the prevention and management of certain chronic diseases, and could be helpful in the development and modification of movement behaviour recommendations

which could reduce healthcare costs due to cardiometabolic diseases (Poulter et al., 2015; Taylor, 2013) and could increase many people's health-related quality of life.

Sedentary Breaks and Cardiometabolic Health Risk

In addition to the previously mentioned research involving the relationship between sedentary time and cardiometabolic health risk, some research has examined the association between sedentary breaks and cardiometabolic health risk (Chastin et al., 2015; Dempsey, Biddle, et al., 2020; Loh et al., 2020). While many cross-sectional studies have shown mixed or inconclusive findings for this potential relationship (Chastin et al., 2015; Cooper et al., 2011; Healy et al., 2011; Owen et al., 2010), recent randomized controlled trials have found that certain types of sedentary breaks may be beneficially associated with postprandial glucose, insulin, and triglycerides (Hawari et al., 2016; Loh et al., 2020; Yates et al., 2020). Cross-sectional studies using device-based measures of sedentary breaks typically do not distinguish between the type of activity completed during a sedentary break (i.e. standing or ambulating), therefore direct comparisons between these types of cross-sectional studies and experimental studies cannot be made (Loh et al., 2020).

Cross-sectional Studies

There is a growing body of literature investigating the cross-sectional associations between device-measured sedentary breaks and cardiometabolic health risk. As previously mentioned, sedentary breaks are defined as an interruption of sedentary behaviour (Tremblay et al., 2010), and the number, frequency, and duration of sedentary breaks can be measured using devices such as accelerometers or inclinometers (Chastin et al., 2018; Tremblay et al., 2010). The daily average number and duration of sedentary breaks can be determined using several days of device wear-time, and the average length

and number of sedentary bouts can also be measured. Limited cross-sectional studies have been completed regarding device-measured sedentary breaks and cardiometabolic disease risk, but some research suggests that the number of daily sedentary breaks is negatively associated with the incidence of type II diabetes in middle-aged adults (Huang et al., 2021), but is not associated with metabolic syndrome in middle-aged adults (van der Berg et al., 2016) or all-cause mortality in older adult men (Jefferis et al., 2019). However, Bankoski et al. (2011) found that the number of sedentary breaks was associated with metabolic syndrome in their sample of older adults, such that participants with metabolic syndrome had a lower daily average number of sedentary breaks than participants without metabolic syndrome. Bankoski et al. (2011) also noted that participants with metabolic syndrome had a longer average duration of sedentary bouts, meaning that they engaged in more prolonged sedentary behaviour. In contrast, van der Berg et al. (2016) reported that neither the number of sedentary breaks nor the length of sedentary bouts was associated with the incidence of type II diabetes or metabolic syndrome in their sample of middle-aged adults. However, cross-sectional studies are not able to determine the causality or directionality of these potential associations.

In comparison to the paucity of research regarding sedentary breaks and the incidence of cardiometabolic diseases, substantially more research has been published regarding device-measured sedentary breaks and cardiometabolic risk biomarkers. A greater daily average number of sedentary breaks in adults has been found to be cross-sectionally associated with lower CRP (Chastin et al., 2015; Healy et al., 2011; Zheng et al., 2020), triglycerides (Aho et al., 2021; Brocklebank et al., 2015; Farrahi et al., 2021), glycosylated hemoglobin (Huang et al., 2021), postprandial insulin (Farrahi et al., 2021), body mass index (Chastin et al., 2015; Farrahi et al., 2021; Huang et al., 2021), and blood

pressure (Garcia-Hermoso et al., 2015). A greater number of sedentary breaks has also been found to be associated with higher HDL cholesterol in women, but not men (Aho et al., 2021; Healy et al., 2011). In contrast, some research suggests that the number of sedentary breaks in adults are not associated with LDL cholesterol (Aho et al., 2021; Brocklebank et al., 2015; Farrahi et al., 2021; Zheng et al., 2020), total cholesterol (Aho et al., 2021; Farrahi et al., 2021; Zheng et al., 2020), insulin sensitivity (Brocklebank et al., 2015), or HOMA-IR (Brocklebank et al., 2015; Cooper et al., 2011; Zheng et al., 2020). The current literature is inconsistent regarding the potential associations between the number of sedentary breaks in adults and fasting blood glucose (Brocklebank et al., 2015; Cooper et al., 2011; Farrahi et al., 2021; Healy et al., 2011), postprandial blood glucose (Brocklebank et al., 2015; Chastin et al., 2015; Farrahi et al., 2021), fasting insulin (Brocklebank et al., 2015; Cooper et al., 2011; Farrahi et al., 2021; Zheng et al., 2020), and waist circumference (Chastin et al., 2015; Cooper et al., 2011; Dempsey, Biddle, et al., 2020; Farrahi et al., 2021; Healy et al., 2011).

Diaz et al. (2017) reported that mean sedentary bout length was associated with HOMA-IR and postprandial glucose, but not glycosylated hemoglobin, in their sample of Hispanic/Latino adults. In contrast, Zheng et al. (2020) found that sedentary bout length was not associated with CRP, triglycerides, total cholesterol, HDL cholesterol, LDL cholesterol, or insulin in their sample of Chinese young adult males. Thus, it is currently unclear if the specific frequency and duration of sedentary breaks is associated with cardiometabolic health risk biomarkers.

Experimental Studies

While cross-sectional studies have primarily examined the device-measured number of sedentary breaks under free-living conditions, recent experimental and quasi-

experimental studies have further expanded the current understanding of the effects of different numbers, frequencies, durations, and types of sedentary breaks on cardiometabolic health risk (Whipple et al., 2021). Although a sedentary break can include any type of non-sedentary activity, various randomized controlled trials have explored whether different types and intensities of activities have unique effects on cardiometabolic health (Loh et al., 2020; Whipple et al., 2021). For example, sedentary breaks can include standing, resistance training, or various intensities of ambulating, such as light, moderate, or vigorous intensity (Loh et al., 2020).

Several review articles have been published regarding the effects of various ways of breaking up prolonged bouts of sedentary behaviour in a laboratory setting (Chastin et al., 2015; Loh et al., 2020; Saunders, Atkinson, et al., 2018; Whipple et al., 2021). Chastin et al. (2015) completed a systematic review and meta-analysis on sedentary breaks, and included randomized controlled trials of breaking up prolonged sedentary behaviour. The authors noted that previous randomized controlled trials found that one prolonged bout of physical activity was less effective than frequent shorter bouts at reducing blood glucose, but had results of comparable effectiveness for blood lipids and insulin concentrations. However, Chastin et al. (2015) also mentioned that this finding might reflect the benefits of increasing light-intensity physical activity instead of the benefits of breaking up long, uninterrupted bouts of sedentary time. This is supported by the finding that breaking up sedentary time with standing time did not appear to have the same beneficial effects on biomarkers of cardiometabolic health as was exhibited by breaking up sedentary time with light-intensity physical activity (Chastin et al., 2015).

More recently, Loh et al. (2020) completed a systematic review and meta-analysis of studies investigating the differences in postprandial glucose, insulin, and triglyceride

concentrations when participants were engaged in prolonged sitting versus sitting with intermittent physical activity breaks of any intensity. The authors found that intermittent physical activity breaks resulted in lower postprandial glucose, insulin, and triglyceride concentrations than prolonged sitting in adults (over the age of 17 years), which suggests that these breaks could be beneficial for long-term cardiometabolic health. The authors also found that the beneficial effects of physical activity breaks on measures of insulin and glucose were greater in individuals with a higher body mass index, which suggests that people with a high body mass index might benefit even more in terms of reduced cardiometabolic health risk from intervention strategies involving physical activity breaks than people without a high body mass index. Based on their findings, Loh et al. (2020) noted that incorporating physical activity breaks throughout the day might assist in the prevention of atherosclerosis and type II diabetes, especially in people with a higher body mass index or in people who are unable to meet the current physical activity guidelines through one continuous bout of physical activity. However, the authors noted that current cross-sectional and experimental evidence is inconsistent regarding whether intermittent physical activity is equally or more beneficial than one continuous bout of physical activity for postprandial insulin, glucose, or triglycerides when the two conditions are matched for energy expenditure (Loh et al., 2020).

Saunders, Atkinson, et al. (2018) completed a similar systematic review and meta-analysis as Loh et al. (2020), but their sample population included healthy people of all ages. In their systematic review, the Saunders, Atkinson, et al. (2018) found that breaking up sedentary time with short bouts of physical activity (less than 10 minutes in duration) was associated with lower postprandial blood glucose and insulin, but was not consistently associated with same-day postprandial blood triglycerides, when compared to

prolonged sitting. However, the authors also found that breaking up sedentary time with short bouts of physical activity was associated with lower blood triglycerides when measured the day following the intervention when compared to prolonged sitting. While physical activity can have rapid effects on blood glucose and insulin, it can require approximately 24 hours for physical activity to exhibit a beneficial effect on triglycerides (Saunders, Atkinson, et al., 2018). Thus, single-day study designs may not fully capture the effects of intermittent physical activity breaks on triglycerides. In their meta-analysis, Saunders, Atkinson, et al. (2018) completed a subgroup analysis on the intensity of physical activity completed during a sedentary break, and found that light and moderate intensity physical activity did not have statistically different effects on postprandial blood glucose, insulin, or triglycerides. However, the authors noted that they had limited statistical power for this subgroup analysis due to the small number of studies available (Saunders, Atkinson, et al., 2018).

Loh et al. (2020) included studies that examined breaks in sedentary behaviour that involved physical activity, but excluded studies that only examined the effects of standing breaks. This was because standing breaks have not been shown to substantially increase energy expenditure compared to sitting or other sedentary postures, and because standing may result in greater leg muscle activity in individuals who are overweight or obese compared to individuals at a normal bodyweight (Loh et al., 2020). However, Hawari et al. (2016) explored the effects of standing breaks by completing a randomized controlled trial on normoglycemic overweight or obese men with three experimental conditions: prolonged sitting, sitting with prolonged standing breaks, and sitting with intermittent standing breaks. The authors found that interrupting sitting more frequently resulted in significantly greater increases in fat oxidation and overall energy expenditure

than interrupting sitting less frequently, even though the total time spent standing and sitting were equal in both the prolonged standing and intermittent standing conditions. Although the results of this study suggest that frequently interrupting prolonged sitting by intermittent standing breaks may be beneficial for energy expenditure, Hawari et al. (2016) noted that their intermittent standing condition was unlikely to be feasible for real-world application because it involved changing body postures every few minutes. In addition to the findings of Hawari et al. (2016), Yates et al. (2020) completed a similar randomized controlled trial in older adults with three experimental conditions: prolonged sitting, sitting with periodic standing breaks, and sitting with periodic walking breaks. The authors found that while periodic standing breaks were not clinically beneficial for postprandial triglycerides, glucose, insulin, or blood pressure, periodic walking breaks had significant beneficial effects on these same variables (except for postprandial triglycerides). However, the current evidence is still insufficient to allow for specific guidelines regarding the use of standing breaks to reduce cardiometabolic health risk (Loh et al., 2020).

Whipple et al. (2021) also examined the effects of standing breaks and physical activity breaks of various intensities. The authors completed a systematic review of experimental and quasi-experimental research regarding the cardiovascular health effects of interventions to break up prolonged sedentary behaviour, and specifically examined this effect in adults who had type II diabetes or were at an elevated risk of developing type II diabetes. Whipple et al. (2021) found that while standing breaks were not consistently associated with any of the assessed measures of cardiovascular health, sedentary breaks of light or moderate intensity physical activity were associated with acutely lower systolic and diastolic blood pressure values when compared to prolonged

sitting, but not with other measures of cardiovascular health such as arterial stiffness. Overall, the authors noted that while much of the current research on sedentary behaviour focuses on healthy adults, research is currently lacking in older adults and in adults with chronic diseases (Whipple et al., 2021).

While there have been numerous recently published studies investigating the relationship between sedentary breaks and cardiometabolic health (Chastin et al., 2015; Loh et al., 2020; Saunders, Atkinson, et al., 2018; Whipple et al., 2021), there is currently insufficient evidence at the review level to support specific recommendations for sedentary bouts and sedentary breaks that would minimize the negative effects of sedentary behaviour on cardiometabolic health risk (Dempsey, Biddle, et al., 2020). Future prospective cohort and longitudinal studies are needed to determine if there is a consistent and causal relationship between sedentary breaks and cardiometabolic disease risk, and to determine if there is an association between the frequency and duration of sedentary breaks and cardiometabolic health risk biomarkers. In the area of studies examining intermittent physical activity compared to one continuous bout of physical activity (with the same energy expenditure) and its effect on postprandial biomarkers, Loh et al. (2020) noted that future prospective cohort studies using device-based measures of sedentary breaks are needed to further clarify the current findings from cross-sectional and experimental studies. Specific further research is also needed to clarify if physical activity breaks are associated with multi-day changes in blood triglyceride concentrations due to previous findings that single-day study designs may not capture the full effects of intermittent physical activity breaks on triglycerides. Future studies could also examine the relationship between these postprandial biomarkers and sedentary breaks consisting of various intensities of physical activity, or sedentary breaks consisting

of quiet standing (Saunders, Atkinson, et al., 2018). Whipple et al. (2021) noted that additional research on the effects of sedentary breaks is needed populations other than healthy adults, such as in older adults and in adults with chronic diseases. In summary, future research is needed to confirm and further support the current recommendations regarding sedentary behaviour, and to determine new recommendations regarding the patterns of accumulating sedentary behaviour (Ford & Caspersen, 2012) such as the optimal frequency of sedentary breaks and the types of activities that should be completed during a sedentary break (Saunders, Atkinson, et al., 2018) in order to minimize the undesirable effects of sedentary behaviour on cardiometabolic health.

Potential Physiological Mechanisms

The specific mechanisms by which sedentary behaviour increases cardiometabolic health risk are currently uncertain. Several mechanisms have been proposed to account for the relationship between cardiometabolic health risk and sedentary behaviour (Brocklebank et al., 2015; Dempsey, Matthews, et al., 2020; Edwardson et al., 2012; Healy et al., 2011; Wilmot et al., 2012), and some studies have used prolonged immobilization as an extreme model of sedentary behaviour (Le Roux et al., 2021). However, it is important to note that while similar mechanisms may be activated in both sedentary behaviour and bed rest or prolonged immobilization, the latter are substantially more extreme forms of inactivity than what is typically defined as sedentary behaviour. Thus, the potential mechanisms for the effects of sedentary behaviour on health risk based on the findings from bed rest studies and prolonged immobilization should be interpreted with caution as very few studies have directly examined the specific mechanisms of sedentary behaviour on health risk.

Much of the current research exploring the mechanisms of sedentary behaviour have come from one of two sources: prolonged bed rest studies involving humans, and prolonged immobilization studies involving rats (Le Roux et al., 2021). In both humans and rodents, immobilization has been shown to result in changes to both glucose metabolism and lipid metabolism. With regard to glucose metabolism, light-intensity physical activity has been shown to stimulate local glucose uptake (Saunders, Atkinson, et al., 2018) while bed rest leads quickly to muscles becoming insulin resistant (Le Roux et al., 2021) because a prolonged lack of muscle contractions leads to reduced glucose transporter 4 (GLUT4) translocation and contraction-stimulated capillary recruitment in the affected muscles (Brocklebank et al., 2015). This reduced translocation leads to reduced local glucose uptake in response to the insulin that is released by the pancreas, which leads to hyperinsulinemia, indicating that bed rest makes it more difficult for the body to maintain glucose homeostasis. Additionally, insulin resistance is a precursor for type II diabetes (Brocklebank et al., 2015), which could partially explain the association between the excessive accumulation of sedentary behaviour and type II diabetes.

The specific effects of fewer muscle contractions (or a lack of muscle contractions, as is the case for immobilization) on lipid metabolism appears to mainly be a result of changes to lipoprotein lipase. Lipoprotein lipase is an enzyme that is present in the capillaries of muscles (Peng et al., 2017), and it is essential for the regulation of circulating lipid concentrations and overall cardiometabolic homeostasis (Ford & Caspersen, 2012). Specifically, lipoprotein lipase allows for the lipolysis of circulating triglyceride-rich lipoproteins such as chylomicrons and very low-density lipoprotein (VLDL) cholesterol to occur in the capillaries (Peng et al., 2017), which is essential for lipid metabolism in the muscles because triglycerides must be hydrolyzed into glycerol

and free fatty acids before they can be taken up into the muscle (Peng et al., 2017) to be used as fuel for the production of energy (Bastin, 2014). Under normal circumstances, light-intensity physical activity stimulates the upregulation of lipoprotein lipase and this upregulation peaks around eight to 16 hours after the activity has been completed (Saunders, Atkinson, et al., 2018). In contrast, a lack of muscle contractions has been shown to result in the reduced expression of lipoprotein lipase in the affected muscles (Brocklebank et al., 2015; Edwardson et al., 2012; Ford & Caspersen, 2012), which results in the reduced uptake of lipids into the muscle cells. The reduced uptake of lipids into the affected muscles can result in higher circulating triglycerides especially following a meal, which can lead to a greater storage of fat in adipocytes and weight gain in the short term (Le Roux et al., 2021) and an increased risk of atherosclerosis and cardiovascular events in the long term (Peng et al., 2017).

Immobilization has also been found to cause an energy substrate shift in the affected muscle cells from a combination of glucose oxidation and fat oxidation to favouring mainly glucose oxidation (Le Roux et al., 2021), which could further exacerbate rising blood triglyceride levels. In addition to affecting blood triglycerides, prolonged immobilization of only the hindlimbs of rats has been shown to reduce circulating concentrations of HDL cholesterol, which is another potential mechanism by which sedentary behaviour could affect cardiometabolic health outcomes such as cardiovascular disease incidence (Ford & Caspersen, 2012). This is because HDL cholesterol is heavily involved in reverse cholesterol transport by carrying excess cholesterol back to the liver from the body's cells, which regulates cholesterol balance and thus helps to prevent atherosclerosis (He et al., 2013).

Immobilization specifically has been shown to result in an increase in both ectopic and visceral fat storage, such that fat storage is increased in the liver, bones, and muscles, as well as around the internal organs, respectively (Le Roux et al., 2021). Over time, this increase in visceral fat storage could lead to excess abdominal adiposity, which could contribute to the relationship found between sedentary behaviour and waist circumference, as well as the relationship between sedentary behaviour and body mass index. With regard to the increases in ectopic fat storage, it has been shown that when fat stores in the liver increase, the liver synthesizes more VLDL cholesterol which can lead to high blood triglycerides, and the liver is less able to supress gluconeogenesis which even further exacerbates the body's difficulty in maintaining glucose homeostasis (Le Roux et al., 2021). In addition to these negative effects on blood glucose homeostasis and blood lipid homeostasis, prolonged immobilization and bed rest have been shown to also result in increased inflammation (Le Roux et al., 2021), which is also associated with cardiometabolic disease incidence (Pepys & Hirschfield, 2003). Overall, the combined and intertwined effects of bed rest or prolonged immobilization on factors relating to glucose and lipid homeostasis leads to increased cardiometabolic health risk in several ways, such as an increased risk of cardiovascular disease and other metabolic diseases such as type II diabetes, metabolic syndrome, and obesity. If bed rest is indeed an exaggerated but somewhat accurate model of engaging in extreme amounts of sedentary behaviour, similar mechanisms might also extend to engaging in high amounts of sedentary behaviour especially when accumulated in prolonged bouts.

In addition to findings from prolonged immobilization and bed rest studies, other studies have mentioned additional proposed mechanisms and pathways by which sedentary behaviour may be affecting cardiometabolic health based on "inactivity

physiology" (Brocklebank et al., 2015; Dempsey, Matthews, et al., 2020; Edwardson et al., 2012; Healy et al., 2011; Wilmot et al., 2012). In their article, Dempsey, Matthews, et al. (2020) explained how various specific local and acute effects of inactivity can lead to systemic and whole-body semi-acute effects, which can then contribute to overall vascular damage and challenges of the body's ability to maintain homeostasis (Dempsey, Matthews, et al., 2020). The specific local and acute effects of inactivity reported by these authors include reduced lipid oxidation and trafficking, muscle atrophy, habitual declines in metabolic demand of the affected muscles, reduced habitual blood flow in the affected muscles, reduced shear stress in the affected blood vessels, greater postprandial nutrient loading, and decreased insulin sensitivity in the liver and affected muscles (Dempsey, Matthews, et al., 2020). The authors noted that each of these acute effects are likely to contribute to the semi-acute cardiometabolic health effects of ectopic fat storage, oxidative stress, insulin resistance, decreased oxidative capacity of the mitochondria, and chronic inflammation throughout the body (Dempsey, Matthews, et al., 2020). These effects can then lead to more chronic and clinically diagnosable conditions such as hypertension, dyslipidemia, and hyperglycemia, which greatly increase the risk of severe cardiovascular or metabolic effects and mortality (Dempsey, Matthews, et al., 2020). However, it is important to note that many of the proposed mechanisms reported in the current literature are based on "inactivity physiology" instead of specific and unique aspects of "sedentary physiology" (Dempsey, Matthews, et al., 2020), and most authors have emphasized that additional research is necessary to pinpoint the distinctive effects of sedentary behaviour on cardiometabolic health.

Types of Sedentary Time

Most research has focused on the total amount and pattern of accumulated sedentary time without accounting for the type of activities that were completed while sedentary (Powell et al., 2017). Although the definition of sedentary behaviour includes all waking activities completed in a seated or reclined position, findings from some studies suggest that the type of activity an individual completes while sedentary could also affect their cardiometabolic health risk (Brenda Biaani et al., 2020; Ford & Caspersen, 2012; Garcia et al., 2019; Marshall & Merchant, 2013; Pinto Pereira et al., 2012). Some studies suggest that accumulating high amounts of sedentary time while watching television (TV) or viewing other types of screens (such as smartphones or tablets) is more detrimental for health than accumulating high amounts of sedentary time while completing other activities, such as reading, socializing, or working while in a sedentary posture (Ford & Caspersen, 2012; Garcia et al., 2019; Patterson et al., 2018; Pinto Pereira et al., 2012).

Television Viewing Time

Adults in various Western countries spend an average of 3.5 to 5 hours per day watching TV, making it one of the most common sources of leisure-time sedentary behaviour (Ford & Caspersen, 2012; Grøntved & Hu, 2011; Pinto Pereira et al., 2012). Accordingly, much of the early literature regarding sedentary behaviour and health has focused specifically on time spent watching TV while sedentary and its impact on cardiometabolic health risk (Biddle et al., 2017; Biswas et al., 2015; de Rezende et al., 2014; Edwardson et al., 2012; Grøntved & Hu, 2011; Patterson et al., 2018; Rhodes et al., 2012; Wijndaele et al., 2010; Wilmot et al., 2012; Zhao et al., 2020). Grøntved and Hu (2011) completed a meta-analysis of prospective cohort studies examining the

relationship between TV viewing time and the risk of cardiovascular disease, type 2 diabetes, and all-cause mortality. The authors found that the risk of cardiovascular disease was 15% higher (Relative Risk 1.15; 95% Confidence Interval 1.06-1.23), the risk of type 2 diabetes was 20% higher (Relative Risk 1.20; 95% Confidence Interval 1.14-1.27), and the risk of all-cause mortality was 13% higher (Relative Risk 1.13; 95% Confidence Interval 1.07- 1.18) for every two additional hours per day spent watching TV (Grøntved & Hu, 2011). Similarly, Zhao et al. (2020) completed a systematic review and meta-analysis of sedentary time and certain chronic diseases to explore the possibility of a dose-response association, and found that there was a dose-dependent but non-linear relationship between TV viewing time and cardiovascular disease and all-cause mortality. Specifically, each additional daily hour of TV viewing time increased the risk of cardiovascular disease by 7% (Hazard Ratio 1.07; 95% Confidence Interval 1.06–1.09) and the risk of all-cause mortality by 4% (Hazard Ratio 1.04; 95% Confidence Interval 1.01–1.06), but the regression line was curved indicating that the relationship was not linear.

Some studies have also examined the effects of TV viewing time in comparison to total sedentary time or other comparable measures of domain-specific sedentary time. Similar to Zhao et al. (2020), Patterson et al. (2018) also examined mortality in their systematic review and meta-analysis regarding sitting time and TV viewing time. The authors found that TV viewing time was detrimentally associated with all-cause mortality in a large prospective sample of adults (n = 1,331,468), and that TV viewing time was more strongly associated with mortality outcomes than total sitting time (Patterson et al., 2018). Furthermore, Garcia et al. (2019) completed a prospective cohort study with a sample of black Americans (n = 3592) and found that self-reported TV-viewing time of

greater than four hours per day at baseline was associated with a 50% increased risk of cardiovascular events/all-cause mortality at the 11-year follow-up (Hazard Ratio 1.49; 95% Confidence Interval 1.13–1.97) whereas self-reported occupational sitting time was not. Interestingly, the authors also noted that in participants who reported meeting or exceeding the current physical activity guidelines (75 minutes per week of vigorous activity or 150 minutes per week of moderate to vigorous physical activity), the association between TV-viewing time and risk of cardiovascular events/all-cause mortality was no longer statistically significant (Garcia et al., 2019).

With regard to cardiometabolic health risk biomarkers, Biddle et al. (2017) completed a review of reviews on screen time, sedentary behaviour, and obesity (high body mass index), and found that although sedentary time was not consistently associated with obesity, TV time was significantly associated with obesity in most studies. Wijndaele et al. (2010) examined data from an Australian prospective cohort study involving TV viewing time and several cardiometabolic risk biomarkers (n = 3846), and found that TV viewing time was not significantly associated with the measures of systolic blood pressure, fasting plasma glucose, HDL cholesterol, or triglycerides at the five-year follow-up. However, the authors noted that the participants whose TV viewing time increased over a duration of five years had higher diastolic blood pressures, waist circumferences, and clustered cardiometabolic risk scores (Wijndaele et al., 2010). Similarly, Ullrich et al. (2018) examined domain-specific sedentary time and clustered cardiometabolic risk scores in apparently healthy middle-aged adults (n = 173), and found a positive association between TV viewing time and clustered cardiometabolic risk scores.

Although numerous studies have found a consistent association between TV viewing time and cardiometabolic disease risk, it has been suggested that this association could be at least partially due to other behaviours associated with TV viewing, such as engaging in unhealthy dietary behaviours while viewing TV (Biddle et al., 2017; Ford & Caspersen, 2012; Pinto Pereira et al., 2012). Additionally, the timing of TV viewing could affect its association with cardiometabolic health risk because prolonged TV viewing often occurs after a large evening meal, which can lead to higher postprandial blood glucose, insulin, and triglyceride concentrations and thereby increase cardiometabolic health risk (Brenda Biaani et al., 2020; Patterson et al., 2018). Furthermore, the rising popularity of using TV streaming services (i.e. Netflix) increases the likelihood of binge-watching behaviours (Rubenking et al., 2018), which may lead to more frequent engagement in very prolonged bouts of sedentary time while watching TV. In comparison, other sedentary activities such as working, reading, or socializing may be more frequently interrupted (Brenda Biaani et al., 2020), which could lead to a lesser cardiometabolic health risk. Overall, the pattern of sedentary behaviour that people engage in while watching TV in comparison to other sedentary activities could partially account for the difference in health risk associated with TV viewing time (Garcia et al., 2019).

Although many studies have used TV time as a measure of total leisure-time sedentary behaviour, it is not the best measure of overall sedentary time (Wilmot et al., 2012) or of other types of sedentary screen time such as using smartphones or tablets (Vizcaino et al., 2019). Some authors have foregone specifically measuring sedentary behaviour and have instead used TV viewing time as a proxy for leisure-time sedentary behaviour (Patterson et al., 2018), but Pinto Pereira et al. (2012) noted that TV viewing

time and sedentary time are considered two separate exposure variables and thus have different mediating patterns, behavioural patterns, and/or sociodemographic patterns. Additionally, Dempsey, Biddle, et al. (2020) noted that measures of TV viewing time and sedentary time may have differences in measurement validity, measurement error, and residual confounding. While TV viewing time may have better criterion validity than estimates of sitting time (Patterson et al., 2018), both of these self-reported measures are subject to biases such as recall bias and social desirability bias (Chastin et al., 2018; Tremblay et al., 2010). Additionally, Brenda Biaani et al. (2020) noted that while TV time specifically is positively associated with mortality in adults, other research has shown that engaging in sedentary behaviour while using any type of screen is also associated with mortality (Brenda Biaani et al., 2020).

Screen Time

Although a substantial amount of the current literature has examined the impact of TV time on health risk (Rhodes et al., 2012), little research has been published regarding the more modern ways of accumulating sedentary "screen time" (Biddle et al., 2017; Vizcaino et al., 2019). Grøntved and Hu (2011) noted that overall screen time appeared to stem mainly from TV viewing time in 2011, but this may have changed in the past decade due to the increased prevalence of using modern technology such as smartphones and tablets while sedentary (Saunders, MacDonald, et al., 2018; Vizcaino et al., 2019). Notably, Vella et al. (2020) recently completed a cross-sectional study examining leisure screen time and cardiometabolic biomarkers in college-aged adults (aged 18-25 years) and found that self-reported screen time was detrimentally associated with body mass index, triglycerides, waist circumference, and fat mass. These associations were independent of total device-measured sedentary time, physical activity, and other

potentially confounding variables; therefore, sedentary screen time may be worse for markers of obesity and cardiometabolic disease risk than time spent in other types of sedentary activities (Vella et al., 2020). Additionally, Ford and Caspersen (2012) completed a systematic review and meta-analysis of prospective studies examining the association between self-reported screen time, self-reported sedentary time, and non-fatal cardiovascular disease incidence. The authors found that while each additional two hours of sitting time increased cardiovascular disease risk by 5% (Hazard Ratio 1.05; 95% Confidence Interval 1.13–1.20), each additional two hours of screen time increased cardiovascular disease risk by 17% (Hazard Ratio 1.17; 95% Confidence Interval 1.01–1.09). Ford and Caspersen (2012) also noted that the participants in the highest category of sitting time had a risk estimate of up to 1.68 compared to the lowest category of sitting time, whereas participants in the highest category of screen time had a risk estimate of up to 2.25 compared to the lowest category. Furthermore, Ford and Caspersen (2012) noted that in 2010 the most common sedentary behaviour during leisure-time in Americans was viewing screens, therefore understanding the health consequences of sedentary leisure-time screen time is of paramount importance.

Other Sedentary Activities

While the specific sedentary activities of TV viewing time or screen time have been found to be detrimentally associated with cardiometabolic health risk, other studies have explored the potential relationship between cardiometabolic health risk and other types of domain-specific sedentary time such as reading, socializing, travelling, or working while sedentary (Patterson et al., 2018; Pinto Pereira et al., 2012; Ullrich et al., 2018). Patterson et al. (2018) mentioned previous research has shown that reading while seated may be beneficially associated with cardiometabolic health, and Ullrich et al.

(2018) reported that self-reported time spent reading or socializing while sedentary were not associated with clustered cardiometabolic risk scores in their sample of apparently healthy middle-aged adults. Similarly, Nang et al. (2013) found that self-reported sedentary reading time was not significantly associated with cardiometabolic biomarkers in a large sample of Singaporean adults, and Kikuchi et al. (2014) found that self-reported "mentally-active" sedentary time (such as reading a book or newspaper) was not associated with self-reported overweightness in a large sample of Japanese older adults. Additionally, Dempsey et al. (2018) found that self-reported occupational or transport sitting time were not detrimentally associated with clustered cardiometabolic risk scores in apparently healthy adults, and Pinto Pereira et al. (2012) found that self-reported occupational sitting time was not detrimentally associated with individual cardiometabolic health risk factors such as total cholesterol, blood pressure, or CRP in a large sample of British adults (n = 7660). However, relatively few studies have been published regarding the relationship between domain-specific sedentary time and cardiometabolic health risk beyond that of TV viewing time or screen time, therefore more research is needed to confirm these findings. Also, Dempsey, Biddle, et al. (2020) noted that there is currently insufficient review-level evidence to support specific recommendations for engaging in different types of sedentary behaviour. Overall, it is important to measure the type of activity that an individual engages in while in a sedentary posture, because different types of activities appear to have different effects on cardiometabolic health risk (Marshall & Merchant, 2013; Powell et al., 2017).

Measures of Sedentary Behaviour

There are numerous ways that sedentary behaviour can be measured, and the two commonly used measurement categories are self-report methods and device-based

methods (Tremblay et al., 2010). Both of these techniques can measure sedentary time, sedentary bouts, and sedentary breaks, and certain self-report methods may also measure the amount of time that participants spend competing various types of activities while sedentary (Tremblay et al., 2010).

Self-report Methods

Two main types of self-reported sedentary behaviour measurements are questionnaires and activity logs (Tremblay et al., 2010). Questionnaires may be self-administered by participants or administered by a researcher using interviews, and may include self-reported time spent sitting, driving a vehicle, watching TV, or using screens (Chastin et al., 2018; Tremblay et al., 2010). Sedentary behaviour logs or activity diaries may be completed by participants throughout the day, or completed retrospectively (Tremblay et al., 2010). Some commonly used self-report measures for sedentary behaviour are previous day recall, previous week recall, and "usual day" estimate, and each of these recalled time periods can include questions addressing total time spent sedentary, proportion of day spent sedentary, and domain-specific sedentary time such as TV viewing time (Chastin et al., 2018).

One main strength of self-reported measures of sedentary behaviour is the ability to measure valuable information regarding the type of activity completed while sedentary (Powell et al., 2017; Tremblay et al., 2010). If leisure-time screen-based sedentary activities may be worse for health than other types of sedentary activities (Brenda Biaani et al., 2020; Copeland et al., 2017; de Rezende et al., 2014; Vella et al., 2020), and TV viewing time or screen time are specifically associated with an increased risk of negative health outcomes compared to other types of sedentary time (Grøntved & Hu, 2011; Patterson et al., 2018; Wilmot et al., 2012), then assessing the type of sedentary behaviour

would be of great importance. However, a main disadvantage of using self-report methods for quantifying sedentary behaviour is that they are vulnerable to biases such as recall bias and social desirability bias, which may result in participants over- or under-estimating their sedentary behaviour involvement (Chastin et al., 2018; Tremblay et al., 2010). Additionally, many cross-sectional studies using self-reported methods only measure sedentary behaviour at one time point, which can lead to an over- or under-estimation of sedentary time due to the increased chance of random-measurement error (Grøntved & Hu, 2011).

Device-based Methods

In addition to these self-reported measures of sedentary behaviour, there are numerous devices that can be used to quantify an individual's sedentary behaviour (Tremblay et al., 2010). These devices include sitting pads (Powell et al., 2017), pedometers (Tremblay et al., 2010), tri-axial accelerometers (Buman et al., 2014; Healy et al., 2011; Vella et al., 2020), and inclinometers (Powell et al., 2017; Wirth et al., 2016), with the most commonly used device being tri-axial accelerometers (Tremblay et al., 2010). Pedometers are typically worn on the hip of each participant and are only able to measure their daily step counts (Tremblay et al., 2010). Pedometers can approximate sedentary behaviour by differentiating between individuals who achieve many steps per day or fewer steps per day, and individuals who take more steps during the day are likely engaging in sedentary behaviour for fewer minutes of the day because their light-intensity physical activity displaces some time they would have otherwise spent sedentary (Buman et al., 2014). However, this method of approximating sedentary time may not be the best measure in participants who are highly active but also highly sedentary, which has been termed the "active couch potato" phenomenon (Owen et al., 2010). Instead, a method

combining pedometers and log sheets may be a better approximation of sedentary time (Donahoe et al., 2018), especially in highly active participants.

In contrast to pedometers, triaxial accelerometers measure any change in movement within three-dimensional space and can approximate sedentary time by distinguishing between the minutes of each day with very few movements (time spent sedentary) and more movements (time not spent sedentary). Each minute of accelerometer wear time can then be categorized as sedentary time, light activity, moderate activity, or vigorous activity based on previously established cut-off points (Freedson et al., 1998). A main advantage of using accelerometers to measure sedentary behaviour is that they are able to not only measure sedentary time, but are also able to measure the duration, frequency, and pattern of accumulated sedentary behaviour such as the number of sedentary bouts, number of sedentary breaks, and average length of sedentary bouts (Tremblay et al., 2010). However, accelerometers identify sedentary time based solely on a lack of movement but are not able to measure differences in body posture such as time spent standing versus sitting or reclining (Brocklebank et al., 2015; Dempsey, Biddle, et al., 2020), which is a key component of the definition of sedentary behaviour (Tremblay et al., 2017). Another key limitation of using traditional accelerometers to measure sedentary behaviour is that accelerometers are not as precise as other measurement methods at detecting the end of a sedentary bout, and may therefore provide inconsistent or less accurate results when examining the cardiometabolic health risks associated with sedentary breaks (Chastin et al., 2015).

Lastly, inclinometers are another type of device that can be used to measure sedentary time (Chastin et al., 2018; Grant et al., 2006). Inclinometers are uniaxial or multi-axial accelerometers that are worn on the middle of the participant's anterior thigh,

and can detect body position by measuring the inclination of that participant's thigh (Edwardson et al., 2017). If a person's thigh is vertical then they are likely standing, and if a person's thigh is horizontal (or close to horizontal) then they are likely in a seated or reclined position. Thus, inclinometers are able to measure sedentary time more accurately than accelerometers because inclinometers can detect specific body positions (Brocklebank et al., 2015; Chastin et al., 2018; Grant et al., 2006). Inclinometers have also been found to validly and reliably measure body position in order to differentiate between sedentary postures and non-sedentary postures during various activities of daily living (Grant et al., 2006), and are therefore appropriate to use in an individual's free-living environment (Edwardson et al., 2017). Overall, inclinometers appear to be the most valid and reliable way of measuring sedentary time, sedentary breaks, and sedentary bouts, but are unable to measure the types of activities completed while sedentary.

Summary

Despite growing evidence that sedentary time is detrimentally associated with cardiometabolic health independently of physical activity, there are some overall gaps in the current literature. A substantial number of published studies regarding sedentary behaviour are based on less accurate methods of quantifying it (Chastin et al., 2018; Edwardson et al., 2017; Tremblay et al., 2010). Many studies use only self-reported sedentary time, sitting time, or TV viewing time which may not be as accurate as device-based measures (Owen et al., 2010; Patterson et al., 2018; Rhodes et al., 2012), and some studies consider TV viewing time as a proxy for overall sedentary behaviour (Pinto Pereira et al., 2012). Other studies have used accelerometers to estimate sedentary time based on lack of movement, but these devices are not able to distinguish between sedentary and non-sedentary body postures (Owen et al., 2010; Rhodes et al., 2012).

Additionally, certain activities completed while sedentary have differing effects on health risk (Marshall & Merchant, 2013) such that TV viewing time may be more detrimental for cardiometabolic health than total sedentary time (Brenda Biaani et al., 2020; Patterson et al., 2018; Vella et al., 2020) or occupational sedentary time (Pinto Pereira et al., 2012).

Leisure-time screen-based sedentary time is the most common form of leisure-time sedentary time on average (Pinto Pereira et al., 2012), and is also more frequently associated with negative health outcomes than other types of leisure-time sedentary time such as reading or socializing (Copeland et al., 2017; de Rezende et al., 2014; Ullrich et al., 2018). Also, a substantial amount of the current literature has assessed TV time as an important predictor of health risk (Grøntved & Hu, 2011; Patterson et al., 2018), but limited research has been completed regarding the health effects of time spent using modern screen-based technology such as phones and tablets. In order to more precisely determine the effects of sedentary behaviour on cardiometabolic health risk in adults, a new method is needed to measure sedentary behaviour that will accurately quantify total accumulated sedentary time and also how much of that sedentary time is considered leisure-time "screen time" (Copeland et al., 2017; Marshall & Merchant, 2013; Patterson et al., 2018). Several authors have specifically called for a new measurement method that accurately combines information on the total amount of sedentary time accumulated as well as information regarding the type of activity completed while sedentary (Copeland et al., 2017; Dempsey, Biddle, et al., 2020; Dempsey, Matthews, et al., 2020; Pinto Pereira et al., 2012), especially in light of the findings that different types of sedentary activities have different effects on cardiometabolic health risk (Marshall & Merchant, 2013; Pinto Pereira et al., 2012; Powell et al., 2017).

Conclusion

As shown in the literature, sedentary behaviour is associated with the incidence of various cardiometabolic diseases as well as numerous cardiometabolic health risk factors. Sedentary behaviour measurement methods in the literature varied widely, and based on the health risks associated with the amounts, patterns, and types of sedentary behaviour that an individual engages in, it is important to have a measurement tool that is capable of measuring these elements with a low risk of bias (Powell et al., 2017). This type of measurement tool is essential for developing strategies and interventions to reduce the negative impacts of excessive sedentary time on cardiometabolic health (Powell et al., 2017), and to identify individuals who may be at greater health risk based on their movement behaviours.

Table 1. Literature review findings for the relationship between sedentary behaviour and cardiometabolic health outcomes

Authors	Study Design	Sample Population	Measurement of SB	Measurement of Health Risk	Key Findings
Aho et al. (2021)	Cross-sectional data	Adult women (aged 50-60 years; *n* = 571)	Device-measured SBR (accelerometers)	HDL, LDL, TC, TG	↑ SBR = ↑ HDL, ↓ TG; SBR ≠ LDL, TC
Bankoski et al. (2011)	Cross-sectional data from NHANES (2003-2006)	Adults (aged ≥60 years; *n* = 1367)	Device-measured ST, SBR, and SBO (accelerometers)	Incidence of MetS	Incidence of MetS = ↑ ST, ↓ SBR, ↑ SBO length
Berger et al. (2019)	Systematic Review and Meta-Analysis (*n* = 12 papers; prospective cohort)	Male adults (*n* = 671,852)	Self-reported ST (self-administered questionnaires or interviews)	Incidence of prostate cancer or aggressive prostate cancer	ST ≠ prostate cancer (RR 1.07, 95% CI 0.99-1.16); ↑ ST + high BMI (mediator) = ↑ aggressive prostate cancer
Biddle et al. (2017)	Review of Reviews (*n* = 10 review papers [a]; cross-sectional, experimental)	Adults (aged ≥18 years)	Self-reported or device-measured ST (total or domain-specific)	Measures of adiposity or weight status	ST ≠ excess adiposity, high BMI, obesity
Biswas et al. (2015)	Systematic Review and Meta-Analysis (*n* = 47 papers; prospective, cross-sectional, case-control)	Adults (aged ≥18 years)	Self-reported daily overall ST, sitting time, TV or screen time, or leisure sitting time	Diabetes, CV disease, cancer, cause-specific mortality, all-cause mortality	↑ ST = ↑ CV disease (HR 1.143, 95% CI 1.002-1.729), ↑ type II diabetes (HR 1.910, 95% CI 1.642-2.222), ↑ cancer (HR 1.130, 95% CI 1.052-1.213)
					↑ ST = ↑ mortality due to CV disease (HR 1.179, 95% CI 1.106-1.257), cancer (HR 1.173, 95% CI 1.108-1.242), all-causes (HR 1.240, 95% CI 1.090-1.410)
Brocklebank et al. (2015)	Systematic Review (*n* = 29 papers; cross-sectional, prospective cohort)	Adults (aged ≥18 years)	Device-measured ST and SBR (accelerometers)	FPG, fasting insulin, insulin sensitivity, HOMA-IR, TC, HDL, LDL, TG, 2-hour plasma glucose	↑ ST = ↑ TG, ↑ fasting insulin, ↓ insulin sensitivity, ↑ HOMA-IR; ST ≠ FPG, TC, LDL, HDL, 2-hour plasma glucose
					↑ SBR = ↑ TG; SBR ≠ any other measured variables
Buman et al. (2014)	Cross-sectional data from	Adults (aged >19 years; *n* = 923)	Device-measured ST (ActiGraph tri-	WC, SBP, DBP, CRP, HDL, LDL, TG, fasting insulin, FPG, HOMA-B, HOMA-S	↑ ST = ↑ TG, ↑ fasting insulin, ↑ HOMA-B, ↓ HOMA-S, ↓ SBP[†]

Authors	Study Design	Sample Population	Measurement of SB	Measurement of Health Risk	Key Findings
	NHANES (2005-2006)		axial accelerometers)		ISM: ↓ ST and ↑ LPA by 30 min = ↓ TG, ↓ fasting insulin, ↓ HOMA-B, ↑ HOMA-S, ↑ SBP†, ↑ DBP†
Chastin et al. (2015)	Systematic Review and Meta-Analysis (*n* = 13 papers [b]; observational, RCT)	Adults (aged ≥ 21 years)	Device-measured SBR (accelerometers)	Biomarkers of adiposity, CV health, glucose metabolism, inflammation	Observational: ↓ SBR (independent of ST) = ↑ CRP, higher BMI; SBR ≠ glucose metabolism, CV health, WC, other biomarkers
					RCT: ↓ SBR = ↑ postprandial glucose, ↑ postprandial insulin, ↑ C-peptides; SBR ≠ TG, cholesterol
Cooper et al. (2011)	Cross-sectional and longitudinal data (6-month follow-up)	Adults (aged 30-80 years; *n* = 528; recently diagnosed with type II diabetes)	Device-measured ST and SBR (accelerometers)	WC, HDL, fasting insulin, FPG, HOMA-IR	Cross-sectional: ↑ ST = ↑ WC, ↑ fasting insulin, ↑ HOMA-IR, ↓ HDL; ST ≠ FPG ↑ SBR = ↓ WC, SBR ≠ fasting insulin, FPG, HOMA-IR, HDL
					Longitudinal: ↑ baseline ST = ↑ follow-up fasting insulin, ↑ HOMA-IR, ↓ HDL; baseline ST ≠ follow-up WC baseline SBR ≠ follow-up biomarkers
de Rezende et al. (2014)	Systematic Review (*n* = 23 papers; cross-sectional, prospective cohort, case-control)	Older adults (aged >60 years)	Self-reported ST (sitting time, TV viewing time, passive transport) or device-measured ST	All-cause mortality, MetS, WC, overweightness/obesity (BMI), and individual biomarkers	↑ ST = ↑ all-cause mortality, ↑ MetS, ↑ TC-HDL ratio, ↑ CRP, ↑ WC, ↑ waist-to-hip ratio, ↑ BMI; ST ≠ TG, HDL, SBP, DBP, HbA1c, TC
Dempsey, Biddle, et al. (2020)	Review of Reviews (*n* = 13 papers [c])	Adults (aged ≥18 years)	Self-reported and device-measured ST and SBR	Incidence of CV disease, cancer, type II diabetes, CV mortality, cancer mortality, all-cause mortality, excess adiposity	↑ ST = ↑ CV disease, ↑ cancer, ↑ type II diabetes, ↑ CV mortality, ↑ cancer mortality, ↑ all-cause mortality ST ≠ BMI, WC

Authors	Study Design	Sample Population	Measurement of SB	Measurement of Health Risk	Key Findings
					Insufficient evidence regarding SBR and health risk
Diaz et al. (2017)	Cross-sectional data from HCHS/SOL	Hispanic/Latino adults (aged 18-74; *n* = 12,083)	Device-measured ST and mean SBO length (accelerometers)	HOMA-IR, HbA1c, 2-hour glucose	↑ ST = ↑ mean SBO length, ↑ HOMA-IR, ↑ 2-hour glucose; ST ≠ HbA1c
					↑ mean SBO length = ↑ HOMA-IR, ↑ 2-hour glucose; mean SBO length ≠ HbA1c
					↑ ST + ↑ mean SBO length = ↑ ↑ HOMA-IR, ↑ ↑ 2-hour glucose
Dickins et al. (2018)	Review of Reviews (*n* = 6 review papers [d])	Intended sample was older adults (aged ≥65 years); included adults <65 years	Mainly self-reported SB; some device-measured SB	CV events, incidence, mortality (excluded CV risk factors)	↑ ST = ↑ CV events, ↑ CV incidence, ↑ CV mortality
Edwardson et al. (2012)	Systematic Review and Meta-Analysis (*n* = 10 papers; cross-sectional)	Adults (aged 18-65 years; *n* = 21,393)	Self-reported TV time, screen time, sitting time, or accelerometer-measured ST	Risk of MetS (↑ WC, ↑ BP, ↑ TG, ↑ fasting glucose, and/or ↓ HDL)	↑ ST = ↑ MetS (OR 1.73, 95% CI 1.55-1.94); independent of PA
Farrahi et al. (2021)	Cross-sectional data from NFBC (1966)	Adults (aged 46 years; *n* = 4439)	Device-measured SBR (accelerometers)	BMI, WC, BF%, FPG, fasting insulin, TC, HDL, LDL, TG, 2-hour glucose, 2-hour insulin	↑ SBR = ↓ BMI, ↓ WC, ↓ BF%, ↓ FPG, ↓ fasting insulin, ↓ TG, ↓ 2-hour insulin; SBR ≠ TC, HDL, LDL, 2-hour glucose
Garcia et al. (2019)	Prospective cohort	Black Adults (aged ≥21 years; *n* = 3592)	Self-reported TV viewing time and self-reported occupational sitting time	Incidence of CV disease, all-cause mortality	↑ TV time (4+ hours/day) = ↑ CV disease or all-cause mortality (HR 1.49, 95% CI 1.13-1.97); Occupational sitting time ≠ CV disease or all-cause mortality
Garcia-Hermoso et al. (2015)	Cross-sectional data from EVIDENT project	Spanish adults (aged 20-80 years; *n* = 1365; apparently healthy)	Device-measured ST and SBR (ActiGraph accelerometers)	Pulse pressure, arterial stiffness	↑ ST = ↑ pulse pressure, ↑ arterial stiffness; not significant when MVPA controlled for
					↑ SBR = ↓ pulse pressure, ↓ arterial stiffness

Authors	Study Design	Sample Population	Measurement of SB	Measurement of Health Risk	Key Findings
Grøntved and Hu (2011)	Meta-analysis (*n* = 8 papers; prospective cohort)	Adults (aged ≥ 21 years; apparently healthy)	Self-reported TV viewing time	Incidence of type II diabetes, CV disease, CV mortality, all-cause mortality	↑ TV time (+2 hr/day) = ↑ type II diabetes (RR 1.20, 95% CI 1.14-1.27; linear), ↑ CV disease or mortality (RR 1.15, 95% CI 1.06-1.23; linear), ↑ all-cause mortality (RR 1.13, 95% CI 1.07-1.18; non-linear)
Hawari et al. (2016)	RCT data (3 experimental conditions)	Adult men (*n* = 10; overweight/obese but normoglycemic)	PRO sitting vs. PRO standing vs. INT standing	Plasma glucose, insulin, TG; expired air (EE, energy substrate utilization)	Compared to PRO sitting: PRO standing = ↑ EE, ↑ carbohydrate oxidation; INT standing = ↑ ↑ EE, ↑ fat oxidation, ↑ carbohydrate oxidation
Healy et al. (2011)	Cross-sectional data from NHANES (2003-2006)	Adults (aged >19 years; *n* = 4757)	Device-measured ST and SBR (ActiGraph accelerometers)	WC, HDL, CRP, TG, insulin, HOMA-B, HOMA-S, SBP, DBP, FPG	↑ ST = ↑ WC, ↓ HDL, ↑ CRP, ↑ TG, ↑ insulin, ↑ HOMA-B, ↓ HOMA-S; ST ≠ SBP, DBP, FPG
					↑ SBR = ↓ CRP, ↓ WC, ↓ FPG (independently of ST); ↑ SBR = ↑ HDL in women but not men
Huang et al. (2021)	Cross-sectional data from British Cohort Study (1970)	Adults (aged 46-48 years; *n* = 4892)	Device-measured ST and SBR (activPAL inclinometers)	BMI, BF%, SBP, DBP, HbA1c, HDL, TC, TG, CRP, incidence of type 2 diabetes	↑ ST = ↑ BMI, ↑ BF%, ↑ TC:HDL; ST ≠ type 2 diabetes
					↑ PRO ST = ↑ BMI, ↑ BF%, ↑ TC:HDL, ↑ HbA1c; PRO ST ≠ type 2 diabetes
					↑ SBR = ↓ BMI, ↓ BF%, ↓ HbA1c (independent of total ST); ↓ type 2 diabetes (OR 0.80, 95% CI 0.71-0.90)
Jefferis et al. (2019)	Prospective cohort data from the British Regional Heart Study	Older adult men (aged 71-92 years; *n* = 1274; community-dwelling)	Device-measured ST and SBR (ActiGraph accelerometers)	All-cause mortality	↑ ST (each additional 30 min) = ↑ all-cause mortality (HR 1.17, 95% CI 1.10-1.25)
					SBR ≠ all-cause mortality
Loh et al. (2020)	Systematic Review and Meta-analysis	Adults (aged ≥18 years) without	PRO sitting vs. sitting with INT SBR of PA	Postprandial insulin, glucose, TG	↑ SBR of INT PA = ↓ insulin, ↓ glucose, ↓ TG

Authors	Study Design	Sample Population	Measurement of SB	Measurement of Health Risk	Key Findings
	(*n* = 42 papers [e] in review; *n* = 37 papers in meta-analysis; RCT)	major health complications			↑ SBR of INT PA + high BMI = ↓ ↓ insulin, ↓ ↓ glucose
					↑ SBR of INT PA (with matched EE to continuous PA) = ↓ glucose; ≠ insulin, TG
Marin et al. (2020)	Review (*n* = 20 papers; cross-sectional)	South American Adults (aged >18 years)	Self-reported or device-measured (accelerometer) total ST, sitting time, or TV viewing time	Cardiometabolic diseases and cardiometabolic biomarkers	↑ SB = ↑ obesity, ↑ type 2 diabetes, ↑ hypertension, ↑ MetS, ↑ dyslipidemia, ↑ hypercholesterolemia, ↑ BMI, ↑ WC, ↑ BF%, ↑ FPG, ↑ fasting insulin, ↑ HOMA-IR, ↑ TG, ↓ HDL; SB ≠ LDL, TC, HbA1c
Pandey et al. (2016)	Meta-analysis (*n* = 9 papers; prospective)	Adults (aged ≥18 years; *n* = 720,425)	Self-reported total ST	Adverse CV events (stroke, myocardial infraction, coronary artery disease, CV mortality)	High ST = ↑ CV disease (HR 1.14, 95% CI 1.09-1.19; non-linear) independently of PA
Patterson et al. (2018)	Systematic Review and Meta-Analysis (*n* = 34 papers; prospective)	Adults (aged ≥18 years; *n* = 1,331,468; non-diseased)	Self-reported or device-measured (accelerometer) total ST or TV viewing time	All-cause mortality, CV mortality, cancer mortality, type 2 diabetes incidence (independently of PA)	↑ ST = ↑ all-cause mortality, ↑ CV mortality, ↑ type 2 diabetes; ST ≠ cancer mortality
					↑ TV time = ↑ all-cause mortality, ↑ CV mortality, ↑ type 2 diabetes, ↑ cancer mortality
Powell et al. (2017)	Systematic Review and Meta-Analysis (*n* = 46 papers; cross-sectional)	Adults (aged 18-87 years; *n* = 70,576; apparently healthy)	Device-measured ST (accelerometer, inclinometer, or sitting pad)	Numerous anthropometric and blood biomarkers	Meta-Analysis: ↑ ST = ↑ fasting glucose, ↑ fasting insulin, ↑ TG, ↑ WC, ↓ HDL
					Review: ↑ ST = ↑ MetS; ST ≠ BMI, HbA1c, LDL, TC, BF%, SBP, DBP
Saunders, Atkinson, et al. (2018)	Systematic Review and Meta-Analysis (*n* = 44 in review [e]; *n* = 20 in meta-analysis [e])	Healthy individuals (any age)	PRO sitting (<24 hours) vs. sitting with INT SBR of LPA or MPA (>10 minutes long)	Postprandial insulin, glucose, TG, SBP, DBP, FMD, arterial stiffness	Compared to PRO sitting, ↑ SBR = ↓ insulin, ↓ glucose; SBR ≠ TG; Intensity of SBR (LPA vs. MPA) ≠ effect on insulin, glucose, TG; BMI did not impact the findings

Authors	Study Design	Sample Population	Measurement of SB	Measurement of Health Risk	Key Findings
Ullrich et al. (2018)	Cross-sectional data	Adults (aged 40-65 years; *n* = 173; apparently healthy)	Self-reported domain-specific leisure time ST	CMRS	↑ TV time = ↑ CMRS ↑ ST (reading or socializing) ≠ CMRS
van der Berg et al. (2016)	Cross-sectional data from The Maastricht Study	Adults (aged 40-75; *n* = 2497)	Device-measured ST, SBR, and SBO (activPAL inclinometers)	Glucose metabolism, MetS	↑ ST (1 hour) = ↑ type 2 diabetes (OR 1.22, 95% CI 1.13-1.32), ↑ MetS (OR 1.39, 95% CI 1.27-1.53)
					SBR ≠ glucose metabolism, MetS SBO ≠ glucose metabolism, MetS
Vella et al. (2020)	Cross-sectional data collected in the USA	Adults (aged 18-25 years; *n* = 95; college students; apparently healthy)	Self-reported screen time and device-measured total ST (accelerometers)	BMI, WC, VO_{2peak}, SBP, DBP, TC, HDL, LDL, TG, FPG, BF%, lipid accumulation product	↑ Screen Time = ↑ BMI, ↑ WC, ↑ lipid accumulation product, ↑ BF%, ↓ VO_{2peak} (independently of total ST); Screen Time ≠ SBP, DBP, TC, HDL, LDL, FPG
Whipple et al. (2021)	Systematic Review (*n* = 20 papers; experimental, quasi-experimental)	Adults (aged ≥18 years; *n* = 627) with type 2 diabetes or at an elevated risk for type 2 diabetes	SBR (interventions targeting breaking up PRO ST)	CV health (i.e. SBP, DBP, MAP, arterial stiffness, FMD, cerebral blood flow, blood biomarkers)	↑ SBR (LPA or MPA) = ↓ acute SBP and DBP (compared to PRO sitting) SBR (LPA or MPA) ≠ other measures of CV health SBR (standing) ≠ CV health
Whitaker et al. (2018)	Cross-sectional data from the CARDIA study	Adults (aged 18-30 years at baseline; *n* = 1922)	Device-measured ST (accelerometers)	WC, SBP, DBP, FPG, insulin, TG, HDL, CMRS	↑ ST = ↑ WC, ↑ FPG, ↑ insulin, ↑ TG, ↑ CMRS, ↓ HDL
					ISM: ↓ ST and ↑ LPA by 30 min = ↓ CMRS, ↓ WC, ↓ insulin, ↑ HDL
Wilmot et al. (2012)	Systematic Review and Meta-Analysis (*n* = 18 papers; cross-sectional, prospective)	Adults (aged ≥18 years; *n* = 794,577)	Self-reported ST or TV/screen-based entertainment	Incidence of diabetes, CV events, CV mortality, all-cause mortality	↑ ST = ↑ diabetes, ↑ CV events, ↑ CV mortality, ↑ all-cause mortality
Wijndaele et al. (2010)	Prospective cohort data (population-based; 5-year follow-up)	Adults (aged ≥25 years at baseline; *n* = 3,846)	TV viewing time	WC, TG, HDL, SBP, DBP, FPG, CMRS	Baseline TV time ≠ any biomarkers 5-year ↑ TV time = ↑ WC, ↑ DBP, ↑ CMRS 5-year ↑ TV time ≠ TG, HDL, SBP, FPG

Authors	Study Design	Sample Population	Measurement of SB	Measurement of Health Risk	Key Findings
Wirth et al. (2016)	Systematic Review (*n* = 26 papers; RCT, prospective, cross-sectional)	Older adults (community-dwelling)	Device-measured ST (accelerometer or inclinometer) or self-reported ST	Anthropometric, renal, and blood biomarkers (*n* = 63 biomarkers)	↑ ST = ↑ HbA1c, ↑ WC, ↑ leptin, ↑ HOMA-IR; ST ≠ BMI, SBP, DBP, TC, HDL, fasting insulin, FPG, CRP, IL-6
Yates et al. (2020)	RCT data (3 experimental conditions)	Older adults (aged 65-79 years; *n* = 60)	PRO sitting vs. periodic standing breaks vs. periodic walking breaks	Blood pressure, glucose, insulin, TG	Compared to PRO sitting, walking breaks were beneficial for postprandial SBP, DBP, insulin, and blood glucose; standing breaks were not clinically beneficial
Zhao et al. (2020)	Systematic Review and Meta-Analysis (*n* = 24 papers; prospective cohort)	Adults (aged 18-99 years; *n* = 1,156,400) with/without diabetes, hypertension, high BMI, high PA	Self-reported ST (sitting time and TV viewing time)	CV, cancer, all-cause mortality risk	↑ ST = ↑ risk of CV, cancer, all-cause mortality; ↑ ST + diabetes = ↑ ↑ risk; ↑ ST + hypertension = ↑ ↑ risk; ↑ ST + high BMI = ↑ ↑ risk; ↑ ST + high PA = ↓ risk
Zheng et al. (2020)	Cross-sectional data	Adult males (aged 18-35 years; *n* = 94) that were physically active, Chinese, BMI ≤24.9 kg/m^2, normotensive, non-smoker, non-drinker	Device-measured ST, SBR, and SBO (activPAL inclinometers)	CRP, C-peptide, insulin, TG, TC, HDL, LDL, leptin, resistin, adiponectin, P-selectin, E-selectin, ICAM-1, VCAM-1	↑ ST = ↑ TG, ↑ HOMA-IR, ↑ insulin, ↑ E-selectin
					↑ SBR = ↓ CRP, ↓ leptin
					↑ SBO = ↑ P-selectin, ↑ E-selectin, ↑ leptin

Note. The ≠ sign indicates relationships that were either not statistically significant in original studies, or relationships that were mixed, inconclusive, or not statistically significant in review studies. The ↑ sign indicates "higher", the sign ↑ ↑ indicates "much higher", and the ↓ sign indicates "lower".

† Detrimental association opposite of what would be expected.

[a] This review included Chastin et al. (2015); de Rezende et al. (2014); Rhodes et al. (2012).

[b] This review included Healy et al. (2011).

[c] This review included Berger et al. (2019); Patterson et al. (2018).

[d] This review included de Rezende et al. (2014); Wilmot et al. (2012).

[e] Both of these reviews included Hawari et al. (2016).

Abbreviations: AUC = Area Under the Curve; BF% = Body Fat Percentage; BMI = Body Mass Index; CARDIA = Coronary Artery Risk Development in Young Adults; CI = Confidence Interval; CMRS = Clustered Cardiometabolic Risk Score; CRP = C-reactive Protein; CV = Cardiovascular; DBP = Diastolic Blood Pressure; EE = Energy Expenditure; FMD = Flow-mediated Vasodilation; FPG = Fasting Plasma Glucose; HbA1c = Glycosylated Hemoglobin; HCHS/SOL = Hispanic Community Health Study/Study of Latinos; HDL = High-Density Lipoprotein Cholesterol; HCHS/SOL = Hispanic Community Health Study/Study of Latinos; HOMA-B = Homeostatic Model Assessment of β-cell Function; HOMA-IR = Homeostatic Model Assessment of Insulin Resistance; HOMA-S = Homeostatic Model Assessment of Insulin Sensitivity; ICAM-1 = Intercellular Adhesion Molecule 1; IL-6 = Interleukin-6; INT = Intermittent; ISM = Isotemporal Substitution Models; LDL = Low-Density Lipoprotein Cholesterol; LPA = Light Intensity Physical Activity; MAP = Mean Arterial Pressure; MetS = Metabolic Syndrome; MPA = Moderate Intensity Physical Activity; MVPA = Moderate to Vigorous Physical Activity; NHANES = National Health and Nutrition Examination Survey; NFBC = North Finland Birth Cohort; PA = Physical Activity; PRO = Prolonged; RCT = Randomized Controlled Trial; SB = Sedentary Behaviour; SBO = Sedentary Bout; SBP = Systolic Blood Pressure; SBR = Sedentary Breaks; ST = Sedentary Time; TC = Total Cholesterol; TG = Triglycerides; TV = Television; VCAM-1 = Vascular Cellular Adhesion Molecule 1; VO_{2peak} = Peak Volume of Oxygen Consumed; WC = Waist Circumference.

CHAPTER 2: RELIABILITY OF ISST SCORES

Abstract

Background: Excessive sedentary behaviour may negatively impact health, and some activities completed while sedentary (i.e. passive screen time) may be more detrimental than others (i.e. reading). The purpose of this study was to develop a new method of quantifying sedentary time that includes both total sedentary time and sedentary screen time, and to measure the test-retest reliability of this new method.

Methods: For two separate weeks, healthy adult volunteers (n = 87; 68% women; 40.7 ± 16.1 years; age range = 19-71 years) wore an ActivPAL4^{TM} inclinometer for seven consecutive days and completed a questionnaire to assess leisure screen time. Three Index of Sedentary Screen Time (ISST) scores were calculated as a combination of device-measured sedentary time and self-reported screen time: one using a weighted mean, one using an ordinal score, and one using a proportional score. Test-retest reliability of each calculation technique was assessed using intraclass correlation coefficients (ICCs).

Results: The ICC for the continuous ISST score was 0.844 (95% CI: 0.771, 0.895; $p <$ .001), for the ordinal ISST score was 0.727 (95% CI: 0.610, 0.812; $p <$ .001) and for the proportional ISST score was 0.631 (95% CI: 0.486, 0.742; $p <$ .001). These ICCs are categorized as “good”, “moderate to good” and “poor to moderate”, respectively.

Conclusions: All three ISST scoring techniques showed acceptable test-retest reliability, with the continuous ISST scores exhibiting the highest test-retest reliability. The next step is to determine if the ISST is predictive of health risk.

Background

Cardiometabolic diseases such as heart disease and type II diabetes are among the leading causes of morbidity and premature mortality worldwide, especially in higher-

income countries (World Health Organization, 2020b). Habitual movement behaviours can influence the risk of numerous cardiometabolic diseases such as cardiovascular disease, type II diabetes, and metabolic syndrome (Buman et al., 2014; Tremblay et al., 2010; van der Berg et al., 2016; Warburton et al., 2006; Wilmot et al., 2012). Engaging in excessive amounts of sedentary behaviour has emerged as an important risk factor for poor cardiometabolic health, independently of physical activity participation (Owen et al., 2010). Sedentary behaviour is defined as any activity completed while in a seated or reclined position with low energy expenditure while awake (Tremblay et al., 2017), and sedentary time refers to the amount of time that an individual spends in sedentary behaviour (Tremblay et al., 2010). Individuals who accumulate high amounts of sedentary time are at increased cardiometabolic health risk compared to those who spend less time sedentary (Brocklebank et al., 2015; Buman et al., 2014; de Rezende et al., 2014; Dickins et al., 2018; Edwardson et al., 2012; Healy et al., 2011; Owen et al., 2010; Patterson et al., 2018; Powell et al., 2017; Vella et al., 2020; Wilmot et al., 2012; Wirth et al., 2016; Zhao et al., 2020). However, some recent findings suggest that the type of activity completed while sedentary can influence health risk (Brenda Biaani et al., 2020; Ford & Caspersen, 2012; Garcia et al., 2019; Marshall & Merchant, 2013; Pinto Pereira et al., 2012). For example, TV viewing and other screen-based activities completed while in a sedentary posture are associated with greater health risks than other activities completed while sedentary, such as reading or socializing (Copeland et al., 2017; de Rezende et al., 2014; Ford & Caspersen, 2012; Garcia et al., 2019; Patterson et al., 2018; Pinto Pereira et al., 2012; Ullrich et al., 2018). More research is needed to better understand the effects of time spent in various types of sedentary activities in adults of all ages, and some studies have called for a new measurement tool for sedentary behaviour that accurately measures

the amount of time spent in sedentary behaviour while also considering the types of activities completed while sedentary (Copeland et al., 2017; Marshall & Merchant, 2013; Patterson et al., 2018). Accordingly, the purpose of this study was to develop a new method of quantifying sedentary time that includes both total sedentary time and sedentary screen time, and to measure the test-retest reliability of this new method in healthy adults of all ages.

Methods

Apparently healthy adults (aged ≥18 years) were voluntarily recruited from the Lethbridge area using digital posters displayed on social media, physical posters displayed in local businesses with permission, and word-of-mouth. Quota sampling of participants in the age categories of 18-30 years, 30-39 years, 40-49 years, 50-59 years, and 60+ years was used to recruit a sample of participants of a variety of ages. Participants were excluded if they could not speak and read English, if they were a current smoker, if they were currently ill, or if they had been diagnosed with chronic diseases such as type II diabetes, cardiovascular disease, or cancer. This project received ethical approval from the Human Participant Research Committee at the University of Lethbridge (HPRC #2021-033), and written informed consent was obtained from all research participants prior to their participation in the study (Appendix 1).

Procedures

Each participant completed four in-person visits to the lab (see Figure 1). All appropriate COVID-19 precautions were taken to prevent transmission of the virus during study participation, such as masking, frequently sanitizing surfaces and equipment, verbally screening participants for COVID-19 symptoms at the beginning of each visit and following all current local and provincial COVID-19 restrictions.

During each participant's first visit to the lab, they provided informed consent (Appendix 1) and completed the health screening form which included basic demographic information (age, biological sex, gender, marital status, ethnicity, current education level, and current employment status). Participants were provided with an ActivPAL4^{TM} (PAL Technologies Ltd, Scotland, UK) inclinometer, which was secured to their anterior right thigh using medical tape and worn continuously for the next seven consecutive days (Week 1). After seven days of wear-time, participants returned to the lab for their second visit in which the inclinometer was removed, and they completed a screen time questionnaire (Appendix 2).

Two weeks after their second visit, participants returned to the lab and were provided with an inclinometer to wear for another seven consecutive days (Week 2). After the second week of wear-time, participants returned to the lab for their final visit in which the inclinometer was removed, and they completed the same screen time questionnaire. At the end of their participation in this study, participants received a $25 gift card and a copy of their own personal data.

Assessment of Sedentary Time

Device-based sedentary time was measured using ActivPAL4^{TM} inclinometers, which have been shown to be reliable and valid for measuring sedentary behaviour in both laboratory settings (Grant et al., 2006) and free-living environments (Edwardson et al., 2017). The data collected by the inclinometers were used to determine each participant's total time spent in sedentary postures using proprietary software (PAL Technologies Ltd, n.d.-b), and total sedentary time was used in subsequent calculations.

Assessment of Screen Time

Each participant's self-reported screen time was measured using the Screen Time Questionnaire (Appendix 2) developed by Vizcaino et al. (2019) which showed excellent test-retest reliability in American adults (Vizcaino et al., 2019). This questionnaire asks participants about the typical amount of time they spend each weekday and weekend day using common devices such as TVs, TV-connected devices (such as gaming consoles), computers, smartphones, and tablets. It also distinguishes between primary screen usage and background screen usage, which is important because primary screen usage is more likely to represent sedentary screen time while background screen usage may not (Vizcaino et al., 2019). Each participant's total weekday and weekend day primary screen time was used to calculate a weighted daily average, and each participant's value for "total screen time" was used in subsequent calculations.

Calculation of ISST Scores

Each participant's total sedentary time from their ActivPAL4^{TM} inclinometer data and sedentary screen time from the Screen Time Questionnaire data were used in combination to calculate an Index of Sedentary Screen Time (ISST) score. Three methods for calculating ISST scores were explored: a continuous scoring system, an ordinal scoring system, and a proportional scoring system.

Continuous ISST scores were calculated by determining each participant's hours per day of sedentary screen time and sedentary non-screen time, multiplying their sedentary screen time by 1.5 to account for the higher health risk associated with screen time (Patterson et al., 2018), and adding their sedentary screen time and sedentary non-screen time together to create an ISST score in units of "hour equivalents":

$$ISST\ Score\ (hour\ equivalents/day)$$
$$= [(total\ sedentary\ time\ in\ hours/day$$
$$- sedentary\ screen\ time\ in\ hours/day) \times 1\ hour\ equivalents$$
$$/hours]$$
$$+ [sedentary\ screen\ time\ in\ hours/day \times 1.5\ hour\ equivalents$$
$$/hours]$$

In this calculation, total sedentary time in hours per day was derived from inclinometer data, and sedentary screen time was the "total screen time" value as previously described. The primary screen use questions were used because values for primary screen usage are more likely to represent sedentary screen time, whereas "background screen usage" may not (Vizcaino et al., 2019). The value of 1.5 as the weighing factor was selected based on previous estimates of the amount of screen time and total sedentary time associated with health risk. Some previous research suggests that sedentary screen time is between approximately 1.05 and 1.5 times worse for cardiometabolic health risk than other types of sedentary time, therefore the weighing factor could be between 1.05 and 1.5 hour equivalents per day (Dempsey et al., 2018; Marin et al., 2020; Patterson et al., 2018; Ullrich et al., 2018; Vella et al., 2020). Additionally, in a recent systematic review and meta-analysis, Patterson et al. (2018) found similar health risks associated with over 3-4 hours of daily screen time compared to over 6-8 hours of daily total sedentary time. In light of this evidence, sedentary screen time was weighed at 1.5 times the reported amount, then combined with total sedentary time to create the ISST score. A higher continuous ISST score indicates greater health risk.

For the ordinal ISST scoring system, participants were placed into one of four distinct categories according to their total sedentary time and sedentary screen time (see Table 2). A previous systematic review and meta-analysis found that the negative health effects of total sedentary time appear to be worse above 6-8 hours per day of sedentary time and the negative health effects of sedentary screen time appear to be worse above 3-4 hours per day of screen time (Patterson et al., 2018). In anticipation that average sedentary time and sedentary screen time would be fairly high in this sample, the upper ends of these ranges were used as the cut-points. Thus, participants who had greater than eight hours per day of total device-measured sedentary time were considered higher risk, and participants who had greater than four hours per day of self-reported sedentary screen time were considered higher risk (Table 2). Ordinal ISST scores could range from 1-4, with a higher score indicating greater health risk.

Proportional (or ratio) ISST scores were also calculated to determine what proportion of each participant's sedentary time was also screen time. Proportional ISST scores were calculated by dividing each participant's self-reported sedentary screen time by their total device-measured sedentary time:

$$ISST\ Score = sedentary\ screen\ time\ (hours/day) \div total\ sedentary\ time\ (hours/day)$$

In this calculation, total sedentary time in hours per day was from inclinometer data and sedentary screen time was the self-reported "total screen time" value as previously described. Using this proportional method, ISST scores should range from 0 to 1, where 0 would indicate that a participant had no sedentary screen time and 1 would indicate that all a participant's sedentary time was also screen time.

Statistical Analysis

Statistical analysis was completed using RStudio (R Core Team, 2013). Descriptive statistics were calculated for the variables of interest, data visualization was conducted, and inferential statistics were calculated. Normal distribution of continuous variables was assessed using Shapiro-Wilk tests and visualized using density plots of tooth length, and normal distribution of ordinal variables was assessed by calculating skewness and kurtosis and visualized using bar charts. Continuous variables that were not normally distributed were transformed (i.e. log-transformed or squared) to see if they could be made normally distributed, and the transformed values of successfully transformed variables were used for further statistical analyses (McGraw & Wong, 1996). The test-retest reliability of the ISST scores was examined using Intraclass Correlation Coefficients (ICCs) between the ISST scores in Week 1 and Week 2 (Koo & Li, 2016). All ICCs were calculated using single-rating, absolute-agreement, two-way mixed-effects models (Koo & Li, 2016; McGraw & Wong, 1996). Results were interpreted using a common procedure for interpreting reliability coefficients, where values less than 0.5 indicate poor reliability, values between 0.5 and 0.75 indicate moderate reliability, values between 0.75 and 0.9 indicate good reliability, and values above 0.9 indicate excellent reliability (Koo & Li, 2016; Vizcaino et al., 2019).

Results

Participant Characteristics

A total of 91 participants were successfully recruited, and 87 participants completed both weeks of data collection (n = 4 chose to withdraw after Week 1 for unspecified reasons). Characteristics of the volunteer participants in total and by self-reported gender are shown in Table 3. The overall sample was 68% women, 59% of

participants were married/common-law, and 82% of participants were Caucasian/White. Most participants (85%) had attained some post-secondary education (23% had attended college, 40% had a bachelor's degree, and 22% had a graduate degree), and the majority of participants were employed full-time at the beginning of their participation (59%).

Movement Behaviours

ActivPAL4™ data were analyzed using the standard PAL Technologies software (version 8.10.12.60). Specifically, the CREA algorithm (v1.3) for 24-hour days was used such that each "day" began at midnight and ended at 11:59 pm. Only days in which the ActivPAL4™ recorded movement behaviours for at least 20 of the 24 hours of a day ("valid days" assessed using the MORA algorithm v1.0) were included in the analysis by using the "average valid day summaries" csv export in PALBatch. The ActivPAL4™ inclinometers were worn by participants for an average of 6.7 (± 1.0) and 6.5 (± 0.6) valid days during Week 1 and Week 2, respectively. On average, participants took 9,118 (± 3506) steps per day during Week 1 and 8,807 (± 3432) steps per day during the Week 2. Participants accumulated 156.1 minutes and 138.6 minutes of moderate to vigorous physical activity (measured as minutes of stepping time with a cadence of ≥100 for a duration of >1 minute) during Week 1 and Week 2, respectively. Total sedentary time was calculated in R by summing the "total sitting time (m)", "seated transport time (m)", and "secondary lying time (m)" values from the "average valid day summaries" csv export in PALBatch, because each of these variables represent sedentary time. Participants accumulated an average of 10.3 (± 2.0) and 10.4 (± 1.9) hours per day of total sedentary time and reported 6.3 (± 4.4) and 5.7 (± 3.7) hours per day of sedentary screen time during Week 1 and Week 2, respectively.

Index of Sedentary Screen Time Scores

The continuous ISST scores were an average of 13.4 (± 3.2) and 13.2 (± 2.9) hour equivalents per day for Week 1 and Week 2, respectively. Figure 2 shows the individual continuous ISST scores in each week by participant. For the ordinal ISST scores, 4 was the most common score with 59% of participants receiving a score of 4 for the first week of data collection and 53% of participants receiving a score of 4 for the second week of data collection (Figure 3). The proportional ISST scores had an average of 0.6 (± 0.4) in Week 1 and 0.6 (± 0.3) in Week 2 (Figure 4).

Intraclass Correlation Coefficients

The ICCs between Week 1 and Week 2 for each calculation method of the ISST scores are shown in Table 4. Continuous ISST scores were normally distributed in Week 1, but slightly departed from normality in Week 2 (W = 0.968, $p = .028$). Ordinal ISST scores were substantially skewed (first week -1.462; second week -1.385) and kurtotic (first week 4.346; second week 4.367), but given the ordinal nature of this variable, transformation may not be appropriate. The resulting ICC for ordinal ISST scores should be interpreted with caution. Proportional ISST scores significantly departed from normality for both weeks and were log-transformed before analysis. The continuous ISST score had an ICC of 0.844 (95% CI: 0.771, 0.895; $p < .001$), which is categorized as "good" test-retest reliability. The ordinal ISST score had an ICC of 0.727 (95% CI: 0.610, 0.812; $p < .001$) which is categorized as "moderate to good" test-retest reliability. The proportional ISST score (log-transformed) had an ICC of 0.631 (95% CI: 0.486, 0.742; $p < .001$), which is categorized as "poor to moderate" test-retest reliability.

Discussion

The purpose of this study was to examine the test-retest reliability of three different ways of combining device-measured total sedentary time and self-reported sedentary screen time. We explored three methods, and the key finding was that the continuous ISST scoring method showed the best test-retest reliability compared to the other two scoring methods. In addition to showing the best reliability, the continuous ISST scoring method has other advantages. Continuous measures of both total sedentary time and sedentary screen time were available from participants, and maintaining the continuous form of the data maintains more statistical power than if the data were converted into categorical data (Dempsey et al., 2018). Continuous variables are useful for research in movement behaviours and cardiometabolic health, especially for when comparisons are made between studies such as in systematic reviews and meta-analyses. Overall, continuous ISST scores provide a more precise measure of total sedentary time and sedentary screen time than categorical data, and this could partially explain the better test-retest reliability of the continuous ISST scores when compared to the other two scoring methods.

The main limitation of using the continuous ISST scoring method was that we were not able to find an established weighting factor in the literature to account for the proportional increase in cardiometabolic health risk associated with sedentary screen time when compared to total sedentary time. Patterson et al. (2018) conducted a systematic review and dose-response meta-analysis of 38 studies examining the relationship between sedentary behaviour and cardiovascular mortality, cancer mortality, and incidence of type II diabetes, and the authors found that there was a threshold for cardiovascular mortality and all-cause mortality of 3-4 hours per day of TV viewing time and 6-8 hours per day of

total sitting time. Based on these findings from Patterson et al. (2018), TV viewing time may be 1.5 times more harmful for health than total sitting time. Similarly, Dempsey et al. (2018) examined context-specific self-reported sedentary time in Australian adults, and found that when total sedentary time was kept constant in the linear regression model, TV viewing time and computer use while sitting were both associated with a higher clustered cardiometabolic risk score by 0.05 (95% CI 0.02, 0.08) and 0.04 (95% CI 0.01, 0.06), respectively. However, few published studies at this time have directly examined differences in domain-specific sedentary time and cardiometabolic health risk (Dempsey et al., 2018; Ullrich et al., 2018), and some studies have only looked at self-reported sedentary time which may be less valid than device-based measures of sedentary time (Chastin et al., 2018). We selected 1.5 as our best estimate of the proportional increase in cardiometabolic health risk when comparing sedentary screen time to total sedentary time in this study, and future research will examine the validity of this choice when quantifying the cardiometabolic health risk associated with sedentary screen time, total sedentary time, and continuous ISST scores.

The ordinal ISST scoring method was selected for this study to measure which participants were above the identified thresholds for sedentary screen time and total sedentary time that were associated with increased cardiometabolic health risk (Patterson et al., 2018). As previously mentioned, these thresholds are 3-4 hours per day of TV viewing time and 6-8 hours per day of total sitting time (Patterson et al., 2018). We used the upper end of these ranges as the cut-points between lower cardiometabolic health risk and higher cardiometabolic health risk in this study to provide an indication of participants who may be at even greater cardiometabolic health risk, and because we anticipated that participants in this study would accumulate large amounts of sedentary

screen time and total sedentary time. In this study, the majority of participants accumulated an average of over four hours per day of self-reported sedentary screen time and over eight hours per day of device-measured total sedentary time. This means that a large proportion of the participants had an ordinal ISST score of 4 during the first and second weeks of data collection (Table 3), which greatly contributed to the ordinal ISST scores being substantially skewed and kurtotic. Converting the continuous variables of sedentary screen time and total sedentary time into four ordinal categories also reduced the remaining statistical power of the ICC tests or other statistical tests that could be used, and made a parametric test such as an ICC not appropriate to use due to the violation of the assumption of normality. This finding could indicate that this ordinal ISST scoring method is not sensitive enough to use in studies with smaller sample sizes, but may be less of an issue in studies with large sample sizes. Despite this limitation, the ordinal scoring method uses cut-off points that are well-supported by the current literature (Patterson et al., 2018) and therefore might be more valid than the continuous scoring methods with regard to cardiometabolic health risk, and future research will examine this.

The proportional ISST score values were expected to be between 0 and 1; however, 26.4% (n = 23) participants had a proportional ISST score above 100% (ranging from 1.01 to 2.63). This suggests that their primary screen usage exceeded their total sedentary time, which indicates that participants over-estimated their typical screen time, possibly reported "dual screen use" as two separate values, or exhibited some other reporting error. For example, if a participant watched TV while also checking social media on their smartphone, they may have reported this concurrent behaviour as both TV viewing time and smartphone use time separately instead of as primarily smartphone use time. Thus, our findings suggest that the Screen Time Questionnaire from Vizcaino et al.

(2019) may have limitations for capturing certain aspects of screen time such as dual screen use, despite this behaviour becoming increasingly common (Van Cauwenberge et al., 2014). Alternately, our results support previous suggestions that participants may be less accurate at reporting their own screen time use when using retroactive questionnaires compared to other screen time measurement techniques such as screen time logs, direct observation, or device-based measures (Vizcaino et al., 2019). Future research on sedentary screen time may benefit from avoiding the use of retrospective questionnaires for measuring the use of screens during leisure time, and instead developing device-based measures that accurately account for sedentary screen use across a variety of devices such as using a phone app to track smartphone usage.

One main disadvantage of the proportional ISST scoring method that we used in this study is that it does not provide any information regarding the total volume of sedentary behaviour that participants accumulate. For example, two participants could have the same proportional ISST score but one participant could have double or triple the total sedentary time and sedentary screen time as the other participant. This could result in both participants being categorized as having the same anticipated cardiometabolic health risk even though the participant with less total sedentary time and sedentary screen time would be at lower cardiometabolic health risk based on their movement behaviours than the other participant. Overall, the proportional ISST scoring method we used in this study may be less useful than the continuous scoring method or the ordinal scoring method, but the validity of the proportional scoring method with regard to cardiometabolic health risk could still be explored in future research.

Strengths and Limitations

A strength of this study was the broad age range of the participants, as the final sample included participants from 19 years to 71 years of age. Most of the currently published studies regarding screen time focus on either children, adolescents, or older adults (Vella et al., 2020), therefore this study on healthy participants at various stages of adulthood helped to begin to address this gap in the current literature. Despite this strength, the participants in this study are not likely to represent all Canadians or North Americans because they were recruited from the Lethbridge area using convenience sampling and quota sampling by age category. Most (82%) of the participants in this study reported their ethnicity as Caucasian/White, and the average minutes per week of moderate-to-vigorous physical activity among study participants was almost two times higher than average Canadians with full-time employment (Prince et al., 2020). Additionally, there were more women than men who participated in this study (68% women). Taken together, the specific characteristics of the participants in this study limit the generalizability of these findings, and future studies are needed to assess the test-retest reliability of the various ISST scoring methods in diverse populations such as other ethnic groups, people who are less physically active, people living with cardiometabolic diseases, and older adults over the age of 71 years.

The screen time questionnaire from Vizcaino et al. (2019) that was used in this study has several strengths and limitations. While much of the previous literature has focused exclusively on TV viewing time, a main benefit of using this screen time questionnaire is that it captures both TV viewing time and more modern ways of using screens such as TV-connected devices, smartphones, laptops/computers, and tablets. This screen time questionnaire has acceptable test-retest reliability across three days (Vizcaino

et al., 2019); however, the validity has not been established. Retrospective screen time questionnaires such as the one used in this study may be less valid than other measures of screen time such as screen time logs (Vizcaino et al., 2019; Wade et al., 2021). Despite this limitation, some studies have demonstrated an association between scores on this questionnaire and important health outcomes, including mental health (Wiciak et al., 2022), sleep quality (Bani-Issa et al., 2022), smartphone-related anxiety during COVID-19 (Sui et al., 2022), and a device-based measure of screen time (Wade et al., 2021). Future research is needed to assess the validity of this screen time questionnaire in relation to cardiometabolic health.

A strength of this study is the novel combination of device-measured total sedentary time and self-reported sedentary screen time. The device-based measure of total sedentary time was also a strength of this study because the ActivPAL4^{TM} inclinometers used have been shown to be valid and reliable for measuring total sedentary time in adults (Edwardson et al., 2017; Grant et al., 2006). This combination of methods allows a more nuanced approach to characterizing sedentary time that may allow better prediction of health risk.

Conclusion

In this study, we were able to demonstrate that the continuous and proportional ISST scores showed acceptable test-retest reliability across two weeks in a group of healthy adults between the ages of 19 and 71 years. Future research should assess the criterion validity of the new ISST scores and cardiometabolic health risk.

Table 2. Ordinal Scoring Method for the Index of Sedentary Screen Time

	< 8 hours of total ST/day	≥ 8 hours of total ST/day
< 4 hours of sedentary screen time/day	Low ST + low screen time; **ISST Score = 1** (lowest risk)	High ST + low screen time; **ISST Score = 2** (moderate risk)
≥ 4 hours of sedentary screen time/day	Low ST + high screen time; **ISST Score = 3** (high risk)	High ST + high screen time; **ISST Score = 4** (highest risk)

Abbreviations: ISST = Index of Sedentary Screen Time; ST = Sedentary Time

Table 3. Characteristics of Study Population (overall and by self-reported gender)

	Total Sample	**Man**	**Woman**	**Other**
N (%)	87 (100)	26 (30)	59 (68)	2 (2)
Age, years (mean ± SD)	40.7 ± 16.1	41.0 ± 13.9	41.3 ± 16.9	20 ± 1.4
Sex (N; %)				
Male	26 (30)	26 (100)	0 (0)	0 (0)
Female	60 (69)	0 (0)	59 (100)	1 (50)
Other	1 (1)	0 (0)	0 (0)	1 (50)
Gender (N; %)				
Man	26 (30)	26 (100)	0 (0)	0 (0)
Woman	59 (68)	0 (0)	59 (100)	0 (0)
Other	2 (2)	0 (0)	0 (0)	2 (100)
Marital Status (N; %)				
Single	28 (32)	5 (19)	21 (36)	2 (100)
Married/Common-law	51 (59)	21 (81)	30 (51)	0 (0)
Divorced	6 (7)	0 (0)	6 (10)	0 (0)
Widowed	2 (2)	0 (0)	2 (1)	0 (0)
Ethnicity				
Caucasian/White	71 (82)	19 (73)	50 (85)	2 (100)
African American/Black	0 (0)	0 (0)	0 (0)	0 (0)
Indigenous/Aboriginal	1 (1)	0 (0)	1 (1)	0 (0)
Asian	7 (8)	3 (12)	4 (6)	0 (0)
Other	8 (9)	4 (15)	4 (6)	0 (0)
Current Education Level (N; %)				
Grade School	2 (2)	0 (0)	2 (3)	0 (0)
Junior High	0 (0)	0 (0)	0 (0)	0 (0)
High School	11 (13)	2 (8)	9 (15)	0 (0)
College (2-4 years)	20 (23)	10 (38)	10 (17)	0 (0)
Bachelor's Degree	35 (40)	6 (23)	27 (46)	2 (100)
Graduate Degree	19 (22)	8 (31)	11 (19)	0 (0)
Current Employment Status (N; %)				
Full-time	51 (59)	19 (73)	31 (53)	1 (50)
Part-time	16 (18)	3 (12)	12 (20)	1 (50)
Unemployed	6 (7)	1 (4)	5 (8)	0 (0)
Other	14 (16)	3 (12)	11 (19)	0 (0)

	Total Sample	Man	Woman	Other
ActivPAL Wear Time, days (mean ± SD)				
Week 1	6.7 ± 1.0	6.4 ± 1.2	6.9 ± 0.9	7 ± 0
Week 2	6.5 ± 0.6	6.2 ± 0.7	6.6 ± 0.5	7 ± 0
Physical Activity, steps/day (mean ± SD)				
Week 1	9118 ± 3506	10918 ± 3745	8361 ± 3148	8023 ± 3407
Week 2	8807 ± 3432	10458 ± 3458	8088 ± 3183	8558 ± 4965
Physical Activity, min/day of MVPA (mean ± SD)				
Week 1	22.3 ± 20.8	24.0 ± 23.7	22.0 ± 19.8	12.9 ± 13.9
Week 2	19.8 ± 20.4	20.9 ± 20.9	19.6 ± 20.7	14.1 ± 2.5
Sedentary Time, hours/day (mean ± SD)				
Week 1	10.3 ± 2.0	10.6 ± 2.1	10.1 ± 1.9	9.4 ± 4.2
Week 2	10.4 ± 1.9	10.7 ± 2.0	10.2 ± 1.9	9.6 ± 3.8
Screen Time, hours/day (mean ± SD)				
Week 1	6.3 ± 4.4	6.4 ± 3.3	6.1 ± 4.8	11.1 ± 7.3
Week 2	5.7 ± 3.7	5.1 ± 2.5	5.8 ± 4.0	11.4 ± 5.3
Continuous ISST Score, hour equivalents/day (mean ± SD)				
Week 1	13.4 ± 3.2	13.8 ± 2.7	13.2 ± 3.3	14.9 ± 7.9
Week 2	13.2 ± 2.9	13.3 ± 2.7	13.1 ± 3.0	15.3 ± 6.4
Ordinal ISST Score (N; %)				
Week 1				
Score of 1	6 (7)	1 (4)	5 (8)	0 (0)
Score of 2	5 (6)	1 (4)	3 (5)	1 (50)
Score of 3	25 (29)	8 (31)	17 (29)	0 (0)
Score of 4	51 (59)	16 (62)	34 (58)	1 (50)
Week 2				
Score of 1	6 (7)	2 (8)	4 (7)	0 (0)
Score of 2	4 (5)	0 (0)	3 (5)	1 50)
Score of 3	31 (36)	10 (38)	21 (36)	0 (0)
Score of 4	46 (53)	14 (54)	31 (53)	1 (50)
Proportional ISST Score (mean ± SD)				
Week 1	0.6 ± 0.4	0.6 ± 0.3	0.6 ±0.4	1.1 ± 0.3
Week 2	0.6 ± 0.3	0.5 ± 0.2	0.6 ± 0.4	1.2 ± 0.1

Note. ISST = Index of Sedentary Screen Time; SD = Standard Deviation

Table 4. Intraclass Correlation Coefficients for the Index of Sedentary Screen Time Scores in Week 1 and Week 2

	ICC	95% Confidence Interval		*p*-value
		Lower	Upper	
Continuous ISST Score	0.844	0.771	0.895	0.000
Ordinal ISST Score	0.727	0.610	0.812	0.000
Proportional ISST Score	0.631	0.486	0.742	0.000

Note. Intraclass correlation coefficients (two-way mixed-effects agreement model with a single rater) for the Index of Sedentary Screen Time scores calculated using a continuous scoring method, an ordinal scoring method, and a proportional scoring method. ISST scores were calculated using the sedentary time and screen time measures for each participant (n = 87), where sedentary time was measured using ActivPAL4™ inclinometers two separate times and screen time was measured using a questionnaire two separate times. Abbreviations: ICC = Intraclass Correlation Coefficient; ISST = Index of Sedentary Screen Time

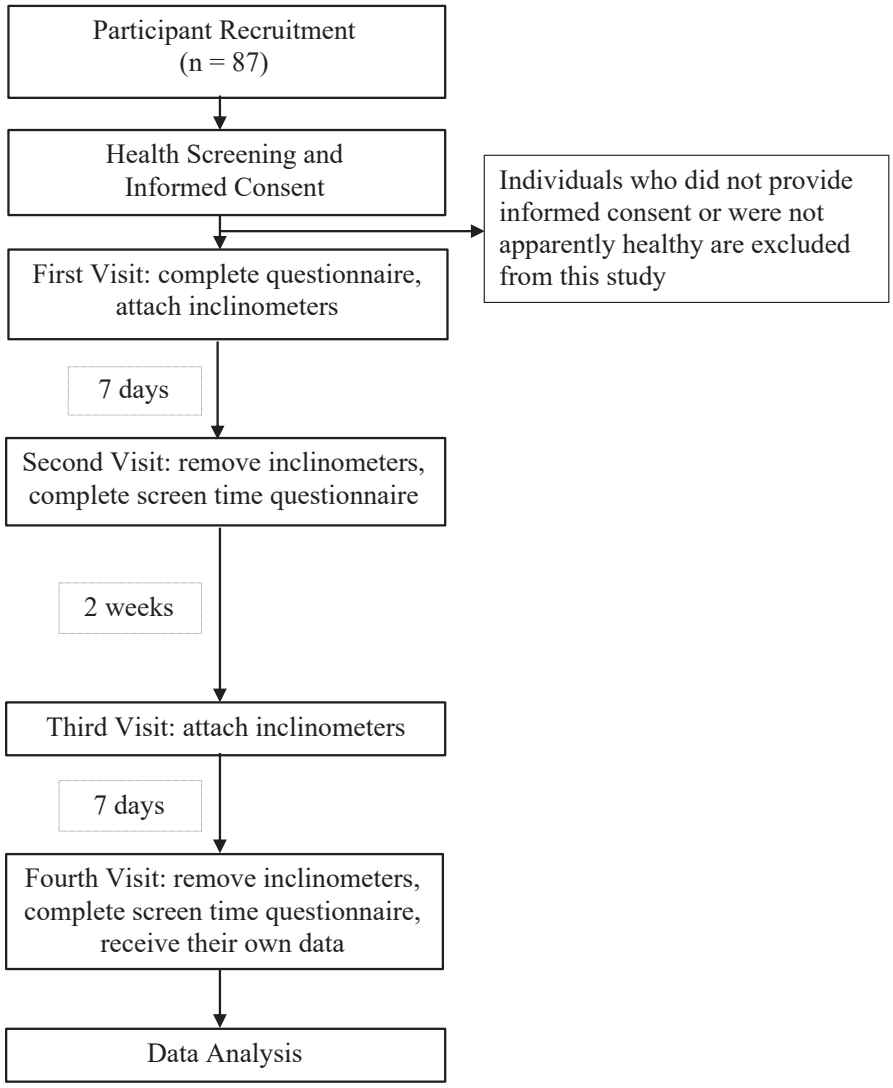

Figure 1. Study Procedure Timeline

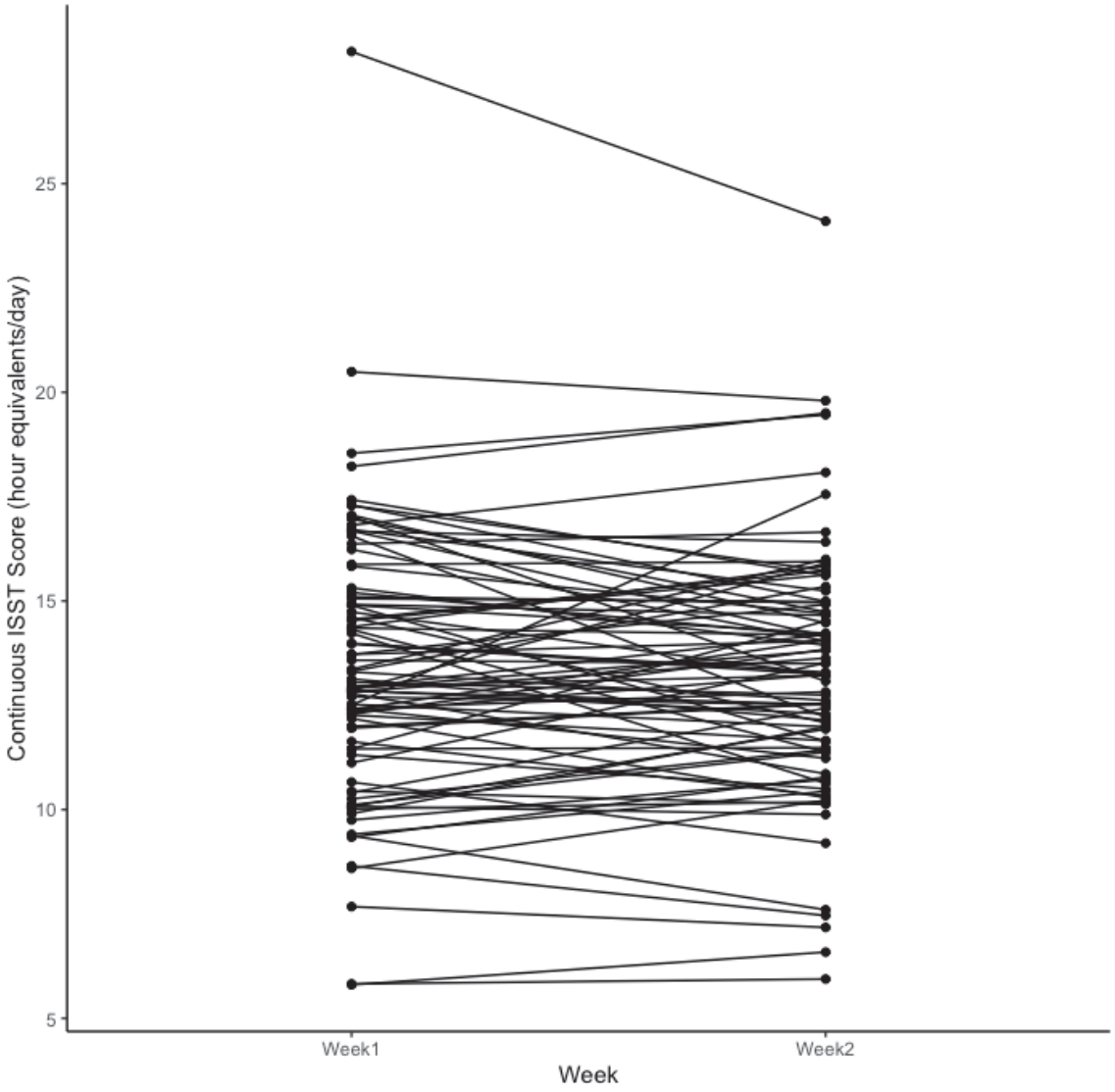

Figure 2. Individual continuous ISST scores in healthy adult participants, by week including connecting lines between weeks for each participant (n = 87)

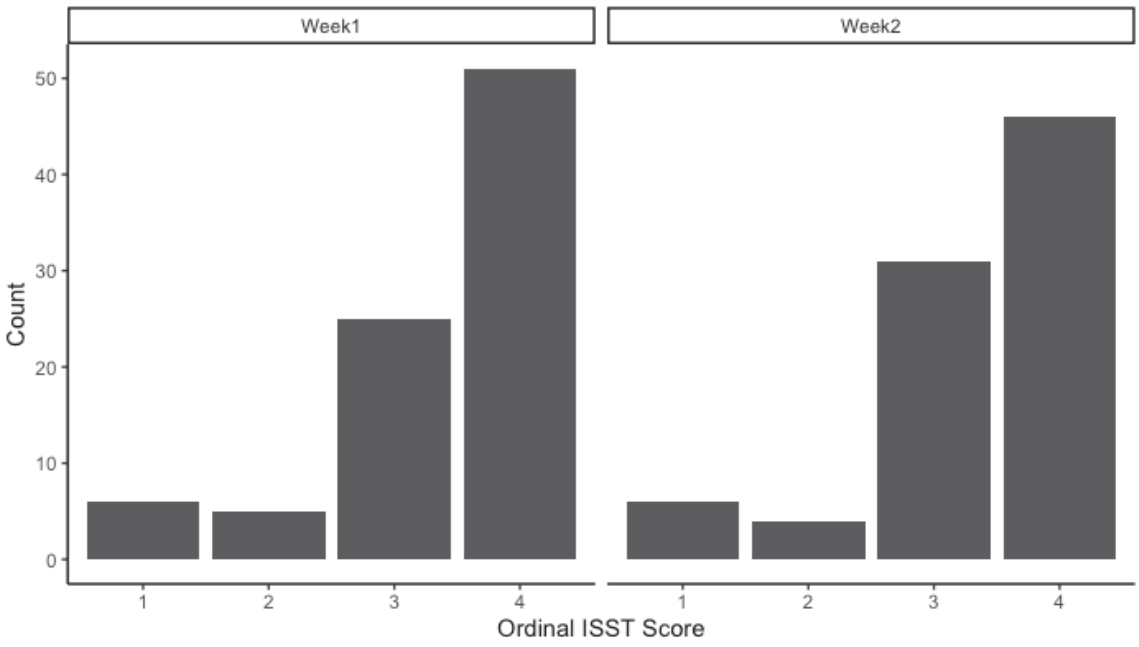

Figure 3. Count of ordinal ISST scores in healthy adult participants, by week (n = 87)

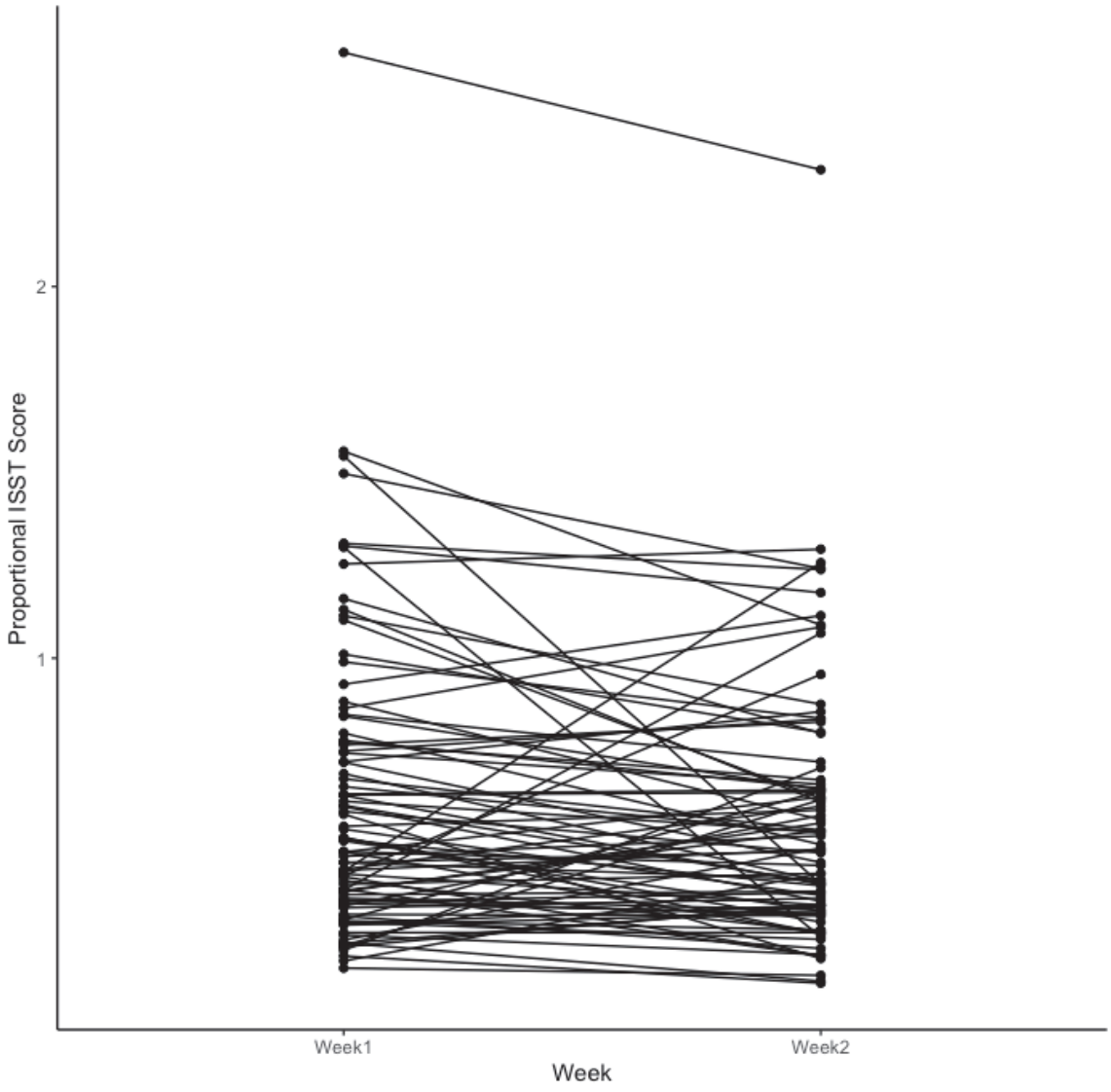

Figure 4. Proportional ISST scores in healthy adult participants, by week including connecting lines between weeks for each participant (n = 87)

CHAPTER 3: ISST SCORES AND CARDIOMETABOLIC HEALTH RISK

Abstract

Background: Engaging in prolonged periods of sedentary behaviour is increasingly common and is associated with numerous cardiometabolic health risk factors. Screen time is a ubiquitous activity often completed while sedentary and may pose a greater health risk than other sedentary activities like reading or socializing. The purpose of this study was to determine if a novel composite measure of device-measured total sedentary time and self-reported screen time could better predict cardiometabolic health risk than sedentary time or screen time alone.

Methods: In this cross-sectional study, healthy participants (n = 91; 67% female; 40.6 ± 15.9 years) wore an ActivPAL4™ (PAL Technologies Ltd) for seven days to measure sedentary time and physical activity. A questionnaire was used to assess typical leisure screen time. Device-measured sedentary time and self-reported screen time were combined to create continuous Index of Sedentary Screen Time (ISST) scores. Fasted capillary blood samples were collected to measure glucose, glycosylated hemoglobin, and lipid panels using the CardioChek® Plus Analyzer (PTS Diagnostics) and A1CNOW®+ machine (PTS Diagnostics). Saliva samples were collected to measure salivary C-reactive protein as a marker of inflammation. Body mass index, waist circumference, and resting blood pressure were also measured. Clustered cardiometabolic risk scores (CMRS) were calculated as an average of the standardized z-scores of the 11 risk factors. Associations between the dependent variable of CMRS and the independent variables of sedentary time, screen time, and ISST scores were assessed using multiple linear regressions (covariates of age, biological sex, and physical activity).

Results: ISST scores were significantly correlated with CMRS (r[79] = 0.29, p = .010). In the fully adjusted Model 3, multiple linear regression showed that while self-reported screen time was a predictor of CMRS (B = 0.04, 95% CI 0.01 – 0.07, p = 0.013), device-measured total sedentary time was not. ISST scores were also a predictor of CMRS (B = 0.06, 95% CI 0.01 – 0.10, p = 0.009).

Conclusions: Using a novel approach of combining device-based and self-report measures, we showed that accounting for screen time in measures of total sedentary time may improve the prediction of health risk. However, further research is needed to determine if the ISST scores are a better technique for helping identify individuals at greater cardiometabolic health risk based on their habitual movement behaviours than screen time or sedentary time alone.

Background

In higher-income countries worldwide, the leading causes of morbidity and premature mortality include cardiometabolic diseases such as heart disease and type II diabetes (World Health Organization, 2020b). An important modifiable risk factor for the development and management of the cardiometabolic diseases of cardiovascular disease, type II diabetes, and metabolic syndrome is an individual's habitual movement behaviours, including physical activity and time spent in sedentary behaviour (Buman et al., 2014; Tremblay et al., 2010; van der Berg et al., 2016; Warburton et al., 2006; Wilmot et al., 2012). Sedentary behaviour is defined as any activity completed while in a seated or reclined position with low energy expenditure while awake (Tremblay et al., 2017), and sedentary time refers to the amount of time that an individual spends in sedentary behaviour (Tremblay et al., 2010).

Individuals who regularly engage in high amounts of sedentary time are at an increased risk for poor cardiometabolic health (Brocklebank et al., 2015; Buman et al., 2014; de Rezende et al., 2014; Dickins et al., 2018; Edwardson et al., 2012; Healy et al., 2011; Owen et al., 2010; Patterson et al., 2018; Powell et al., 2017; Vella et al., 2020; Wilmot et al., 2012; Wirth et al., 2016; Zhao et al., 2020) independently of their physical activity involvement (Owen et al., 2010). Specifically, total sedentary time is positively correlated with the incidence of cardiovascular disease (Dickins et al., 2018; Pandey et al., 2016; Wilmot et al., 2012), type II diabetes (Biswas et al., 2015; Grøntved & Hu, 2011; Patterson et al., 2018; Wilmot et al., 2012), metabolic syndrome (de Rezende et al., 2014; Edwardson et al., 2012; Marin et al., 2020; Powell et al., 2017), certain types of cancer (Berger et al., 2019; Biswas et al., 2015), cause-specific mortality (Biswas et al., 2015; Dickins et al., 2018; Grøntved & Hu, 2011; Patterson et al., 2018; Wilmot et al., 2012; Zhao et al., 2020) and all-cause mortality (Biswas et al., 2015; de Rezende et al., 2014; Grøntved & Hu, 2011; Patterson et al., 2018; Wilmot et al., 2012; Zhao et al., 2020). Total sedentary time is also detrimentally associated with various cardiometabolic health risk factors including waist circumference (de Rezende et al., 2014; Healy et al., 2011; Powell et al., 2017; Wirth et al., 2016), glycosylated hemoglobin (Wirth et al., 2016), high-density lipoprotein (HDL) cholesterol (Healy et al., 2011; Powell et al., 2017), triglycerides (Brocklebank et al., 2015; Powell et al., 2017), and C-reactive protein (CRP) concentrations (Chastin et al., 2015; de Rezende et al., 2014; Healy et al., 2011).

While any activity completed in a sedentary posture is considered sedentary behaviour (Tremblay et al., 2017), recent findings suggest that the type of activity completed while sedentary has an important impact on cardiometabolic health risk (Brenda Biaani et al., 2020; Ford & Caspersen, 2012; Garcia et al., 2019; Marshall &

Merchant, 2013; Pinto Pereira et al., 2012). Several studies have identified TV viewing time or screen time as specific risk factors for poor cardiometabolic health (Ullrich et al., 2018; Vella et al., 2020), and TV viewing and other screen-based sedentary activities appear to have a worse effect on health risk than other sedentary activities, such as socializing or reading (Copeland et al., 2017; de Rezende et al., 2014; Ford & Caspersen, 2012; Garcia et al., 2019; Patterson et al., 2018; Pinto Pereira et al., 2012; Ullrich et al., 2018). Other authors have reported that some sedentary behaviours such as working (occupational sedentary time), reading, or socializing while in a sedentary posture appear to have little or no negative effects on cardiometabolic health (Garcia et al., 2019; Pinto Pereira et al., 2012; Ullrich et al., 2018). Thus, these newer findings suggest that accounting for the type of activity completed while sedentary could be as important if not more important than measuring total sedentary time, and leisure-time sedentary screen time has specifically emerged as a critical risk factor for poor cardiometabolic health. Also, some authors have reported that sedentary screen time is the most common source of leisure-time sedentary time (Ford & Caspersen, 2012), therefore it may be an important target for interventions designed to reduce cardiometabolic health risk by limiting leisure-time sedentary time.

According to the difference in cardiometabolic health risk associated with various types of sedentary activities, it appears prudent to consider the type of sedentary activity completed when assessing health risk. However, the only feasible way to assess time spent in specific behaviours to date is by using self-report, which has numerous previously established limitations such as recall bias and social desirability bias (Chastin et al., 2018; Grøntved & Hu, 2011; Tremblay et al., 2010). Device-based measures of sedentary time collected using wearable technology such as accelerometers or

inclinometers are widely considered more accurate than self-reported measures, because they do not rely on a person's memory (Olanrewaju et al., 2020; Powell et al., 2017). Thus, some studies have identified a need for a measurement approach that accurately accounts for not only the amount of time spent in sedentary behaviour, but also the types of activities completed while sedentary (Copeland et al., 2017; Marshall & Merchant, 2013; Patterson et al., 2018). The purpose of this study was to develop and test a new quantification technique that combines device-measured sedentary time and self-reported leisure-time sedentary screen time, and to determine if this new technique was a better predictor of cardiometabolic health risk than either total sedentary time or sedentary screen time alone in healthy adults of all ages.

Methods

Apparently healthy adults (aged ≥18 years) were voluntarily recruited from the Lethbridge area using digital posters displayed on social media, physical posters displayed in local businesses with permission, and word-of-mouth. Participants were excluded if they could not speak and read English, if they were a current smoker, if they were currently sick, or if they had currently been diagnosed with any chronic disease such as type II diabetes, cardiovascular disease, or cancer. This project was reviewed and approved by the Human Participant Research Committee at the University of Lethbridge (HPRC #2021-033), and written informed consent was obtained from all research participants prior to their participation in the study (Appendix 1).

Procedures

Each participant completed two in-person visits to the lab (see Figure 1). All appropriate COVID-19 precautions were taken to prevent transmission of the virus during study participation, such as masking, frequently sanitizing surfaces and equipment,

verbally screening participants for COVID-19 symptoms at the beginning of each visit, and following all current local and provincial COVID-19 restrictions.

During each participant's first visit to the lab, they provided informed consent (Appendix 1) and basic demographic information (age, biological sex, gender, marital status, ethnicity, current education level, and current employment status). Participants were provided with an ActivPAL4™ (PAL Technologies Ltd, Scotland, UK), which was secured to their anterior right thigh using medical tape and worn continuously for the next seven consecutive days.

After seven days of wear-time, participants returned to the lab for their second visit in which the ActivPAL4™ was removed, and they completed a screen time questionnaire (Appendix 2). Participants were fasted (9-12 hours) and the following cardiometabolic risk factors were collected: resting systolic blood pressure, resting diastolic blood pressure, height, weight, waist circumference, salivary C-reactive protein (CRP) concentration, high-density lipoprotein (HDL) cholesterol, low-density lipoprotein (LDL) cholesterol, total cholesterol, fasting blood triglycerides, fasting blood glucose, and glycosylated hemoglobin. All participants received a $25 gift card and a copy of their own personal data which included their sedentary behaviour, physical activity, screen time, and cardiometabolic risk factor measures.

Assessment of Sedentary Time

Device-based sedentary time was measured using ActivPAL4™ devices (PAL Technologies Ltd, Scotland, UK), which include both accelerometers and inclinometers and can therefore measure both body movement and body position. ActivPAL4™s have been shown to be reliable and valid for measuring sedentary behaviour in both laboratory settings (Grant et al., 2006) and free-living environments (Edwardson et al., 2017). The

raw ActivPAL4™ data was analyzed in the PALBatch proprietary software (version 8.10.12.60) using the v1.3 CREA algorithm and valid days were determined using the v1.0 MONA algorithm (PAL Technologies Ltd, n.d.-b). The PALBatch "average valid day summaries" csv export was used, such that only days in which the ActivPAL4™ recorded movement behaviours for at least 20 of the 24 hours of a day ("valid days") were included in the analysis. The data collected by the ActivPAL4™s and exported from PALBatch were used to determine each participant's total time spent in sedentary postures by summing "total sitting time", "seated transport time", and "secondary lying time", and this calculated total sedentary time was used in subsequent calculations and statistical analyses.

Assessment of Screen Time

Each participant's self-reported leisure-time screen time was measured using the Screen Time Questionnaire (Appendix 2) recently developed by Vizcaino et al. (2019) which showed excellent test-retest reliability in American adults (Vizcaino et al., 2019). This questionnaire asked participants about the typical amounts of time they spend each weekday and weekend day using the common devices of TVs, TV-connected devices (such as gaming consoles), computers, smartphones, and tablets. It also distinguishes between primary screen usage and background screen usage, which is important because primary screen usage is more likely to represent sedentary screen time while background screen usage may not (Vizcaino et al., 2019). Participants filled out the questionnaire in the lab during their study visit, and were verbally instructed to only report leisure-time screen time in the questionnaire. Each participant's total weekday and weekend day primary screen time were used to calculate a weekly average, and each participant's value for "total screen time" was used in subsequent calculations and statistical analyses.

Assessment of Cardiometabolic Health

Cardiometabolic health risk was assessed using measures of cardiovascular health (resting blood pressure), anthropometry (body mass index and waist circumference), blood lipids (HDL cholesterol, LDL cholesterol, total cholesterol, and blood triglycerides), blood glucose control (fasting blood glucose and glycosylated hemoglobin), and systemic inflammation (salivary CRP) (Dempsey, Matthews, et al., 2020; Edwardson et al., 2012; Kirk & Klein, 2009). Height and weight were measured using a balance beam scale and stadiometer (Pelstar LLC, n.d.), and were then used to calculate body mass index (kg/m^2). Waist circumference was measured using a Gulick tension-controlled tape measure (FitnessMart division of Country Technology Inc., n.d.). Resting systolic and diastolic blood pressures were measured three times using an automated sphygmomanometer (Almedic, n.d.) after sitting quietly for 5-10 minutes, and the average of the three measures was used. Finger capillary blood samples were used to measure each participant's fasting blood glucose, glycosylated hemoglobin, HDL cholesterol, LDL cholesterol, total cholesterol, and blood triglycerides. Approximately 60 μL of blood was collected from each participant, and samples were immediately analyzed using the CardioChek Plus Analyzer (PTS Diagnostics, Whitestown, IN) and the A1CNOW®+ machine (PTS Diagnostics, Whitestown, IN) according to the manufacturer's instructions. A saliva sample was collected via the passive drool method (Salimetrics LLC, State College, PA), and immediately frozen at -80°C until analysis. Saliva samples were analysed for CRP using enzyme-linked immunosorbent assay (ELISA) kits (Salimetrics LLC, State College, PA) according to the manufacturer's instructions. Any salivary CRP concentration exceeding 6000 pg/mL was excluded from

further analyses, because this indicates an acute infection instead of chronic systemic inflammation (Ouellet-Morin et al., 2011; Pepys & Hirschfield, 2003; Truba et al., 2018).

Calculation of Clustered Cardiometabolic Risk Scores

Clustered cardiometabolic risk scores were calculated for each participant as according to the procedures described in Dempsey et al. (2018). Each of the 11 cardiometabolic health risk factors were standardized according to the means and standard deviations in this sample to create a z-score. The z-score from each of the participant's 11 cardiometabolic health risk factors was summed, then divided by 11 to provide the average z-score. For all clustered cardiometabolic risk score calculations, the value of HDL cholesterol was inverted since this biomarker is inversely correlated with cardiometabolic health risk (Ullrich et al., 2018). A higher clustered cardiometabolic risk score indicates higher cardiometabolic health risk.

Calculation of ISST Scores

The Index of Sedentary Screen Time (ISST) is a measure of sedentary time that combines device-based total sedentary time and self-reported leisure screen time as described in Chapter 2. Briefly, ISST scores were calculated by determining each participant's hours per day of sedentary screen time and sedentary non-screen time, multiplying their sedentary screen time by 1.5 to account for the higher health risk associated with screen time (Patterson et al., 2018), and adding their sedentary screen time and sedentary non-screen time together to create an ISST score in units of "hour equivalents" per day. In this calculation, total sedentary time in hours per day was from ActivPAL4™ data, and sedentary screen time was the "total screen time" value as previously described. The primary screen use questions were used because values for primary screen usage are more likely to represent sedentary screen time, whereas

"background screen usage" may not (Vizcaino et al., 2019). A higher ISST score indicates more sedentary screen time and total sedentary time.

Covariates

The potential covariates of the relationship between cardiometabolic health risk and sedentary behaviour include age, biological sex, gender, ethnicity, current level of education (as a proxy of socioeconomic status), marital status, current employment status, and moderate-to-vigorous physical activity (Rhodes et al., 2012; Van Dyck et al., 2011). All of the potential covariates except for physical activity were assessed using a self-report questionnaire, and moderate-to-vigorous physical activity was measured by the ActivPAL4^{TM}s as minutes per day of stepping time with a cadence of ≥100 for a duration of >1 minute (Lee & Dall, 2019) and as average total number of steps per valid day. The most important potentially confounding variables of age, biological sex, and physical activity were selected *a priori* (Farrahi et al., 2021; Jefferis et al., 2019) based on previous research on sedentary behaviour and cardiometabolic health. Associations between other potentially confounding variables and outcome or exposure variables were assessed using Analysis of Variance (ANOVAs) for nominal and ordinal variables and Spearman's bivariate correlations for continuous variables (results not shown) (Pagano & Gauvreau, 2000).

Statistical Analysis

Statistical analysis was completed using RStudio (R Core Team, 2013). Descriptive statistics were calculated for the variables of interest, data visualization was conducted, and inferential statistics were calculated. There were 10 participants who had missing data values in the following categories: CRP concentrations exceeding 6000

pg/mL (n = 1), inconclusive CRP assay results (n = 4), and blood lipid values that were too low to be measured by the CardioChek Plus analyzer (total cholesterol [n = 1], triglycerides [n = 5], and therefore calculated LDL cholesterol [n = 6]). One additional participant (n = 1) was omitted from the analysis due to reporting greater than 24 hours per day of screen time. Participants with missing data values were omitted from the correlations and regression models. For the outcome and exposure variables, normal distribution of continuous variables was assessed using Shapiro-Wilk tests and visualized using density plots of tooth length. Continuous variables that were not normally distributed were transformed (i.e. log-transformed or squared) to see if they could be made normally distributed (McGraw & Wong, 1996), but the untransformed values for all variables were used for further statistical analyses. A secondary sensitivity analysis was conducted with transformed values to test the robustness of the statistical models (results not shown).

Associations between clustered cardiometabolic risks scores and sedentary time, sedentary screen time, and ISST scores were assessed using Pearson's bivariate correlations for pairs of variables that met the assumptions for parametric tests (Pagano & Gauvreau, 2000) or Spearman's bivariate correlations for variables for which the assumptions were not met. Next, simple and multiple linear regressions were conducted between the clustered cardiometabolic risk scores and the exposure variables.

Results

Participant Characteristics

A total of 91 participants volunteered, and all participants completed both study visits. Characteristics of the volunteer participants in total and by self-reported biological sex are shown in Table 5, Table 6, and Table 7. The overall sample was 67% female, 57%

of participants were married/common-law, and 82% of participants were Caucasian/White. Most participants (84%) had attained some post-secondary education, and the majority of participants were employed full-time at the beginning of their participation (Table 5). Participants had an average clustered cardiometabolic risk score of -0.006 (± 0.542), with a range of -0.995 to 1.238. The means and standard deviations for each measured cardiometabolic health risk factor are shown in Table 6.

Movement Behaviours and Index of Sedentary Screen Time Scores

The ActivPAL4™s were worn by participants for an average of 6.7 (± 1.0) valid days (Table 7). On average, participants took 9167 steps per day, and accumulated 158.9 minutes per week of moderate to vigorous physical activity (measured as minutes of stepping time with a cadence of ≥100 for a duration of >1 minute). Participants accumulated an average of 10.3 (± 2.0) hours per day of total sedentary time and reported 6.3 (± 4.4) hours per day of sedentary screen time. The ISST scores were an average of 13.5 (± 3.2) hour equivalents per day, as shown in Figure 6.

Tests of Normal Distribution

In this sample, sedentary screen time significantly departed from normality ($W = 0.88$, $p < 0.001$), but did not significantly depart from normality after log-transformation ($W = 0.98$, $p = 0.200$). Total sedentary time did not significantly depart from normality ($W = 0.97$, $p = 0.072$), and neither did ISST scores ($W = 0.99$, $p = 0.836$). Clustered cardiometabolic risk scores significantly departed from normality ($W = 0.96$, $p = 0.012$), and still significantly departed from normality after log-transforming the individual biomarkers that were not normally distributed before calculating their individual z-scores and averaging them together (Dempsey et al., 2018; Edwardson et al., 2020). Moderate-

to-vigorous physical activity significantly departed from normality (W = 0.85, $p < 0.001$) as did step counts (W = 0.94, $p < 0.001$), but neither significantly departed from normality after square-root transformation (W = 0.98, $p = 0.298$ and W = 0.98, $p = 0.100$, respectively). Due to the non-normality of some of the variables, Spearman's bivariate correlations were completed between the three measures of sedentary time and clustered cardiometabolic risk scores and served as a sensitivity analysis (Table 8).

Regression Models

Simple and multiple linear regression models were calculated to determine the association between the three measures of sedentary time (self-reported leisure screen time, total device-based sedentary time, and ISST scores) and clustered cardiometabolic risk scores. Model 1 showed crude associations with no adjustment for covariates, Model 2 included the covariates of age and biological sex, and Model 3 included the covariates of age, biological sex, and physical activity measured as step counts per day (as shown in Tables 9, 10, and 11). Plots were examined, and the assumptions for linear regression did not appear to be violated. As a secondary sensitivity analysis, all linear regression models were also conducted with transformed values for clustered cardiometabolic risk scores, and the results did not substantially differ (results not shown).

Screen Time and CMRS

The relationship between sedentary screen time and clustered cardiometabolic risk score is shown in Table 9 and Figure 7. Sedentary screen time was significantly positively associated with clustered cardiometabolic risk scores, and remained significant even after adjusting for age, sex, and physical activity. In the fully adjusted model (Model 3), each additional hour per day of sedentary screen time was associated with a 0.04 increase in clustered cardiometabolic risk score (z-score).

Total Sedentary Time and CMRS

The relationship between total sedentary time and clustered cardiometabolic risk score is shown in Table 10 and Figure 8. Unlike sedentary screen time, total device-measured sedentary time was not significantly associated with clustered cardiometabolic risk scores.

ISST Scores and CMRS

The relationship between ISST scores and clustered cardiometabolic risk score is shown in Table 11 and Figure 9. The ISST scores were significantly positively associated with clustered cardiometabolic risk scores, and remained significant even after adjusting for age, sex, and physical activity. In the fully adjusted model (Model 3), each additional "hour equivalent" per day of ISST score was associated with a 0.06 increase in clustered cardiometabolic risk score (z-score).

Discussion

The purpose of this study was to examine the association between cardiometabolic heath risk (measured as clustered cardiometabolic risk scores) and self-reported leisure-time screen time, device-measured total sedentary time, and the ISST scoring method in a sample of healthy adults. The importance of examining this was to determine if combining self-reported leisure-time screen time and device-based total sedentary time (as an ISST score) would allow for a better prediction of cardiometabolic health risk than measuring either sedentary screen time or total sedentary time separately, or relying exclusively on self-reported measurement methods for sedentary behaviour. Our key finding was that both self-reported screen time and the ISST scores were significantly associated with cardiometabolic health risk scores, but there was no association between device-measured total sedentary time and health risk in our sample. These findings

highlight the importance of considering not only the amount but also the type of sedentary behaviour that a person engages in, and supports previous research demonstrating that leisure-time sedentary screen time may have particularly detrimental effects on health in comparison to total sedentary time.

In the present study, self-reported sedentary screen time was a significant predictor of clustered cardiometabolic health risk scores in all three regression models and resulted in a 0.04 larger clustered cardiometabolic risk score for each additional hour per day of sedentary screen time. This finding is consistent with most of the previous literature, which has reported similar effects for comparable doses of screen time (Altenburg et al., 2013; Dempsey et al., 2018; Ullrich et al., 2018; Wijndaele et al., 2010). Dempsey et al. (2018) examined a large sample of Australian adults (n = 3429), and found that each additional hour per day of self-reported TV viewing or computer sitting time increased clustered cardiometabolic risk scores by 0.07 and 0.06 (respectively) in their multiple linear regression model. Altenburg et al. (2013) completed a study on Dutch young adults (n = 634), and found that each additional hour per week of self-reported TV viewing time resulted in a 0.01 increase in clustered cardiometabolic risk scores. Wijndaele et al. (2010) examined data from adults who were part of the AusDiab prospective cohort study, and found in their linear regression that each increase in self-reported TV viewing time by 10 hours per week from baseline (1999-2000) to follow-up (2004-2005) was significantly associated with an 0.03 increase in clustered cardiometabolic risk score in women (n = 2143), but not in men (n = 1703). Ullrich et al. (2018) examined a sample of apparently healthy middle-aged adults (n = 173) and found that each additional hour of self-reported TV viewing time increased cardiometabolic risk scores by 0.30 in the fully adjusted model using ordinary least-squares regression. The

authors reported the standardized beta coefficients instead of the unstandardized ones, therefore the apparent difference in effect size reported by Ullrich et al. (2018) appears to be due to a difference in the reported statistic. In total, the different doses of screen time and the different forms of screen time measured in previous studies present challenges when attempting to make direct comparisons between results, but our findings of self-reported screen time and clustered cardiometabolic risk scores appear to be fairly consistent with previous findings.

Participants in our sample reported that they accumulated an average of 6.3 hours per day of sedentary screen time. Previous studies have found daily self-reported leisure screen time of between 1.9 to 2.5 hours per day in young and middle-aged adults (Dempsey, et al., 2018; Ulrich et al., 2018; Vella et al., 2020; Wijndaele et al., 2014), therefore our particpants had considerably higher screen time values. However, it is important to note that the wide age range of our sample (19-71 years) may have contributed to these findings. Hamer et al. (2015) found that their large sample of English middle-aged to older adults reported an average of 5.1 hours per day of TV viewing time at baseline (2008/2009). These previously published findings suggest that our participants engaged in substantially more sedentary screen time than previous studies have reported, which may have affected our findings.

It is important to note that the screen time data included in all these previous studies was collected before the COVID-19 pandemic had emerged (and before pandemic-related health measures such as lockdowns had occurred), and some of the data from previous studies was also collected one or two decades ago. Some research suggests that average TV viewing time has increased compared to TV viewing time before the COVID-19 pandemic, and that certain COVID-19 related public health measures such as

lockdowns resulted in increased total sedentary time and sedentary screen time (Chandrasekaran & Ganesan, 2021; Johnson & Dempsey, 2020). Furthermore, most people's screen-based behaviours have changed over the past two decades, and this may be largely due to advances in commonly used technology such as smartphones (Vizcaino et al., 2019). Overall, it seems likely that the timing of our data collection had an impact on sedentary screen time (and total sedentary time) accumulated by our participants, and since most of the previous research on sedentary time and sedentary screen time was collected prior to the COVID-19 pandemic, this adds to the difficulty in making direct comparisons between our findings and the findings of previous studies.

The higher screen time reported by our participants could also be explained by the screen time questionnaire we used (Vizcaino et al., 2019), since it captures nearly all leisure-time screen time instead of only TV viewing time. Much of the previous research on leisure-time screen time and cardiometabolic health in adults has focussed specifically or exclusively on TV viewing time (Biddle et al., 2017; Biswas et al., 2015; de Rezende et al., 2014; Edwardson et al., 2012; Grøntved & Hu, 2011; Patterson et al., 2018; Rhodes et al., 2012; Wijndaele et al., 2010; Wilmot et al., 2012; Zhao et al., 2020), despite TV viewing time not necessarily representing all screen time recent years (Biddle et al., 2017; Vizcaino et al., 2019). In the present study, we used a screen time questionnaire that asked about leisure time spent using TVs, TV-connected devices, computers, smartphones, and tablets, which likely captures nearly all of a participant's leisure-time screen time (Vizcaino et al., 2019). However, self-reported measures of screen time such as these are vulnerable to biases such as recall bias and social desirability bias, and certain items such as smartphone use may be more difficult to accurately recall than TV viewing time due to the ease of access to one's smartphone throughout the day versus specific

times that a person may watch a TV show or movie (Vizcaino et al., 2019). Future studies could examine other ways of measuring leisure-time screen time such as screen time logs or device-based measures of screen time such as smartphone apps.

In the same way that sedentary screen time accumulation may be higher in this study compared to data collected in pre-pandemic studies, total sedentary time also may have increased from pre-pandemic levels. Participants in our sample accumulated an average of 10.4 hours per day of device-measured total sedentary time, which is higher than the amounts of sedentary time reported in the previous literature for adults. Vella et al. (2020) found that their sample of young adults accumulated an average of 8.7 and 8.4 hours per day of self-reported and device-measured total sedentary time (respectively). Whitaker et al. (2018) found that their sample of middle-aged adults accumulated an average of 8.9 hours per day of device-measured sedentary time using accelerometers (data collected in 2015-2016), and Wijndaele et al. (2014) found that their sample of middle-aged adults accumulated an average of 9.1 hours per day of device-measured sedentary time using accelerometers at follow-up (data collected around 2010). The present study's higher values for total sedentary time might also be related to the COVID-19 pandemic and could be different due to the use of ActivPAL4™ inclinometers instead of self-reported or accelerometer-based measures of sedentary time.

Total sedentary time was not significantly associated with clustered cardiometabolic risk scores in any of the three regression models for our sample, which may be in contrast with the previous literature. While numerous studies have found detrimental relationships between total sedentary time and individual cardiometabolic health risk biomarkers (Brocklebank et al., 2015; Buman et al., 2014; Carson et al., 2014; Chastin et al., 2015; de Rezende et al., 2014; Healy et al., 2011; Powell et al., 2017; Wirth

et al., 2016), there is a paucity of currently published research examining total sedentary time and clustered cardiometabolic risk scores. Whitaker et al. (2018) examined cardiometabolic health risk in a prospective sample of middle-aged adults (*n* = 1922), and reported that statistically replacing 30 minutes per day of accelerometer-measured sedentary time with 30 minutes of light-intensity physical activity (multivariable linear regression isotemporal substitution) was associated with a 0.01 decrease in clustered cardiometabolic risk scores. Wijndaele et al. (2014) examined changes in sedentary time between baseline and 6-year follow-up in a sample of middle-aged adults (*n* = 171), and reported that for every one hour per day increase in accelerometer-measured sedentary time from baseline to follow-up, clustered cardiometabolic risk scores increased by 0.08. However, neither of these studies directly examined cross-sectional associations between total sedentary time and clustered cardiometabolic risk scores, therefore direct comparisons between our results and these previous studies cannot be made. Additionally, both of the previous studies used accelerometers to measure total sedentary time, and accelerometers have been shown to be less accurate at measuring total sedentary time compared to inclinometers such as ActivPAL™s.

The present study is one of the first to use ActivPAL™ inclinometers to measure sedentary time when examining the association between clustered cardiometabolic risk scores and device-measured total sedentary time. To the best of our knowledge, only one other currently published study has done this: Edwardson et al. (2020) examined a large sample of middle-aged adults (n = 1457), and found that each additional hour of ActivPAL3™-measured total sedentary time was associated with around a 0.2 increase in clustered cardiometabolic risk score in their main model (Model 1). However, the association between total sedentary time and clustered cardiometabolic risk scores was

not statistically significant in the present study. This could possibly be due to shorter-term pandemic-related changes to habitual movement behaviours since our data was collected in 2021 and 2022. Since some of the overall cardiometabolic health effects of habitual behaviours such as movement behaviours tend to become apparent after several years or decades of accumulation, it is possible that the higher sedentary time and higher screen time in these participants had not yet had enough time to produce changes in their clustered cardiometabolic risk scores.

It is also possible that pandemic-related health restrictions or recommendations resulted in less variability between participants in the accumulation of total sedentary time and sedentary screen time. For example, it is possible that some participants engaged in less sedentary behaviour prior to COVID-19, but that factors related to the pandemic resulted in higher engagement in sedentary behaviour during the data collection for this project. In contrast, participants who were already engaging in high amounts of sedentary behaviour before the pandemic may have maintained their sedentary time and screen time. This plausible scenario would have a substantial impact on our results, and our results show that many of our participants were engaging in high amounts of total sedentary time and sedentary screen time compared to previous studies with data collected before the COVID-19 pandemic. Also, the clearest indicator that pandemic-related changes to people's habitual movement behaviours may have occurred are our findings that neither device-measured total sedentary time nor device-measured physical activity (step counts and moderate-to-vigorous physical activity) were associated with clustered cardiometabolic risk scores. This is inconsistent with the previous literature, as several studies have shown that device-measured total sedentary time is associated with

clustered cardiometabolic risk scores (Edwardson et al., 2020; Whitaker et al., 2018; Wijndaele et al., 2014).

While our finding that total sedentary time was not associated with clustered cardiometabolic risk scores in our sample is in contradiction to some previous findings, taking this null finding together with our finding that sedentary screen time was significantly associated with cardiometabolic health risk is similar to some of the previous findings that not all types of sedentary time appear to be detrimentally associated with health risk. Pinto Pereira et al. (2012) found that occupational sedentary time was not associated with cardiometabolic health risk whereas TV viewing was negatively associated, and Vella et al. (2020) found that sedentary screen time was significantly associated with cardiometabolic health risk biomarkers independently of total sedentary time. Garcia et al. (2019) also found that TV viewing time was positively associated with cardiovascular events and mortality risk, whereas occupational sedentary time was not. Ullrich et al. (2018) examined different domains of leisure-time sedentary time, and found that while TV viewing time was positively associated with cardiometabolic health risk, reading and socializing were not. The findings of these studies in combination with our results provide support to the idea that the type of activity completed while sedentary has important implications for the associated health risk.

The goal of the ISST score to be a better predictor of cardiometabolic health risk than screen time or total sedentary time alone was not clearly achieved based on our findings. The ISST score did result in a greater change to clustered cardiometabolic risk scores than sedentary screen time alone (0.06 and 0.04, respectively) and had a slightly larger effect size (0.301 and 0.263, respectively), but it is possible that this relationship was driven by the higher weight of the screen time in our calculation of ISST scores.

However, since the ISST score was calculated using the sedentary screen time and total sedentary time values, our findings for the ISST scores would be affected by the same issues as its individual components. Thus, additional studies using other samples and using data collected at other timepoints less affected by the COVID-19 pandemic are needed to determine if the ISST score may be advantageous for assessing health risk. Furthermore, even though the results of our project do not directly indicate the usefulness of this ISST scoring method, additional studies exploring different methods of combining total sedentary time and sedentary screen time are needed to determine if other methods could result in a better technique for identifying individuals who are at greater cardiometabolic health risk based on their amount and type of movement behaviours.

Strengths and Limitations

There are several key strengths and limitations to the present study. As mentioned in the previous chapter, the participants in this study were well-educated, highly active, mostly Caucasian/White, and were apparently healthy. These characteristics of the sample population limit the generalizability of the findings, but the wide age range of the sample population (19-71 years) is a strength of the study. Another strength of the study is the use of clustered cardiometabolic risk scores instead of examining individual biomarkers or risk factors, because continuous composite scores such as clustered cardiometabolic risk scores may be a better predictor of future disease risk than individual risk factors examined separately (Ullrich et al., 2018). We did not dichotomize the risk factors using the clinical cut-offs for disease risk, but kept the risk factors as continuous variables which maximized the statistical power in our sample (Wijndaele et al., 2014). We used two point-of-care devices to analyze the biomarkers measured using capillary blood samples, and both devices used have been shown to provide results clinically equivalent

or of similar sensitivity to traditional laboratory methods (Bastianelli et al., 2017; Strauss et al., 2014).

Another key strength of the present study was the use of ActivPAL4™s to measure 24-hour movement behaviours, which is the current "gold standard" for the measurement of total sedentary time (Grant et al., 2006; Lee & Dall, 2019). However, we identified one "day" as 12:00 am – 11:59 pm, whereas other studies have used 5:00 am – 4:59 am in order to account for the typical "waking day". This is a limitation of the present study because we combined the screen time questionnaire data and the total sedentary time data to create the new ISST scoring method, therefore it is important to ensure that our measure of sedentary time and our measure of screen time are capturing the same timeframe. However, total sedentary time would be less affected by the calendar day than sedentary bouts, so using a calendar day for the present study may not have had a large impact on our overall results.

We measured physical activity using the ActivPAL4™s as well, which is a limitation of the present study because minimal research has examined the best method for estimating moderate-to-vigorous physical activity from ActivPAL data, and even less research has validated such methods (Lee & Dall, 2019). One recent study found that using a step cadence-based method for measuring moderate-to-vigorous physical activity was the most closely related to ActiGraph-measured physical activity, but that the ActivPAL™ step cadence-based method tended to underestimate moderate-to-vigorous physical activity compared to the ActiGraph accelerometer (Lee & Dall, 2019). Further research is needed to determine the best method for assessing moderate-to-vigorous physical activity using ActivPAL4™s.

Conclusion

In this study, we combined device-measured total sedentary time and self-reported leisure-time sedentary screen time to create our new ISST score. We found that the new ISST score was a predictor of clustered cardiometabolic risk scores, but may not be a better predictor than sedentary screen time alone. However, methods for combining data of total sedentary time with the type of activity completed while sedentary may be useful for future research to identify individuals who may be at increased cardiometabolic health risk based on their movement behaviours.

Table 5. Characteristics of the Study Population (overall and by biological sex)

	Total Sample	**Male**	**Female**
N (%)	91 (100) *	29 (32)	61 (67)
Age, years (mean ± SD)	40.6 ± 15.9	41. 1 ± 13.7	40.8 ± 16.9
Sex (N; %)			
Male	29 (32)	29 (100)	0 (0)
Female	61 (67)	0 (0)	61 (100)
Other	1 (1)	0 (0)	0 (0)
Gender (N; %)			
Man	29 (32)	29 (100)	0 (0)
Woman	60 (66)	0 (0)	60 (98)
Other	2 (2)	0 (0)	1 (2)
Marital Status (N; %)			
Single	31 (34)	7 (24)	23 (38)
Married/Common-law	52 (57)	22 (76)	30 (49)
Divorced	6 (7)	0 (0)	6 (10)
Widowed	2 (2)	0 (0)	2 (3)
Ethnicity			
Caucasian/White	75 (82)	22 (76)	52 (85)
African American/Black	0 (0)	0 (0)	0 (0)
Indigenous/Aboriginal	1 (1)	0 (0)	1 (2)
Asian	7 (8)	3 (10)	4 (7)
Other	8 (9)	4 (14)	4 (7)
Current Education Level (N; %)			
Grade School	2 (2)	0 (0)	2 (3)
Junior High	0 (0)	0 (0)	0 (0)
High School	12 (13)	3 (10)	9 (15)
College (2-4 years)	23 (25)	12 (41)	11 (18)
Bachelor's Degree	35 (38)	6 (21)	28 (46)
Graduate Degree	19 (21)	8 (28)	11 (18)
Current Employment Status (N; %)			
Full-time	53 (58)	20 (69)	32 (52)
Part-time	18 (20)	5 (17)	13 (21)
Unemployed	6 (7)	1 (3)	5 (8)
Other	14 (15)	3 (10)	11 (18)

Note. Descriptive statistics by biological sex for this sample of apparently healthy adults (n = 91). Demographic information was assessed using a questionnaire. Nominal or ordinal variables were expressed by number of participants and percentage of total participants in group, and continuous or discrete variables were expressed as means ± standard deviations.

*****One participant self-reported their biological sex as neither male nor female. Their data is reflected in the "total" column but not in the "male" nor the "female" columns.

Table 6. Cardiometabolic Health Risk of the Study Population (overall and by biological sex)

	Total Sample	**Male**	**Female**
N (%)	91 (100) *	29 (32)	61 (67)
Cardiometabolic Health Risk Factors (mean ± SD)			
Body Mass Index, kg/m^2	27.0 ± 6.9	27.0 ± 4.7	27.2 ± 7.7
Waist Circumference, cm	87.7 ± 15.5	91.8 ± 12.2	86.1 ± 16.5
Resting SBP, mmHg	125.3 ± 12.6	132.5 ± 9.6	122.3 ± 12.3
Resting DBP, mmHg,	78.3 ± 8.5	82.6 ± 7.5	76.4 ± 8.2
Fasting Blood Glucose, mmol/L	4.6 ± 0.5	4.5 ± 0.6	4.6 ± 0.5
Glycosylated Hemoglobin, %	4.9 ± 0.4	4.9 ± 0.3	4.9 ± 0.4
Fasting HDL Cholesterol, mmol/L	1.4 ± 0.4	1.2 ± 0.4	1.5 ± 0.4
Fasting Total Cholesterol, mmol/L	4.2 ± 1.1	4.3 ± 1.1	4.3 ± 1.0
Fasting Blood Triglycerides, mmol/L	1.3 ± 0.7	1.4 ± 0.8	1.3 ± 0.7
Fasting LDL Cholesterol, mmol/L	2.3 ± 0.9	2.3 ± 1.0	2.3 ± 0.9
Ratio of Total Cholesterol to HDL Cholesterol	3.2 ± 1.0	3.7 ± 1.3	3.0 ± 0.8
Salivary CRP Concentration, pg/mL	687 ± 1118	844 ± 1524	614 ± 859
Clustered Cardiometabolic Risk Score, z-score	-0.006 ± 0.542	0.184 ± 0.455	-0.094 ± 0.553

Note. Descriptive statistics by biological sex for this sample of apparently healthy adults (n = 91). Blood glucose and lipid measures were assessed using the CardioChek Plus Analyzer (PTS Diagnostics, Whitestown, IN) and the A1CNOW®+ machine (PTS Diagnostics, Whitestown, IN), and salivary CRP concentrations were assessed using salivary CRP enzyme-linked immunosorbent assay (ELISA) kits (Salimetrics LLC, State College, PA). Clustered cardiometabolic risk scores were calculated as an average of the standardized z-scores of the eleven cardiometabolic health risk factors measured (body mass index, waist circumference, resting SBP, resting DBP, fasting blood glucose, glycosylated hemoglobin, fasting HDL cholesterol, fasting total cholesterol, fasting blood triglycerides, fasting LDL cholesterol, and salivary CRP). Variables were expressed as means ± standard deviations. Abbreviations: CRP = C-reactive Protein; DBP = Diastolic

Blood Pressure; HDL = High-Density Lipoprotein; LDL = Low-Density Lipoprotein; SBP = Systolic Blood Pressure.

*One participant self-reported their biological sex as neither male nor female. Their data is reflected in the “total” column but not in the “male” nor the “female” columns.

Table 7. Movement Behaviours of the Study Population (overall and by biological sex)

	Total Sample	**Male**	**Female**
N (%)	91 (100) *	29 (32)	61 (67)
ActivPAL Wear Time, days	6.7 ± 1.0	6.4 ± 1.2	6.9 ± 0.8
Physical Activity, steps/day	9167 ± 3541	10606 ± 3661	8462 ± 3319
Physical Activity, min/day of MVPA	22.7 ± 21.4	23.0 ± 23.1	22.9 ± 20.7
Sedentary Time, hours/day	10.3 ± 2.0	10.8 ± 2.1	10.2 ± 1.9
Sedentary Breaks, number/day (mean ± SD)	52.3 ± 14.6	53.9 ± 16.5	51.9 ± 13.4
Screen Time, hours/day (mean ± SD)	6.3 ± 4.4	6.4 ± 3.5	6.2 ± 4.9
Continuous ISST Score, hour equivalents/day (mean ± SD)	13.5 ± 3.2	14.0 ± 2.8	13.3 ± 3.4

Note. Descriptive statistics by biological sex for this sample of apparently healthy adults (n = 91). Physical activity and sedentary time were measured using ActivPAL4™s, screen time was measured using a questionnaire, and ISST scores were calculated using the sedentary time and screen time measures for each participant. Nominal or ordinal variables were expressed by number of participants and percentage of total participants in group, and continuous or discrete variables were expressed as means ± standard deviations. Abbreviation: ISST = Index of Sedentary Screen Time; MVPA = Moderate to Vigorous Physical Activity.

*One participant self-reported their biological sex as neither male nor female. Their data is reflected in the "total" column but not in the "male" nor the "female" columns.

Table 8. Correlations between Exposure Variables and Clustered Cardiometabolic Risk Scores

Variables	**rho**	***p*-value**	**Degrees of Freedom**
Sedentary Screen Time and CMRS	0.22	0.055	78
Total Sedentary Time and CMRS	0.14	0.201	78
Continuous ISST Score and CMRS	0.29	0.010	78

Note. Spearman's bivariate correlations between clustered cardiometabolic risk scores and the exposure variables of sedentary screen time, total sedentary time, and continuous ISST scores (n = 80 because of 10 missing values for CMRS and one excluded participant for screen time). Clustered cardiometabolic risk scores were calculated as an average of the standardized z-scores of the eleven cardiometabolic health risk factors measured (body mass index, waist circumference, resting systolic blood pressure, resting diastolic blood pressure, fasting blood glucose, glycosylated hemoglobin, fasting high-density lipoprotein cholesterol, fasting total cholesterol, fasting blood triglycerides, fasting low-density lipoprotein cholesterol, and salivary C-reactive protein concentration). ISST scores were calculated using the sedentary time and screen time measures for each participant where sedentary time was measured using ActivPAL4™s and screen time was measured using a questionnaire. Abbreviations: CMRS = Clustered Cardiometabolic Risk Score; ISST = Index of Sedentary Screen Time

Table 9. Multiple Linear Regressions between Sedentary Screen Time and Clustered Cardiometabolic Risk Scores

	Clustered Cardiometabolic Risk Score			
	B (95% CI)	Standardized β	Adj R^2	*p*-value
Model 1			**.05**	**0.031**
Sedentary screen time (hours/day)	**0.04 (0.00, 0.07)**	**0.242**		**0.031**
Model 2			**.19**	**0.000**
Sedentary screen time (hours/day)	**0.04 (0.01, 0.07)**	**0.290**		**0.007**
Age	**0.01 (0.00, 0.02)**	**0.299**		**0.006**
Sex (F)	**-0.25 (-0.48, -0.02)**	**-0.222**		**0.034**
Model 3			**.21**	**0.000**
Sedentary screen time (hours/day)	**0.04 (0.01, 0.07)**	**0.263**		**0.013**
Age	**0.01 (0.00, 0.02)**	**0.333**		**0.002**
Sex (F)	**-0.29 (-0.53, -0.06)**	**-0.263**		**0.014**
Steps per day (PA)	-0.00 (-0.00, 0.00)	-0.173		0.111

Note. Multiple regression models between clustered cardiometabolic risk scores and leisure-time sedentary screen time (n = 80 because of 10 missing values for CMRS and one excluded participant for screen time) using untransformed data. Statistically significant components are bolded (p<0.05). Clustered cardiometabolic risk scores were calculated as an average of the standardized z-scores of the eleven cardiometabolic health risk factors measured (body mass index, waist circumference, resting systolic blood pressure, resting diastolic blood pressure, fasting blood glucose, glycosylated hemoglobin, fasting high-density lipoprotein cholesterol, fasting total cholesterol, fasting blood triglycerides, fasting low-density lipoprotein cholesterol, and salivary C-reactive

protein concentration). Screen time was measured using a retrospective questionnaire. Abbreviations: CMRS = Clustered Cardiometabolic Risk Score; DF = Degrees of Freedom; ISST = Index of Sedentary Screen Time; F = Female, PA = Physical Activity.

Table 10. Multiple Linear Regressions between Total Sedentary Time and Clustered Cardiometabolic Risk Scores

	Clustered Cardiometabolic Risk Score			
	B (95% CI)	Standardized β	Adj R^2	*p*-value
Model 1			.03	0.057
Total sedentary time (hours/day)	0.06 (-0.00, 0.12)	0.214		0.057
Model 2			**.15**	**0.003**
Total sedentary time (hours/day)	0.06 (-0.00, 0.12)	0.203		0.067
Age	**0.01 (0.00, 0.02)**	**0.268**		**0.014**
Sex (F)	**-0.26 (-0.49, -0.02)**	**-0.230**		**0.032**
Model 3			**.16**	**0.003**
Total sedentary time (hours/day)	0.04 (-0.02, 0.11)	0.146		0.213
Age	**0.01 (0.00, 0.02)**	**0.296**		**0.008**
Sex (F)	**-0.30 (-0.55, -0.06)**	**-0.272**		**0.015**
Steps per day (PA)	-0.00 (-0.00, 0.00)	-0.163		0.165

Note. Multiple regression models between clustered cardiometabolic risk scores and ISST scores (n = 80 because of 10 missing values for CMRS and one excluded participant for screen time) using untransformed data. Statistically significant components are bolded (p<0.05). Clustered cardiometabolic risk scores were calculated as an average of the standardized z-scores of the eleven cardiometabolic health risk factors measured (body mass index, waist circumference, resting systolic blood pressure, resting diastolic blood pressure, fasting blood glucose, glycosylated hemoglobin, fasting high-density lipoprotein cholesterol, fasting total cholesterol, fasting blood triglycerides, fasting low-density lipoprotein cholesterol, and salivary C-reactive protein concentration). Sedentary time

was measured using ActivPAL4™s. Abbreviations: CMRS = Clustered Cardiometabolic Risk Score; DF = Degrees of Freedom; ISST = Index of Sedentary Screen Time; F = Female, PA = Physical Activity.

Table 11. Multiple Linear Regressions between ISST Scores and Clustered Cardiometabolic Risk Scores

	Clustered Cardiometabolic Risk Score			
	B (95% CI)	Standardized β	Adj R^2	*p*-value
Model 1			**.08**	**0.006**
ISST Score (hour equivalents/day)	**0.06 (0.02, 0.10)**	**0.303**		**0.006**
Model 2			**.22**	**0.000**
ISST Score (hour equivalents/day)	**0.07 (0.03, 0.11)**	**0.340**		**0.002**
Age	**0.01 (0.00, 0.02)**	**0.324**		**0.003**
Sex (F)	**-0.23 (-0.46, -0.01)**	**-0.208**		**0.043**
Model 3			**.22**	**0.000**
ISST Score (hour equivalents/day)	**0.06 (0.01, 0.10)**	**0.301**		**0.009**
Age	**0.01 (0.00, 0.02)**	**0.339**		**0.002**
Sex (F)	**-0.27 (-0.50, -0.03)**	**-0.238**		**0.027**
Steps per day (PA)	-0.00 (-0.00, 0.00)	-0.111		0.326

Note. Multiple regression models between clustered cardiometabolic risk scores and ISST scores (n = 80 because of 10 missing values for CMRS and one excluded participant for screen time) using untransformed data. Statistically significant components are bolded (p<0.05). Clustered cardiometabolic risk scores were calculated as an average of the standardized z-scores of the eleven cardiometabolic health risk factors measured (body mass index, waist circumference, resting systolic blood pressure, resting diastolic blood pressure, fasting blood glucose, glycosylated hemoglobin, fasting high-density lipoprotein cholesterol, fasting total cholesterol, fasting blood triglycerides, fasting low-density lipoprotein cholesterol, and salivary C-reactive protein concentration). ISST scores were

calculated using the sedentary time and screen time measures for each participant, where sedentary time was measured using ActivPAL4™s and screen time was measured using a questionnaire. Abbreviations: CMRS = Clustered Cardiometabolic Risk Score; DF = Degrees of Freedom; ISST = Index of Sedentary Screen Time; F = Female, PA = Physical Activity.

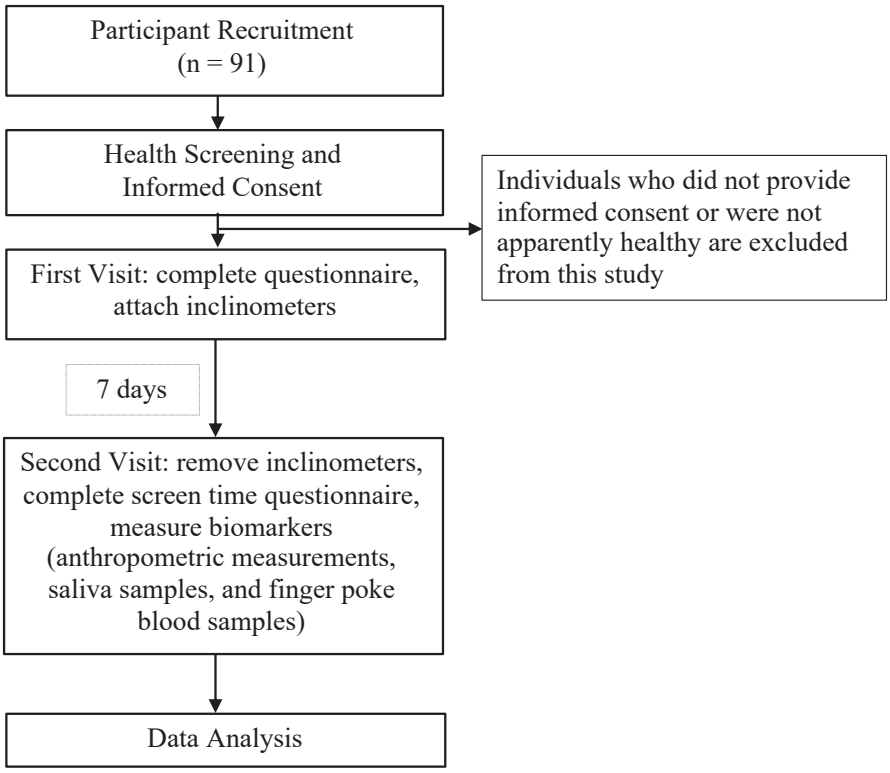

Figure 5. Study Procedure Timeline

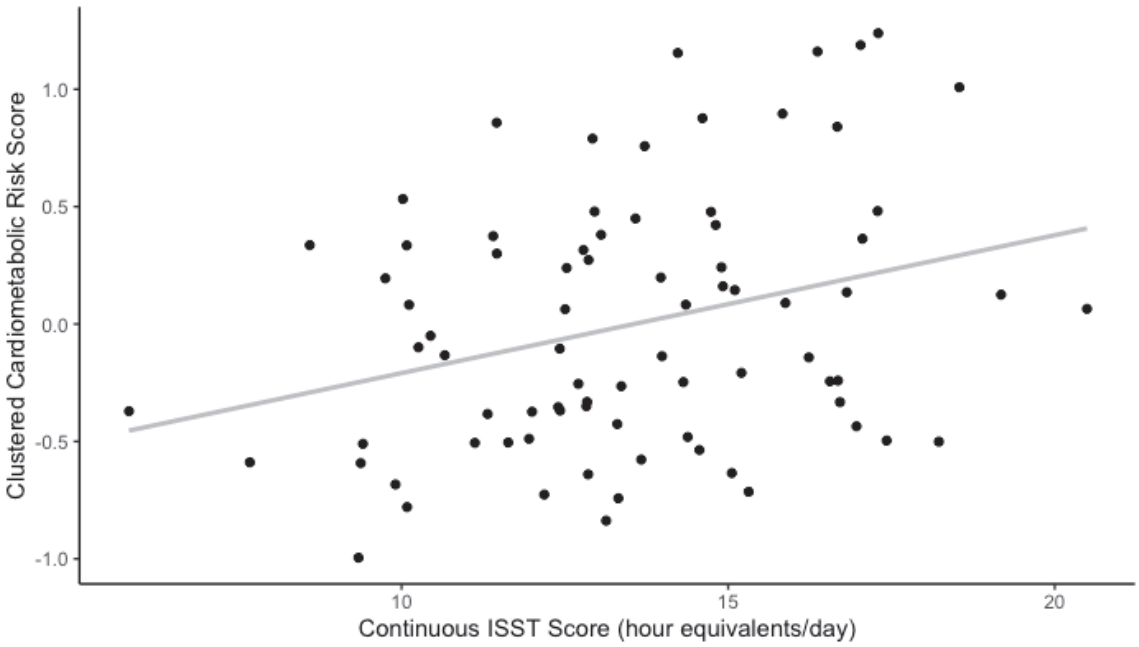

Figure 6. Individual continuous ISST scores and clustered cardiometabolic risk scores in healthy adult participants (n = 80)

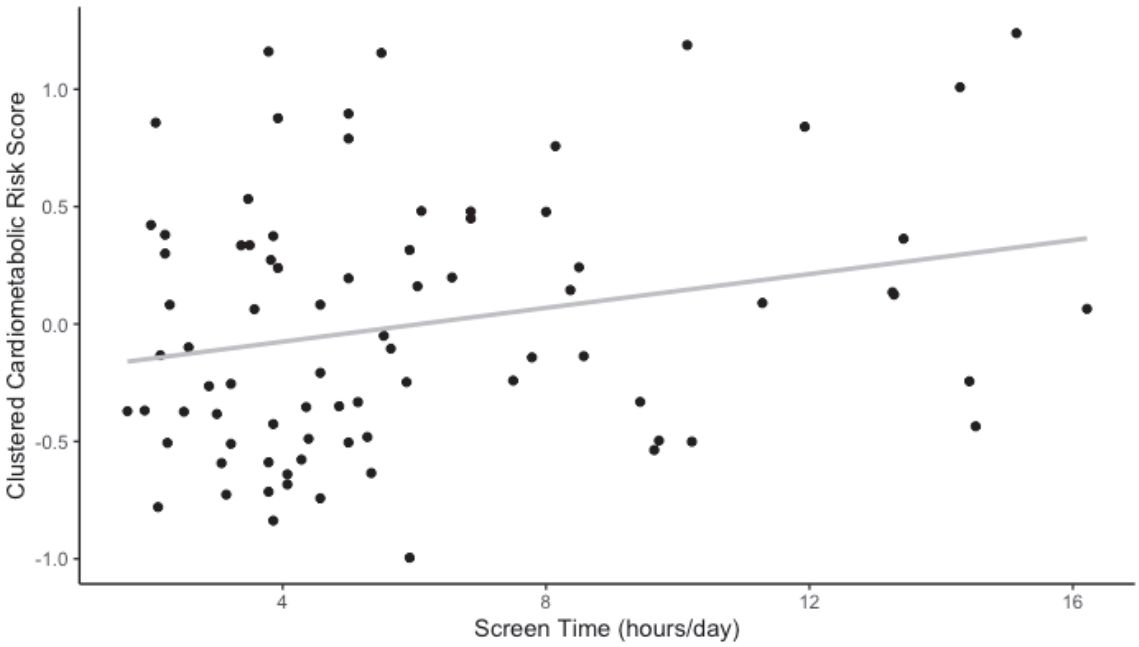

Figure 7. Sedentary screen time and clustered cardiometabolic risk scores in healthy adult participants (n = 80)

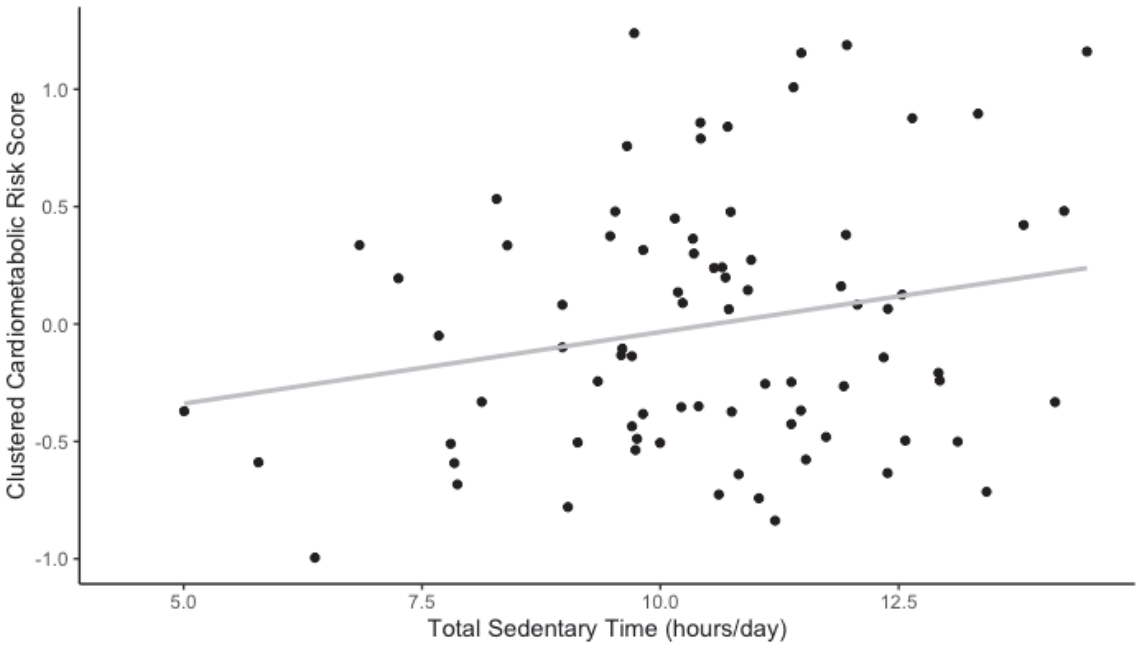

Figure 8. Total sedentary time and clustered cardiometabolic risk scores in healthy adult participants (n = 80)

CHAPTER 4: GENERAL DISCUSSION

Introduction

My goal for this overall project was to develop and test a novel measurement method for sedentary behaviour that incorporated both device-measured total sedentary time and self-reported sedentary screen time. This novel measurement method was called the Index of Sedentary Screen Time (ISST), and the aim of this new method was to provide a better predictor of cardiometabolic health risk by combining a device-based measure of total sedentary time with a self-reported estimation of sedentary screen time, as this type of sedentary behaviour may be particularly detrimental to cardiometabolic health. Based on previous literature examining the health risks associated with total sedentary time and sedentary screen time, I developed three different scoring methods for the ISST. Based on the test-retest reliability results described in Chapter 2, the ability of the continuous ISST score to predict clustered cardiometabolic risk scores was investigated in Chapter 3. While the ISST scoring methods are exploratory, I hypothesized that the ISST would have acceptable test-retest reliability and be a better predictor of clustered cardiometabolic risk scores than either total sedentary time or sedentary screen time alone.

Summary of Key Findings

A total of 91 participants completed both the first and second visits to the lab, and 87 of those participants also completed the third and fourth visits to the lab. Data collected during the first and second visits to the lab were used to assess the relationship between the continuous ISST score and cardiometabolic health risk, and data collected during all four visits to the lab were used to assess the test-retest reliability of the three ISST scoring methods. Continuous ISST scores had the highest test-retest reliability with

an ICC of 0.844, followed by ordinal ISST scores with an ICC of 0.727, and proportional ISST scores had the lowest test-retest reliability with an ICC of 0.631. Continuous ISST scores were the only tested exposure variable correlated with clustered cardiometabolic risk scores (r[79] = 0.29, p = .010), and were also a predictor of clustered cardiometabolic risk scores in a fully adjusted linear regression model (Model 3: B = 0.06, 95% CI 0.01 – 0.10, p = 0.009). Self-reported screen time was a significant predictor of clustered cardiometabolic risk scores in a fully adjusted model (Model 3: B = 0.04, 95% CI 0.01 – 0.07, p = 0.013), but device-measured total sedentary time was not.

Discussion

Previous literature has called for a new measurement method that combines both the amount of sedentary time accumulated and information regarding the type of activity completed while sedentary. This is important because recent studies have shown that the type of activity completed while sedentary may be as important or more important than the total amount of sedentary time accumulated (Garcia et al., 2019; Pinto Pereira et al., 2012; Ullrich et al., 2018), and that leisure-time sedentary screen time may be particularly harmful for cardiometabolic health (Copeland et al., 2017; de Rezende et al., 2014; Ford & Caspersen, 2012; Garcia et al., 2019; Patterson et al., 2018; Pinto Pereira et al., 2012; Ullrich et al., 2018). Although the continuous ISST scores had acceptable reliability, in terms of predicting health risk our results did not suggest the ISST scoring methods we explored are better than just measuring sedentary screen time. There may be several reasons for these findings, and some of the main reasons could be the timing of the data collection, the characteristics of our sample of participants, and the specific calculation methods we used for the ISST scores.

Cross-sectional data for this project were collected from August 2021 to June 2022, which was during the COVID-19 pandemic. While there were no complete provincial or local "lock-downs" during this time, pandemic-related health restrictions were in place and people were encouraged to take precautions to prevent the spread of COVID-19. It seems likely that participants' habitual movement behaviours were different during this time of COVID-19 restrictions than they were before the pandemic (Chandrasekaran & Ganesan, 2021; Johnson & Dempsey, 2020). For example, more participants may have been working from home than usual, and participants may have been unable to attend some of their usual activities due to COVID-19 symptoms or program cancellations. These short-term changes to people's habitual movement behaviours may have temporarily increased the amount of time that participants spent in sedentary screen time or total sedentary time and may have reduced the variability in movement behaviours exhibited by the participants. Furthermore, the time of year may have had an impact on our participant's movement behaviours due to the large difference in typical outdoor temperatures Southern Alberta between the summer months and the winter months (approximately +40°C to -40°C, respectively). Our data were collected from August 2021 until June 2022, and we did not assess the potential impact of time of year on the data that were collected in warmer months versus cooler months as some previous studies have done (Jefferis et al., 2019; Saunders, MacDonald, et al., 2018). In total, our data for sedentary screen time and total sedentary time may not as accurately reflect the habitual movement behaviours of our participants in their typical life before the pandemic-related restrictions, and this may have affected our results.

Our participants were generally healthy (i.e. no diagnosed chronic conditions), mostly Caucasian/White, and highly educated, which does not represent the general

population of Canadians (Colley et al., 2022). Many of our participants also met or exceeded the current physical activity recommendations of 150 minutes per week of moderate-to-vigorous physical activity, but also met or exceeded the sedentary behaviour guidelines of over eight hours per day and leisure-time screen time guidelines of over three hours per day (Canadian Society for Exercise Physiology, 2020). People who are highly active but also highly sedentary can be classified as "active couch potatoes" (Lepp & Barkley, 2019), and since the health risks of high sedentary time may be independent of physical activity involvement, this category of movement behaviours is still at higher cardiometabolic health risk than individuals who accumulate less sedentary behaviour (Lepp & Barkley, 2019). Additionally, the "active couch potato" lifestyle may have slightly different associations with health risk than people who are highly active with low sedentary time, highly sedentary but inactive, or inactive with low sedentary time. The results of the present project may be more reflective of "active couch potatoes" than other movement behaviour phenotypes.

The specific calculation methods we selected to create the ISST scores in this project would have had an impact on our results as well. We selected three methods based on the previous literature, and the continuous ISST scoring method appeared to have the most advantages of the three methods we tried. To demonstrate the theoretical usefulness of the continuous ISST scoring method, we created Table 12 to visually represent possible values for ISST scores and to show the difference between the continuous ISST scoring method and the ordinal ISST scoring method. On the vertical axis of the table are possible values for sedentary screen time, on the horizontal axis are possible values for total sedentary time, and within the table are possible values for continuous ISST scores (with highly improbable values shaded in grey). Additional information on the shading in

the table is described in the note below the table. As described in Chapter 2, the top left of the table would be assigned an ordinal ISST score of 1 (mostly shaded in green or yellow), the top right would have an ordinal ISST score of 2, the bottom left would have an ordinal ISST score of 3, and the bottom right would have an ordinal ISST score of 4 (shaded in red). The ordinal ISST scoring method only allows for four possible values, whereas the colours show the hypothesis that higher sedentary time even with lower sedentary screen time may be of similar health risk to slightly lower total sedentary time and high sedentary screen time. Visuals such as this could be helpful for describing the health risk associated with different amounts and types of sedentary behaviour to individuals who are at increased cardiometabolic health risk, and could be a useful starting point for determining other possible calculation methods for combining sedentary screen time and total sedentary time.

To our knowledge, this is the first project to combine a device-based measure of total sedentary time with a self-reported measure of leisure-time sedentary screen time thus far. We explored three different methods, and it is certainly possible that other useful methods for combining these measures could be attempted in future studies or as a secondary data analysis of previously collected data. Other calculation methods could include using a different weighing factor for sedentary screen time in the continuous ISST scoring method (we used 1.5), using a different equation for the continuous ISST scoring method, using different cut-points or categorizations of the ordinal ISST scoring method, or using different ways of measuring screen time that reduce over-reporting to improve the values for a proportional ISST scoring method. Alternately, future projects could explore incorporating moderate-to-vigorous physical activity participation with screen time and total sedentary time into one composite score to better reflect the different

phenotypes of waking movement behaviours such as “active couch potatoes” versus other movement behaviour characterizations.

Future Applications of our ISST Scores

Test-retest Reliability

Of the three ISST scoring methods we explored, the continuous scoring method showed the highest test-retest reliability. Continuous ISST scores were also normally distributed in both the first and second weeks of data collection, which is helpful for the current project and for potential future research applications because it allows for the appropriate use of a wide variety of statistical tests without transformation. In contrast, the ordinal ISST scores were extremely skewed and kurtotic therefore those results must be interpreted with caution. However, the ordinal ISST scores were the most directly evidence-based of the three scoring methods used because they used the cut-off points from the systematic review and meta-analysis completed by Patterson et al. (2018). Thus, with the appropriate statistical tests, ordinal ISST scores could be useful for potential future research applications, especially in studies with large sample sizes. The proportional ISST scoring method may have acceptable test-retest reliability, but it had the lowest test-retest reliability of the three scoring methods used and had some other key limitations, as previously discussed. Most importantly, the proportional ISST scoring method does not account for the absolute volume of total sedentary time or sedentary screen time that each participant accumulated, therefore two participants could have drastically different hours per day of sedentary time and screen time but could have similar proportional ISST scores. While a proportional ISST scoring method could be used with caution and may have some use in different research applications, it was not the

best scoring method we attempted for our sample based on having lower test-retest reliability and some key limitations.

While no previous studies to our knowledge have explored any of the ISST scoring methods we used (or anything similar), some studies have examined the test-retest reliability of self-reported screen time and of total sedentary time. Vizcaino et al. (2019) developed and tested the screen time questionnaire that we used for this project and found that nearly every item showed acceptable test-retest reliability over a span of three days in their sample of 80 adults. Pettee et al. (2009) examined one survey item on TV viewing time in a sample of 93 adults and found that its test-retest reliability was "moderate" for both the 1-week follow-up and the 3-week follow-up (ICCs of 0.55 and 0.42, respectively). Conversely, Clark et al. (2009) completed a review that included nine studies that examined the reliability of various measures of leisure-time sedentary behaviour, and found that the test-retest reliabilities of the various questionnaires were mostly moderate to high with a mean ICC of 0.66 for interviewer-administered questionnaires and 0.61 for self-administered questionnaires. In comparison, our findings of ICCs ranging from 0.61 to 0.83 for our ISST scoring methods appear to be at least equal or better than previous findings for test-retest reliability of sedentary screen time alone. However, it is important to note that this could be due to the incorporation of the device-based total sedentary time in the ISST scores, since device-based measures typically exhibit better test-retest reliability than self-reported measures. Previous studies have found that ActivPAL™ inclinometers provide a reliable measure of sedentary behaviour provided that there is an acceptable minimum amount of wear time; Edwardson et al. (2017) noted that other authors have reported that around five days of ActivPAL™ wear-time were required to achieve an ICC of 0.8 and around 10 days of wear-time were

required to achieve an ICC of 0.9, both of which are much higher than the previously reported ICCs for self-reported sedentary behaviour. In total, all three ISST scoring methods showed acceptable test-retest reliability and could be useful for future research.

Association with Cardiometabolic Health Risk

The association between the ISST score(s) used in this project and cardiometabolic health risk is of paramount importance because the main purpose of creating an ISST score is to determine if there may be a way to quantify sedentary behaviour that more specifically identifies individuals who may be at increased cardiometabolic health risk than measuring sedentary screen time or total sedentary time alone. In this project, we found that neither sedentary screen time nor total sedentary time were significantly correlated with the clustered cardiometabolic risk scores when assessed using Spearman's bivariate correlations, and that total sedentary time was not a significant predictor of clustered cardiometabolic risk scores in any of the linear regression models. However, sedentary screen time was significantly associated with clustered cardiometabolic risk scores in all three linear regression models, as were the continuous ISST scores. Possible reasons for these findings were discussed in the previous chapter; briefly, pandemic-related restrictions may have temporarily altered the habitual movement behaviours of the participants and reduced the typical variability of movement behaviours. Additionally, while we controlled for the covariates of age, biological sex, and physical activity, there may still be residual confounding (as discussed later).

In this project, we did not directly examine the association between sedentary screen time, total sedentary time, or ISST scores with individual biomarkers of cardiometabolic health risk. Previous research has found that the individual biomarkers of

CRP concentration (Chastin et al., 2015; de Rezende et al., 2014; Healy et al., 2011), HDL cholesterol (Healy et al., 2011; Powell et al., 2017), triglycerides (Brocklebank et al., 2015; Powell et al., 2017), glycosylated hemoglobin (Wirth et al., 2016), and waist circumference (de Rezende et al., 2014; Healy et al., 2011; Powell et al., 2017; Wirth et al., 2016) were detrimentally associated with sedentary time, but that the biomarkers of body mass index (Biddle et al., 2017), resting blood pressure (de Rezende et al., 2014; Healy et al., 2011; Powell et al., 2017; Wirth et al., 2016), and fasting blood glucose (Brocklebank et al., 2015; Buman et al., 2014; Wirth et al., 2016) were not consistently associated with sedentary time. Clustered cardiometabolic risk scores calculated as a composite score of several individual biomarkers may be a better predictor of cardiometabolic disease risk than each biomarker separately, but it is possible that including biomarkers that are not consistently associated with various measures of sedentary behaviour may have masked or diluted the associations between our sedentary behaviour measures and the composite measure cardiometabolic health risk. Future projects could examine the potential associations between each individual biomarker or cardiometabolic risk factor and sedentary screen time, total sedentary time, and ISST scores.

Based on the finding that continuous ISST scores were a significant predictor of clustered cardiometabolic risk scores in our sample, this method may be useful for future research investigating the cardiometabolic health risks of sedentary behaviour. The potential relationships between either of the other two ISST scoring methods were not assessed in this project, and future projects could explore this. The ordinal ISST score would be of particular interest since it uses evidence-based cut-points but was not normally distributed in our sample due to the ordinal nature of the variable and due to the

high prevalence of participants in this sample with total sedentary time exceeding eight hours per day and leisure-time sedentary screen time exceeding four hours per day. Our sample had a higher proportion of participants that exceeded these thresholds compared to Canadian data collected 10 years ago (Colley et al., 2022), which could be in part due to the timing of our data collection or systematic changes to habitual movement behaviours over the past decade. However, given the high prevalence of cardiometabolic diseases and cardiometabolic disease-related mortality in the general population (Patterson et al., 2018), the substantial proportion of our sample showing movement behaviours that put them at greater cardiometabolic health risk appears reasonable. Thus, while the extreme non-normality and the ordinal nature of the ordinal ISST scoring method poses challenges to selecting appropriate statistical tests to assess the associations between ordinal ISST scores and cardiometabolic health risk, ordinal ISST scores may still be a valuable and strongly evidence-based tool for identifying individuals who are at increased health risk based on their movement behaviours.

Strengths and Limitations

In addition to the discussion sections of the previous chapters, there are some further strengths and limitations of the overall project to consider. One of the main limitations of this study was the cross-sectional nature of the data, because cross-sectional data do not allow for the determination of causality of the identified associations. Previous prospective studies have found that high screen time or total sedentary time at baseline can be predictive of cardiometabolic health risk at follow-up (Biswas et al., 2015; Grøntved & Hu, 2011; Pandey et al., 2016; Wilmot et al., 2012), but reverse causality is also a possibility. Additionally, the follow-up period for the test-retest reliability component of this project was relatively short (two weeks between test and re-

test), therefore it has yet to be determined if the screen time questionnaire or the ISST scoring methods are reliable over longer timeframes such as multiple years or decades. Future studies that collect longitudinal data on screen time, total sedentary time, combined measures such as ISST scores, and cardiometabolic health risk are needed to determine the direction of the relationship and to determine if there are direct causal links between cardiometabolic health risk and sedentary behaviour.

Another main limitation of this project could be residual confounding of the measured associations. While we controlled for the critical confounders of age, biological sex, and physical activity in our regression models, there may have been residual confounding of the associations in these models. This could have also contributed to our null findings for the association between total sedentary time and clustered cardiometabolic risk scores, which is inconsistent with previous literature. We did not have the statistical power to control for all the demographic variables we measured (such as ethnicity, marital status, and current level of education), and we also did not control for dietary patterns, sleep quantity, or alcohol consumption in our analysis. Based on previous findings that other behaviours related to TV viewing time such as unhealthy dietary patterns could be contributing to the association between TV viewing time and cardiometabolic health risk (Nang et al., 2013), it is important for future studies to measure these potential confounders. Identifying whether leisure-time sedentary screen time is associated with cardiometabolic health risk independently of other confounding variables is crucial for the development of educational resources, behaviour change recommendations, and health interventions targeted at reducing the incidence or severity of cardiometabolic diseases such as type II diabetes and hypertension.

A main strength of this project was the broad age range of participants in the sample. As previously mentioned, we used quota sampling by age category to ensure that our sample consisted of participants of a variety of ages, and this was important because sedentary behaviour and cardiometabolic health risk are both affected by the age and the life stage of the participant. For example, young adults and older adults may tend to engage in higher screen time than middle-aged adults, and older adults tend to engage in more sedentary time than younger or middle-aged adults (Colley et al., 2022). Additionally, cardiometabolic health risk related to lifestyle behaviours such as movement behaviours tends to increase in every person with age (Bankoski et al., 2011), therefore including only young, healthy participants would have drastically reduced the variability in our data. The broad age range of our participants also aids in showing that the ISST scores may be useful in future research involving participants of a variety of ages.

A limitation of this study could also be the specific screen time questionnaire used. As discussed in a previous chapter, participants may have over- or under-estimated their typical leisure-time screen use due to biases such as recall bias or social desirability bias. Additionally, numerous participants informally mentioned to the researcher during their visits to the lab that the screen time questionnaire questions had confusing wording, and that they felt it was difficult to estimate their screen time on every type of device based on memory alone. Several other recently published studies have used the same screen time questionnaire or slightly modified versions (Bani-Issa et al., 2022; Wade et al., 2021; Wiciak et al., 2022), and their results suggest that the screen time questionnaire has some validity even though it has not been formally validated at this time to our knowledge. Future projects could use other ways of measuring screen time such as screen

time logs or device-based measures and incorporate these measures into ISST scores to better examine the relationship between sedentary behaviour and cardiometabolic health risk.

Practical Implications and Future Directions

Sedentary behaviour consists of three elements: the amount of time spent in sedentary postures, the types of activities completed while sedentary, and the pattern of accumulated sedentary behaviour. The present project examined the combination of total sedentary time and leisure-time sedentary screen time as ISST scores, and its associated cardiometabolic health risk. However, the pattern of accumulated sedentary behaviour has been shown to have an impact on cardiometabolic health such that sedentary time accumulated in long, uninterrupted bouts is associated with worse cardiometabolic health (Aho et al., 2021; Brocklebank et al., 2015; Chastin et al., 2015; Farrahi et al., 2021; Garcia-Hermoso et al., 2015; Healy et al., 2011; Huang et al., 2021; Zheng et al., 2020). The pattern of sedentary behaviour was not incorporated into ISST scores, so future projects could examine the combination of time, type, and pattern of sedentary behaviour and its associated health risks.

One of main goals of creating the ISST scoring methods was to identify individuals who may be at greater cardiometabolic health risk based on their movement behaviours, which could lead to the identification of individuals who may benefit from interventions aimed at reducing harmful engagement in certain movement behaviours. A few published studies have investigated the effects of changes to movement behaviours on cardiometabolic health risk. Buman et al. (2014) used isotemporal substitution modelling to estimate the effect of replacing 30 minutes of sedentary time with either sleep or physical activity, and found that this replacement beneficially impacted various

cardiometabolic health risk factors. Garthwaite et al. (2022) completed a randomized controlled trial and found that reducing sedentary behaviour by 50 minutes per day benefitted some of the cardiometabolic health risk factors as well. Our results in combination with findings such as these highlight the importance of addressing sedentary behaviour as an intervention target for improving cardiometabolic health.

While it is important to encourage all adults to engage in the currently recommended amounts of moderate to vigorous physical activity for their age group (Canadian Society for Exercise Physiology, 2020), additional findings provide support for the implementation of interventions to reduce excessive time spent in sedentary behaviours as a way to improve cardiometabolic health (Buman et al., 2014; Garthwaite et al., 2022). Reducing sedentary behaviour tends to pose a lower risk to participants than increasing intense physical activity, and this may be especially relevant for populations who have difficulty increasing their moderate to vigorous physical activity involvement such as adults with several diagnosed cardiometabolic diseases, adults at high risk of diabetes (Wijndaele et al., 2014), or adults with poor mobility and low exercise tolerance (Dogra et al., 2021). Reducing leisure-time sedentary screen time could be an additional behavioural target, as it may be even more beneficial, could be more appealing to participants, and could be more feasible than targeting occupational sedentary time since participants would have more control over their movement behaviours during their free time. For example, future studies could examine the possible cardiometabolic health effects of replacing one hour per day of leisure-time sedentary screen time with one hour per day of reading or socializing.

Conclusion

The ISST scoring methods we explored may be useful for future research involving sedentary behaviour and health risk. Future studies could examine the same or different calculation methods for ISST sores in other samples or populations, especially with data that were not collected during the COVID-19 pandemic. Future research could also examine the associations between ISST scores and individual cardiometabolic biomarkers or cardiometabolic health risk factors.

Table 12. Theoretical Values and Associated Risk using the Continuous Scoring Method for the Index of Sedentary Screen Time

Sedentary screen time (hours/day) \ Total Sedentary Time (hours/day)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5
2	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
3	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5
4	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5	17.5
6	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
7	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5	17.5	18.5
8	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
9	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5	17.5	18.5	19.5
10	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

Note. Hypothetical values for sedentary screen time are presented on the left and hypothetical values for total sedentary time are presented along the top. The corresponding possible values for the continuous Index of Sedentary Screen Time scores (in "hour equivalents" per day) are presented within the table. Since most screen time is completed while sedentary (Pinto Pereira et al., 2012), highly improbable combinations are shaded in grey (screen time exceeding total sedentary time by ≥ 2 hours). Based on the cut-points of 3-4 hours of screen time and 6-8 hours of total sedentary time from Patterson et al. (2018), values expected to be associated with low cardiometabolic health risk (below 3 and 6, respectively) are shaded in green and are within the bolded lines on the top left. Similarly, values expected to be associated with high cardiometabolic health risk (above 4 and 8, respectively) are shaded in red and are within the bolded lines on the bottom right. Values that may be associated with lower risk are shaded in pale green

(between 3-4 or 6-8, respectively, but with an ISST score not exceeding 7.5 which is the highest value in the green section), values that may be associated with moderate risk are shaded in yellow, and values that may be associated with greater than moderate risk are shaded in orange (between 3-4 or 6-8, respectively, but with an ISST score not below 11.5 which is the lowest value in the red section). Overall, a higher continuous Index of Sedentary Screen Time score may still pose greater health risk irrespective to the proportion of screen time to total sedentary time accumulated per day.

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APPENDIX 1: INFORMED CONSENT FORM

University of Lethbridge
Faculty of Arts & Science

Department of Kinesiology & Physical Education
4401 University Drive
Lethbridge, Alberta, Canada T1K 3M4
Phone 403.329.2680
Fax: 403.380-1839

Sedentary behaviour, screen time, and cardiometabolic health risk

We invite you to participate in a study conducted by Haley Dennis (MSc Student) examining the effects of different types of sedentary time on health risk. High amounts of sedentary time have been found to increase health risk even in people who are physically active, and past research has mainly focused on time spent watching television while sedentary. However, not much is known about the difference in health risk when comparing total sedentary time (all sedentary activities in a day) and sedentary "screen time" (i.e. using smartphones, tablets, and watching television). Thus, the purpose of this study is to determine how total sedentary time and sedentary screen time affect health risk.

Procedures & Participant Responsibilities

Participation involves 4 visits to the Active Healthy Aging Lab at the University of Lethbridge. The first visit will take 30-45 minutes, the second visit will take 45-60 minutes, the third visit will take 5-10 minutes, and the fourth visit will take 15-30 minutes. Participation includes the following:

1. Completing a brief questionnaire about your health status, age, biological sex, gender, education, and any medications you are currently taking. Your answers are strictly confidential, and will be used to ensure that you are eligible to participate in the study. Your responses to this questionnaire will also be used during data analysis to adjust for variables that may affect the results of this study.
2. Wearing an activity monitor (called an inclinometer) to measure your daily sedentary time and physical activity for 24 hours per day for **two** separate weeks. The inclinometer is small, lightweight, and waterproof (once secured), so it can be safely and comfortably secured to the middle of the top of your thigh for seven consecutive days.
3. Having your height, weight, waist circumference, and blood pressure measured.
4. Completing a second brief questionnaire **twice** about your screen-based activities in the past week. This questionnaire will ask about the average amount of time you spent looking at screens (such as smartphones, tablets, and television) and your background screen use (such as watching television while cooking) in the past seven days. This questionnaire does **not** ask about the types of activities you complete on screens.

5. Providing a small saliva sample during the second visit to the Active Healthy Aging Lab. You will be asked to place a non-toxic sterile oral swab under your tongue for a few minutes, and we will be using this saliva sample to measure your C-reactive protein concentration. All analyses will be completed in the Active Healthy Aging Lab at the University of Lethbridge.

6. Providing a small blood sample via a finger poke during the second visit to the Active Healthy Aging Lab. You will be asked to fast for 9-12 hours before the second visit, and we will use this blood sample from your finger to measure your HDL cholesterol, LDL cholesterol, total cholesterol, blood triglycerides, blood glucose, and glycosylated hemoglobin. All analyses will be completed in the Active Healthy Aging Lab at the University of Lethbridge.

Potential Risks and Discomforts

There is a slightly increased risk of disease transmission when collecting a saliva sample, as this requires you to briefly remove your face mask in the laboratory. This risk will be minimized by using an individually wrapped single-use oral swab that you place in your mouth yourself, and the researcher will maintain strict social distancing within the lab when your face mask is temporarily removed.

The collection of a blood sample may cause some minor discomfort, and could pose a small risk of infection. This risk will be minimized using the approved finger poke blood sample collection procedure, and all blood samples will be collected by a researcher who has completed training in the proper sample collection technique. The surrounding skin will first be disinfected, then your finger will be pricked with a single-use lancet and a very small amount of blood will be collected (45 µL). The researcher will be wearing the appropriate personal protective equipment (including gloves and a face mask) during this brief procedure.

For all in-person visits to the Active Healthy Aging Lab, appropriate COVID-19 precautions will be taken to ensure your health and well-being. When you first arrive at the laboratory for each visit, you will be asked to don a face mask and sanitize your hands. The researcher will ask all participants if they have any signs or symptoms of COVID-19 or have travelled outside Canada in the last 14 days in order to minimize the risk of COVID-19 exposure as a result of participating in this study. Within the Active Healthy Aging Lab, routine sanitary procedures are regularly followed including sanitizing all laboratory surfaces and equipment before and after each visit. The researcher will wear a face mask at all times and physical distancing will be practiced whenever possible, and only one participant will be allowed in the laboratory at a time.

Benefits to Participants and/or Society

Once your participation in this study has been completed, you will be given a copy of all of your own results indicating your personal physical activity profile, blood lipid profile, blood glucose measures, and C-reactive protein concentration. Once the overall study is complete, you can request a summary of the overall results by contacting Haley Dennis (780-781-5292, h.dennis@uleth.ca) or Jennifer Copeland (403-317-2804, jennifer.copeland@uleth.ca). The most important benefit is that you will be contributing

to research that will improve our understanding of the effects of different types of sedentary time on health! ☺

Compensation for Participation

To thank you for your participation, you will be given a **$25 gift card** once your participation in this study is complete. You will also be entered into a draw for a $100 gift card to a local restaurant if you complete any part of study participation. Your odds of winning the draw will be between 1 in 60 and 1 in 75, depending on the number of people who complete part of study participation.

Confidentiality

Your anonymity will be protected by assigning an ID number to you, which will be used within the data set and to label your saliva sample. A master list linking your name to your ID number will be stored on a password-protected computer, which will be kept in the principal investigator's locked laboratory. Only researchers associated with this study will have access to the master list and the data set, and all researchers will all sign a confidentiality agreement. The master list and any other personally identifying information (such as consent forms) will be destroyed one year after the study has been completed. Other anonymous data including the questionnaire responses, activity tracker data, and biomarker data may be kept indefinitely. The data collected in this study will be used for research purposes only, which include a Master's thesis, a journal publication, and a research presentation. All data will be presented as a group (i.e. averages or percentages), and your individual identity will remain anonymous.

Freedom to Withdraw

Your participation in this research is **completely voluntary**. You are free to withdraw from this study at any time until the time of publication by contacting Haley Dennis (780-781-5292, h.dennis@uleth.ca) or Jennifer Copeland (403-317-2804, jennifer.copeland@uleth.ca). Upon withdrawal, you may choose to have the data you have contributed until that point permanently destroyed (up until the time of publication). You are also able to participate in the study but refuse specific components of the study, such as the saliva sample or blood sample collection component. The decision to withdraw will not result in any consequences, and will not impact the benefits of participating.

This letter is yours to keep. If you have questions about this research, please contact either:

Jennifer L. Copeland, PhD
Dept. of Kinesiology
University of Lethbridge
(403) 317-2804 (p)
jennifer.copeland@uleth.ca

Haley A. Dennis, BSc
Dept. of Kinesiology
University of Lethbridge
(780) 781-5292 (p)
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This research has been reviewed for ethical acceptability and approved by the University of Lethbridge Human Participant Research Committee. Questions regarding your rights

as a participant in this research may be addressed to the Office of Research Ethics, University of Lethbridge (Phone: 403-329-2747 or Email: research.services@uleth.ca).

Consent Statement

Title of Study: **Sedentary behaviour, screen time, and cardiometabolic health risk**

MSc Student Investigator: Haley Dennis **Phone Number:** (780) 781-5292
Faculty Supervisor: Dr. Jennifer Copeland **Phone Number:** (403) 317-2804

	Yes	No
Do you understand that you have been asked to be in a research study?	☐	☐
Have you read and received a copy of the attached Letter of Information?	☐	☐
Do you understand the benefits and risks involved in taking part in this research study?	☐	☐
Have you had an opportunity to ask questions and discuss this study?	☐	☐
Do you understand that you are free to leave the study at any time, without having to give a reason?	☐	☐
Has the issue of confidentiality been explained to you?	☐	☐
Do you understand who will have access to your information?	☐	☐
Who explained this study to you? _____		

By signing below, I agree to participate in this study:

Participant's Name	Signature	Date

Investigator's Name	Signature	Date

APPENDIX 2: SCREEN TIME QUESTIONNAIRE

For the following set of questions, ***primary activity*** is defined as the main activity you are engaged in rather than using a television/other screen in the background while performing another activity such as cooking or exercising.

Screen use on an average weekday
Thinking of an average weekday (from when you wake up until you go to sleep), how much time do you spend using each of the following types of screen as the primary activity?
You must answer both hours and minutes. **If zero please type "0" in the box.**

	Hours	Minutes
Television		
TV-connected devices (e.g. streaming devices, video game consoles)		
Laptop/computer		
Smartphone		
Tablet		

Screen use on an average weeknight
Now, thinking of an average weeknight (from when you return from work until you go to sleep), how much time do you spend using each of the following types of screen as the primary activity?
You must answer both hours and minutes. **If zero please type "0" in the box.**

	Hours	Minutes
Television		
TV-connected devices (e.g. streaming devices, video game consoles)		
Laptop/computer		
Smartphone		
Tablet		

Screen use on an average weekend day
Now, thinking of an average weekend day (Saturday or Sunday), how many hours over the course of the whole day (from when you wake up until you go to sleep) do you spend using each of the following types of screen as the primary activity?
You must answer both hours and minutes. **If zero please type "0" in the box**.

	Hours	Minutes
Television		
TV-connected devices (e.g. streaming devices, video game consoles)		
Laptop/computer		
Smartphone		
Tablet		

For the following set of questions, **background screen** is defined as the use of a television or another screen near you while performing other activities such as exercising, cooking, and interacting with family/friends.

Thinking about a regular weekday (Monday through Friday), on average, how many hours **over the course of the whole day** (from when you wake up until you go to sleep) are you exposed to background screen use?

Example: If you exercise in the morning for one hour while watching the TV news, you use your smartphone for one hour while eating lunch and an additional 30 minutes while eating dinner, you would estimate that you are exposed to 2 hours and 30 minutes of background screen use per day.

	Hours	Minutes
Background screen use on a regular weekday		

Now we want to ask about background screen use **during the evening specifically**. On average, how many hours per evening (Monday through Friday) are you exposed to background screen use from when you return from work until you go to sleep?

Example: If you regularly prepare dinner with the television on for one hour, and you keep the television on for an additional hour while using your smartphone for social media use, you can estimate that you are exposed to 2 hours of background screen use every evening.

	Hours	Minutes
Background screen use on a regular weeknight		

Now we want to ask about background screen use **during the weekend**. Thinking about a regular weekend day (Saturday or Sunday), on average, how many hours over the course of the whole day (from when you wake up until you go to sleep) are you exposed to background screen use?

Example: If you have the television on while you do some online shopping for two hours, and you keep the television on when friends come over to visit for an additional two hours, you can estimate that you are exposed to 4 hours of background screen use every evening.

	Hours	Minutes
Background screen use on a regular weekend day		

(Vizcaino et al., 2019)