Examining the association between cycling infrastructure and cycling: Baseline results from INTERACT Victoria

By

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Abstract

The majority of Canadians are not meeting physical activity guidelines. Implementing infrastructure that supports active transportation is an important intervention to increase population physical activity levels. The INTErventions, Research and Action in Cities Team (INTERACT), has the goal to advance research on the design of healthy and sustainable cities for all. My study is a sub-project of INTERACT and has three main objectives. The first objective is to determine whether participants support the All Ages and Abilities (AAA) Cycling Network. The second objective is to examine the association between exposure to the Pandora protected cycle track and physical activity levels and the third objective is to determine if there are gender differences in overall levels of physical activity. I hypothesized that participants would support the AAA Cycling Network and exposure to the Pandora protected cycle track would be associated with greater overall physical activity levels of residents who cycle at least once a month in Victoria. I also hypothesized that women would have lower levels of physical activity when compared to men. INTERACT recruited 281 people who completed online surveys; 149 of whom wore a Sensedoc (an accelerometer and global positioning system (GPS), for ten days to collect physical activity and spatial location data). Data collection took place from May 19, 2017, to November 30, 2017. I calculated exposure to the Pandora protected cycle track using daily path mobility, which measures the ratio of the number of GPS points within 200 metres of the Pandora protected cycle track compared to the participants number of total GPS points. Overall, participants supported the AAA Cycling Network and showed a preference for off-road paths and separated cycling infrastructure. This preference was especially true for women, who also reported much less physical activity per week than men. Regression analysis showed that there were associations between exposure to the Pandora protected cycle track and both self-report and accelerometer-based physical activity, but only after a certain threshold of exposure. The implementation of the AAA Cycling Network with an emphasis on protected cycling infrastructure may increase cycling frequency and physical activity levels in the City of Victoria.

Keywords: cycling, physical activity, cycle track, active transportation infrastructure

General Summary

Physical activity is important but yet many Canadians do not meet the recommended physical activity guidelines. One potential way to increase physical activity levels is by making changes to the built environment such as adding active transportation infrastructure. The INTErventions, Research and Action in Cities Team (INTERACT), is researching the design of healthy and sustainable cities across Canada. My study is a sub-project of INTERACT that is examining the All Ages and Abilities (AAA) Cycling Network in Victoria, British Columbia. Using survey, GPS and accelerometer data, this study determined that participants support the AAA Cycling Network and preferred off-road cycling paths and separated cycling infrastructure. Women reported much less physical activity per week than men. Data analysis showed that there were associations between exposure to the Pandora protected cycle track and both self-report and accelerometer-based physical activity, but only after a certain threshold of exposure. Thus, the AAA Cycling Network may increase cycling frequency and physical activity levels in Victoria, British Columbia.

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List of Abbreviations

CSEP: Canadian Society for Exercise Physiology

MVPA: Moderate-to-vigorous physical activity

GPS: Global Positioning System

AAA: All Ages and Abilities

GIS: Geographic Information System

OR: Odds Ratio

CI: Confidence Interval

UK: United Kingdom

RR: Relative Risk

SD: Standard Deviation

INTERACT: INTErventions, Research and Action in Cities Team

CCHS: Canadian Community Health Survey

CURHA: Contrasted Urban settings for Healthy Aging

IPAQ: International Physical Activity Questionnaire

HELENA: Healthy Lifestyle by Nutrition in Adolescence

MET: Metabolic Equivalent Task

CPM: Counts Per Minute

Chapter 1: Introduction

1.0 Overview

In Canada, over 20% of adults live with cardiovascular disease, cancer, cardiorespiratory disease, and diabetes (Public Health Agency of Canada, 2016). Physical inactivity remains high, and over 90% of Canadian children are not meeting the physical activity guidelines. The Canadian Society for Exercise Physiology (CSEP) recommends that children obtain 60 minutes of moderate-to-vigorous physical activity (MVPA) per day (Canadian Society for Exercise Physiology, n.d.). For adults, CSEP recommends at least 150 minutes of MVPA per week. Physical inactivity is a major problem for the Canadian population. The economic burden of physical inactivity is $5.3 billion (Katzmarzyk & Janssen, 2004). However, physical activity has many benefits including reducing the risk of developing chronic diseases such as stroke, heart disease, hypertension, Type 2 diabetes, cancer and obesity (Public Health Agency of Canada, 2011). Physical activity improves strength, increases bone density, and allow individuals to remain independent as they age. Also, physical activity can increase self-esteem, morale, reduce stress and enhances quality of life. Physical activity has the greatest health benefits, including decreased mortality risk when individuals transition from being completely sedentary to 15 minutes per day (Wen et al., 2011).

One way to improve the health and physical activity levels of the population is through active transportation. Active transportation has been defined as "any form of human-powered travel – most commonly walking and cycling, but also in-line skating or skateboarding" (Public Health Agency of Canada, 2014). Active transportation provides users with many health benefits, including increased physical activity levels (Oja et al., 1998). Cycling to work is protective against all-cause mortality (Andersen et al., 2000). Also, active transportation can have effects that impact the wider community (Reynolds, Winters, Ries, & Gouge, 2010). Active transportation in walkable neighborhoods can contribute to making the world healthier by reducing the quantity of vehicle pollutants emitted due to decreased kilometres travelled by car (Frank & Engelke, 2005). A cost-benefit analysis examining cycling networks investments in Norway estimates the benefits to be 4-5 times the cost (Sælensminde, 2004). Using system dynamics modeling, it has been suggested that implementing bicycling infrastructure with physical separation from motorized traffic on main roads and making local roads more bicycle friendly by reducing speed would result in benefits 10-25 times greater than the cost over the next 40 years (Macmillan et al., 2014). Active transportation infrastructure could serve as an essential public health intervention helping to increase physical activity levels in the population.

Active transportation has the potential to have positive impacts on our communities. However, more research is needed to examine strategies to increase active transportation (Reynolds et al., 2010). One strategy to increase active transportation is the implementation of separated cycling infrastructure in a city. Separated cycling infrastructure is a bike lane that physically separates the cyclist from motorized traffic using a curb, motor vehicle parking or another type of barrier (Pucher et al., 2010). Cycle tracks or protected cycling lanes are other common names for separated cycling infrastructure. Results from a systematic review on the effects of bicycle infrastructure found positive relationships between bike infrastructure and levels of bicycling for most of the studies that examined bicycle networks or larger studies that compared between or within cities and neighbourhoods (Buehler & Dill, 2016). Individual level studies, such as small cross-sectional studies examining a small segment of bicycling infrastructure and levels of bicycling have mixed findings.

One possible reason why the results of individual-level studies have been mixed is the data collection method. Studies have relied on both self-report and Global Positioning Systems (GPS) methods, which may provide different results. GPS data provides researchers with an objective measurement of the actual paths travelled by participants (Duncan et al., 2009). GPS data provides actual routes taken by participants provide information about route choice, which is an essential factor to consider when engaging in active transportation (Duncan & Mummery, 2007). GPS data is often used in combination with accelerometer data (Duncan et al., 2009). Accelerometers measure physical activity by recording changes in acceleration of the participant's movement to provide the researcher with the relative intensity of movement. Some studies use self-report origin-destination data to provide estimate routes derived from Geographic Information Systems (GIS) (Duncan & Mummery, 2007). Both GPS traces and derived estimate routes from GIS typically have no difference in trip distance, the latter method does not take into account how people use or avoid barriers and facilitators to active transportation including motor traffic, hills, and active transportation infrastructure. Multiple studies suggest triangulating GPS data with other sources, including bicycle counts, self-reports, and travel diaries is important to advance the field (Duncan et al., 2009; Heesch & Langdon, 2016).

1.1 Purpose

The purpose of my thesis is to examine whether exposure to the Pandora protected cycle track is associated with more overall physical activity levels. My thesis has three main objectives. The first objective is to determine whether the participants in my sample support the AAA Cycling Network. The second objective is to examine if overall physical activity levels change depending on exposure to the Pandora protected cycle track. Exposure was defined as the percentage of a participants' total GPS points that were within a 200-metre buffer of the Pandora cycle track. The third objective is to determine if there are gender differences in overall levels of physical activity.

1.2 Research Hypotheses

I hypothesize that the participants will support the AAA Cycling Network. I hypothesize that exposure to the Pandora protected cycle track will increase overall physical activity levels of people who cycle in Victoria. I hypothesize that women will have lower levels of overall physical activity than men regardless of exposure status.

1.3 Research Intervention

The AAA Cycling Network is an active transportation network in Victoria, British Columbia. This network is currently being constructed in multiple phases and will eventually be a 32km network connecting every neighborhood in the city. At the time of data collection, the Pandora protected cycling track was the only portion of the network that was completed. The Pandora lane is a protected cycling track that is approximately 1.0km in length. As the AAA Cycling Network grows, it will be analyzed in future INTERACT studies.

1.4 Research Significance

This research is significant because it will examine baseline effects of the AAA Cycling Network. The results of this project have the potential to promote the importance of bicycling infrastructure across the country. In particular, the outcomes from my project can help to shape the Bicycling Master Plan currently being developed by the City of St. John's in Newfoundland.

1.5 Thesis Format

This thesis follows a traditional format that is organized into five chapters (introduction, literature review, methodology, results and discussion), with references included at the end of the thesis. This thesis has been formatted using American Psychological Association (6th edition) referencing style.

Chapter 2: Literature Review

2.0 Introduction

When conducting this review of the literature, I focused on studies that examined the impact of cycling infrastructure on active transportation and overall physical activity. In particular, I emphasized studies that used GPS data collection. The majority of studies have taken place in either Australia or the United States (Broach et al., 2012; Brown et al., 2016; Dill, 2009; Dill et al., 2014; Heesch et al., 2016; Heesch & Langdon, 2016; Rissel et al., 2013, 2015). The studies I reviewed used multiple methods for data collection and analysis, including observational bike counts, GPS, accelerometers, surveys, travel diary data, vehicle collision data, and GIS software.

Throughout the literature review, multiple themes have emerged. The literature can be summarized in several categories, including cycling infrastructure preference, infrastructure and physical activity, and infrastructure and gender.

2.1 Cycling Infrastructure Preference

There are many different types of cycling infrastructure, including bicycle lanes, bicycle boulevards, and separated cycling infrastructure or cycle tracks (Pucher et al., 2010). Previous research has demonstrated that cyclists prefer certain types of infrastructure. In general, routes that are separated from motorized traffic and routes that are easy to travel are important factors to promote cycling (Winters et al., 2011). Separated cycling infrastructure and off-road paths have been found to be preferred types of cycling infrastructure (Broach et al., 2012; Caulfield et al., 2012; Garrard et al., 2008; Heesch et al., 2012; Lusk et al., 2011; Winters et al., 2011) and determined that cyclists prefer cycle tracks and are more likely to use cycle tracks compared to alternate routes without cycling facilities (Broach et al., 2012; Lusk et al., 2011).

Protected cycling infrastructure may encourage a diverse group of riders of all abilities, ages, and genders. Both separated cycling infrastructure and off-road paths are physically separated from motorized traffic, which may allow cyclists to feel comfortable and safe. Results from a systematic review show improved safety for cyclists when facilities for cyclists were present that are marked such as bike lanes, paths or cycling tracks (C. C. Reynolds et al., 2009). In Boston, there was an 11% reduction in the odds of having a bicycle crash causing injury (OR = 0.89; 95% CI = 0.79, 1.00) with each year increase in the study period after the implementation of bicycle infrastructure (Pedroso et al., 2016). Cycle tracks were found to have a 28% lower injury rate when compared to alternate bicycle routes in Montreal, Canada (Lusk et al., 2011).

2.2 Infrastructure and physical activity

Active transportation infrastructure provides opportunities for individuals and populations to be physically active. Previous research has shown that cyclists are more active when compared to non-cyclists. Brown et al. (2016) conducted a study analyzing energy expenditures in a sample of 536 participants who were classified as either never cyclists, continuing cyclists, former cyclists, or new cyclists. Participants wore GPS and accelerometer devices for two one-week periods before and after expansion of a bicycle lane, complete street improvements including widened sidewalks and light rail upgrades. When comparing energy expenditures between cyclists and non-cyclists, cyclists averaged 4.34 kcal/min on cycling days and 2.96 kcal/min on non-cycling days. The average kcal expenditure of non-cyclists was 1.14 kcal/min. Since cyclists have higher average kcal expenditures on both cycling and non-cycling days, this suggests that cyclists are a relatively active group compared to non-cyclists.

Similarly, another study found that levels of physical activity predicted use of active transportation infrastructure. The iConnect study conducted in the UK determined that baseline physical activity levels of individuals were associated with subsequent use of active transportation infrastructure (Goodman et al., 2014). This means that participants with higher physical activity levels at the beginning of the study were more likely to use active transportation infrastructure.

Cycling can be used as a means for individuals to achieve the recommended 150 minutes of physical activity per week (Dill, 2009). In Portland, Oregon, 166 bicyclists were recruited to wear GPS devices during bicycling activities. The GPS devices collected location and speed data every three seconds when the device was turned on. Over seven days, 59% of bicyclists recorded at least 150 minutes of cycling. Half of the distance travelled by the bicyclists occurred on cycling infrastructure. It has been hypothesized that exposure to cycling infrastructure has the potential to increase overall physical activity levels.

2.2.1 Exposure to active transportation infrastructure and physical activity

Several studies indicate that residents living in closer proximity to cycling infrastructure are associated with greater awareness, use of, and increased levels of physical activity (Dill et al., 2014; Frank et al., 2019; Goodman et al., 2014; Panter et al., 2016; Rissel et al., 2015). In one study in Portland, Oregon, using GPS and accelerometer devices, every mile a participant lived closer to downtown was statistically associated with 1.2 additional minutes of moderate to vigorous physical activity (Dill et al., 2014). Living closer to a new bicycle path in Sydney, Australia was associated with greater awareness (Adjusted OR = 5.99, 95% CI = 3.87-9.27), use of the bicycle path (Adjusted OR = 3.58, 95% CI = 2.01-6.40) and intention to use the path (Adjusted OR = 2.77, 95% CI = 1.76 – 4.37) (Rissel et al., 2015). From these studies by Dill et al. (2014) and Rissel et al. (2015), we see that residential location can influence people's physical activity behaviors and engagement.

Similarly, Goodman et al. (2014) highlighted the importance of residential location using a longitudinal survey. This study demonstrated that proximity to Connect2 infrastructure in the UK was associated with increased use of Connect2 compared to those living further away (Goodman et al., 2014). This study sampled adult residents from three UK municipalities. The Connect2 infrastructure was infrastructure that promoted walking or cycling and included motorized traffic-free bridges over busy roads and new paths. The survey was conducted before the infrastructure improvements (n = 3516) and again at one year (n = 1796) and two year (n = 1465) follow up periods. Results from the two year follow up study concluded that living closer to a Connect2 project was associated with greater use of Connect2. Every kilometre that a participant lived closer to the intervention resulted in an increase of 15.3 minutes per week of walking and cycling (95% CI = 6.5, 24.2).

This finding was replicated again in Cambridge, United Kingdom, where a longitudinal quasi-experimental study determined that exposed participants had higher levels of commuting cycling and total cycling time compared to unexposed participants.

This study evaluated the Cambridgeshire Guided Busway which consisted of a new bus network and 22 kilometres of motor traffic-free walking and cycling routes (Panter et al., 2016). Participants were taken from the Commuting and Health in Cambridge cohort study with two data collection periods: pre-construction and post-construction. Exposure was measured by calculating the distance from a participants home to the closest bus stop or path access point. Panter et al. (2016) determined that weekly cycle commuting time was 1.34 times greater in participants who were exposed to the busway than participants who were not exposed (RR = 1.34, 95% CI = 1.03, 1.76). Similar results were found for total time spent cycling with exposed participants having 1.32 times greater total cycling time compared to unexposed participants (RR = 1.32, 95% CI = 1.04, 1.68). There were no significant effects for either total walking time or total walking and cycling time combined.

Most recently in Vancouver, British Columbia researchers found an association between residential location physical activity. This longitudinal study examined the effect of a new urban greenway on physical activity and sedentary behaviour and determined that participants living closer had a higher likelihood of participating in physical activity (Frank et al., 2019). The urban greenway is a two-kilometre cycling route consisting of one-way on-street counterflow lanes, one-way protected lanes, and two-way shared on-street lanes. Individuals who lived within 1 kilometre of the greenway were randomly sampled to participate, and data collection took place before the intervention was constructed and after the intervention was open for public use. Participants were divided into experimental (living <= 300 metres from the greenway) and control (living > 300 metres from the greenway) groups. After the greenway opened, participants in the experimental group were twice as likely to achieve an average of 20 minutes of MVPA per day (OR = 2.00; 95% CI

= 1.00, 3.98). Participants who lived further away from the greenway (100 – 500 metres), had decreased odds of achieving an average of 20 minutes of MVPA per day. The odds of being sedentary for greater than 9 hours per day decreased by 54% (OR = 0.46, 95% CI = 0.25, 0.85) after the opening of the greenway. Proximity to the greenway had the opposite effect on sedentary behaviour then it did on physical activity, with the greatest reductions in sedentary behaviour occurring in participants who lived furthest away.

Studies conducted by Goodman et al. (2014), Panter et al. (2016) and Frank et al. (2019), provide us with valuable results regarding proximity to active transportation infrastructure; however, these studies rely on participant residential location to determine exposure to active transportation infrastructure. More research is needed using dynamic measures of exposure such as GPS data to account for where people actually go along with their residential location. Using objective GPS data will allow researchers to further examine how exposure to infrastructure impacts overall physical activity.

2.2.2 Changes in cycling infrastructure and overall physical activity

Implementing infrastructure that supports active transportation is an important intervention to increase population physical activity levels. Studies have found mixed results when examining infrastructure and cycling overall with some studies finding no changes and other studies reporting increased cycling following changes in infrastructure.

A study conducted in Portland, Oregon found no association between the installation of bicycling boulevards and increased active transportation levels in adults wearing GPS and accelerometer devices for two periods of up to five days (Dill et al., 2014). This study used GPS and accelerometer data along with surveys to collect their data over 3 years. The results showed that there was no association between living in a treatment area after the addition of bicycle boulevards and the number of minutes of moderate to vigorous physical activity per day (b = -3.44, p =.33). Additionally, there was no association between biking more than 10 minutes per day and living in a treatment area after the bike boulevard installations (b = .201, p = .655). The authors concluded that there are multiple possibilities for these results. The amount of time between installation and data collection was between two and twelve months. Data collection may have occurred too soon after the infrastructure improvements which may not have allowed for adequate time for behaviour change to happen. The addition of bicycle boulevards occurred in stages, so residents may not have perceived the changes to be major since they were done in small steps. Additionally, two of the nine bicycle boulevards projects were not fully complete during data collection.

Similarly, Brown et al. (2016) found that participants cycling increased on new cycling infrastructure from 18.51 minutes (*SD* = 54.96) to 22.55 minutes (*SD* = 49.95), but these results were non-significant (*SD* = 49.95; $t_{(203)}$ = .99, p = .32). Another important factor to consider is the placement of the cycling network and the amenities in and surrounding it. Cycling networks that are well connected with mixed land use allow cyclists to perform bicycle trips with more than one purpose, which results in greater cycling (Dill, 2009).

These two studies provide valuable insights into the addition of active transportation infrastructure and changes in overall physical activity. The suggested primary mechanism by which people would increase their overall physical activity as a result of changes in cycling infrastructure would be increases in cycling physical activity.

Although there has been an increase in cycling infrastructure research, there is still a lack of agreement among studies whether the addition of cycling infrastructure increases overall physical activity and cycling physical activity.

2.4 Infrastructure and gender

Cycling rates differ by men and women. In Canada, the United States and the United Kingdom, approximately 25% of bike trips are made by women (Pucher & Buehler, 2010). However, cycling is evenly balanced between gender in Germany, Denmark, and the Netherlands. A case study from Sweden found no differences in bicycle trips distance and levels of bicycling between men and women (Annika Carlsson-Kanyama, Anna-Lisa, 1999). Data from the Canadian Community Health Survey shows gender differences in cycling in Canada. Cycling is increasing in Canada; however, the prevalence in cycling for at least 6 hours or more to school, work, or errands in men (10.4%) is almost two times higher than women (5.7%) (Butler et al., 2007). For Canadians who reported cycling at least once in the past 12 months, 47.0% (95% CI 46.3 – 47.7) were men, and 34.2% (95% CI 33.6 – 34.9) were women (Ramage-Morin & Statistics Canada, 2017).

Studies have determined that the majority of women prefer routes that maximize separation from motorized traffic, such as those with off-road paths (Garrard et al., 2006, 2008). This finding is supported in studies examining gender differences in recreational and transport cyclists, where women cyclists were more likely to use off-road paths than men for both transport and recreational cycling (Heesch et al., 2012).

Chapter 3: Methods

3.0 Overview

The purpose of my thesis is to investigate whether exposure to the Pandora protected cycle track is associated with more overall physical activity levels. I hypothesize that the participants will support the AAA Cycling Network. I hypothesize that exposure to the Pandora protected cycle track will increase overall physical activity levels of people who cycle in Victoria. I hypothesize that women will have lower levels of overall physical activity than men regardless of exposure status.

The INTErventions, Research and Action in Cities Team, a Canadian Institutes of Health Research funded project, has the goal to advance research on the design of healthy and sustainable cities for all (Kestens et al., 2019). The team is composed interdisciplinary scientists, urban planners, and public health decision makers, with the primary goal to evaluate the impact of real-world urban form intervention. INTERACT is studying interventions in four Canadian cities: Vancouver and Victoria, British Columbia, Saskatoon, Saskatchewan, and Montreal, Quebec. In Vancouver, INTERACT is studying the Arbutus Greenway, and the All Ages and Abilities Cycling Network (AAA) is being examined in Victoria. In Saskatoon, a new Bus Rapid Transit System and components of the Sustainable Development Plan 2016-2020 are being evaluated in Montreal. The study will take place in three waves in each city over five years. In each city, 300-3000 participants will be recruited. Participants will have multiple options for participation, but all participants will complete an online survey and will have the option to participate in further data collection opportunities such as wearing a mobile sensing device (Sensedoc).

A Sensedoc is a research grade accelerometer device that collects data on physical activity and spatial location.

My portion of the project examined the association between exposure to the first phase of the AAA Cycling Network in Victoria on overall physical activity levels. I analyzed the first wave of data collected, which specifically examines the Pandora protected cycle track. This project is important because it will examine the baseline effects of the AAA Cycling Network.

3.1 Design

This study is a natural experiment analyzing the effect of exposure to the Pandora protected cycle track on physical activity levels. The study population is residents of Victoria who bike at least once a month. In Victoria, INTERACT recruited 281 participants for the first wave of data collection. The data collection took place from May 19, 2017, to November 30, 2017. INTERACT attempted to recruit a representative sample from those in the population who fit the inclusion criteria taking into account age, gender, and socio-economic status. The inclusion criteria for participants included living in the Capital Regional District and bicycle at least once a month in the City of Victoria. Participants were excluded if they were less than 18 years old, if they were unable to read or write English well enough to complete an online survey and if they had any intentions of moving out of the region in the next two years. All of the 281 participants completed the online survey, and 149 participants chose to wear a SenseDoc to collect data on their physical activity and spatial location data.

Ethics approval was received from the ethics boards of Simon Fraser University, the University of Saskatchewan, the *Centre de Recherche du Centre hospitalier de l'Université de Montréal,* and Memorial University of Newfoundland. For my master's thesis, I obtained sub-project ethics approval from Memorial University of Newfoundland.

3.2 Intervention

The AAA cycling Network is currently being constructed in downtown Victoria, British Columbia (City of Victoria, n.d.). The first phase of this project is a 5.4km grid located in the downtown core with protected bike lanes for high motor traffic volume streets and neighborhood bikeways for lower volume areas. By 2022, the AAA network will connect every neighborhood in the city for a total of 32km of bicycle infrastructure. The AAA network is designed for everybody in the community and is focused on individuals who are interested in cycling but are concerned about safety. I am explicitly analyzing the Pandora Protected cycle track, which is the first segment of the AAA Cycling Network. This was the segment built at the time of data collection.

3.3 Causal Model

Figure 1 illustrates the causal model for this study. I believe there is a direct effect between the exposure and the outcome. The exposure in this study is the Pandora protected cycle track in Victoria, British Columbia, and the outcome is overall physical activity levels. There are multiple confounders in this study, including age, gender, ethnicity, income and weather.

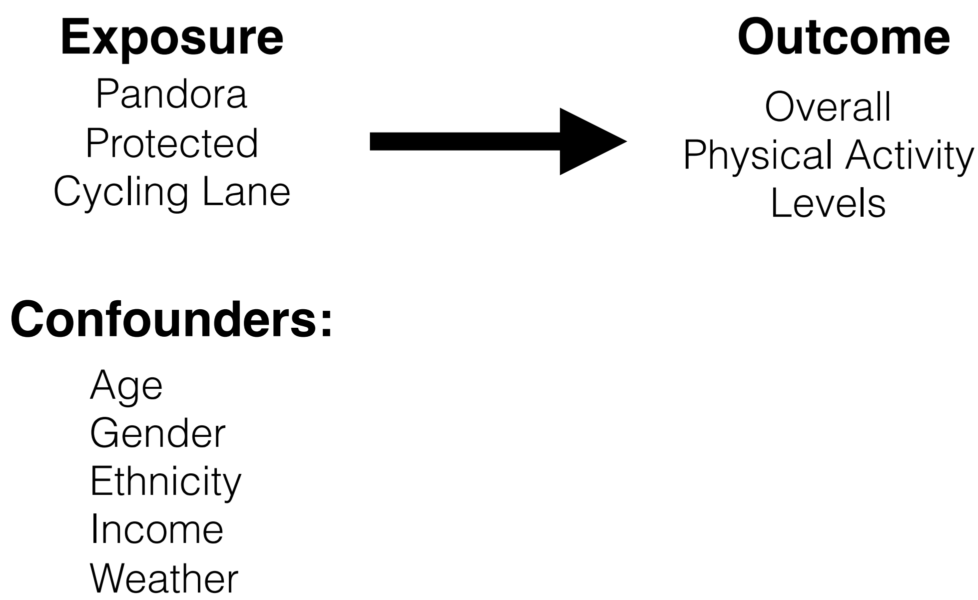

Figure 1. Causal Model for the associations between exposure to the Pandora Protected Cycling Lane and Overall Physical Activity.

3.4 Data Collection

Two methods of data collection were used for this study. Participants had two options for participation, but all participants were required to complete an online survey. Participants had the choice to wear a mobile sensing device (SenseDoc). As some individuals interested in participating may not have had access to the internet or have a mobile phone or compute, there was an option to participate in the survey either in person with a research assistant or over the phone. These individuals also had the opportunity to wear a mobile sensing device.

3.4.1 Online Survey

All participants were required to complete an online survey. The online survey took approximately 20 to 30 minutes to complete and had 56 questions. The online survey was divided into several categories. Participants were asked demographic questions and questions about their health and well-being. Participants were asked about the types of transportation modes they use, their physical activity levels, and their time spent sitting. Participants were asked if they use activity trackers to measure their physical activity levels and their thoughts concerning data security. Participants were asked their sense of community and belonging to their neighborhood. Finally, participants were asked if they use the AAA Cycling Network and different questions surrounding the network. For my thesis, I will focus on the questions about demographics, physical activity, and the AAA Cycling Network. Survey questions were developed by members of INTERACT and included questions from a variety of sources including the Canadian Community Health Survey (CCHS) (Statistics Canada, 2018), CURHA (Kestens et al., 2016) and a modified version of the International Physical Activity Questionnaire (IPAQ) (*International Physical Activity Questionnaire*, 2002).

Several demographic variables from the online survey were identified as being potentially confounding, including, age, gender, ethnicity, and income. Previous literature shows associations between these variables and active transportation which the rationale behind why they were considered confounding (Winters et al., 2011). Age was measured by asking participants to report their date of birth. Gender was measured by asking participants to select a category based on how they describe themselves (male, female, trans, other). Participants who selected male and female were recoded into men and women, respectively. Three participants identified as either trans or other, and these participants were grouped together in a new category called trans and gender non-binary. Participants reported ethnicity by choosing a category which described the ethnic or cultural groups that their ancestors belonged to, including Aboriginal, Asian, Black, Caucasian, Latin American, and Middle Eastern. Several participants identified as belonging to more than one ethnic or cultural group. Participants who identified as anything other than Caucasian were recoded to new group called as racialized. For income, the online survey asked participants to select one of twelve categories that best described their annual household income including no income, $1 to $9,999, $10,000 to $14,999, $15,000 to $19,000, $20,000 to $29,999, $30,000 to $39,999, $40,000 to $49,000, $50,000 to $99,999, $100,000 to $149,999, $150,000 to $199,999, $200,000 or more and I don't know/Prefer not to answer. The twelve income categories were recoded into four income categories including $49,999 or less, $50,000 to $99,999, $100,000 to $149,999 and greater than $150,000. Then, participants were asked the extent to which their income allows them to satisfy their needs using five categories such as very well, decently, not so well, and not at all.

3.4.2 Mobile Sensing Tool

For this portion of the study, participants had the option to wear a SenseDoc, which is a research grade accelerometer device for ten days. Participants were instructed to wear the SenseDoc on their right hip during all activities except during sleeping and activities involving water. Participants were asked to charge the device overnight. The SenseDoc collects physical activity and spatial location data and records data every second for the entire data collection period (Mobysens, n.d.). The SenseDoc is a multi-sensor with a GPS and a tri-axial accelerometer (ADXL3XX). The SenseDoc device uses similar accelerometer technology to the ActiGraph GT3X+, which has been found to be reliable and valid for collecting physical activity data in adults (Aadland & Ylvisåker, 2015). Both of the accelerometers were designed and produced by Analog Devices, Inc. The SenseDoc uses the ADLX3XX accelerometer, and the Actigraph GT3X+ uses the ADLX355 accelerometer. Despite slight differences, the raw accelerometer data is comparable. Several studies have used the Sensedoc in the past to measure accelerometer based physical activity and location using GPS (Brondeel et al., 2019; Kestens et al., 2016).

Different recommendations have been established for valid wear time in accelerometer and GPS data. In both accelerometer and GPS, it is important to collect enough data that reflects a participants daily routine without causing the participant to be overburdened (Stanley et al., 2018; Trost et al., 2005). Considerable research has been done to establish wear time guidelines for accelerometer data. The recommended wear time is 10 hours per day for at least four days (Trost et al., 2005). Less research has been done for establishing valid wear time guidelines for GPS data. However, Stanley, Yoo, Paul and Bell (2018) suggested that complete activity spaces can be determined with less than two weeks of GPS data. Participants were instructed to collect data for 10 days which satisfied both the GPS and accelerometer recommendations. The GPS and accelerometer data from each participant were filtered for the correct days that each participant wore the device. Any days with less than 7500 GPS points which is equal to 125 minutes of wear time were removed from the data set. This value was chosen as 125 minutes is approximatively 8.5% of a participant’s day which may not accurately represent a participant’s regular routine. Of the 154 participants who wore a Sensedoc, three participants were excluded due to insufficient data.

3.5 Outcomes

3.5.1 Support for the AAA Cycling Network

One outcome of this study is to determine participant support for the AAA Cycling Network. Support for the AAA Cycling Network was measured using three variables. These questions were designed specifically to measure the AAA Cycling Network and differ from the other site-specific intervention questions for INTERACT. The first question measured familiarity to the AAA network by asking participants if they had heard of the AAA network before. Participants responded with either yes ("1") or no ("0"). Participants perception of the AAA network was measured by asking participants if they think the AAA network is a good or bad idea for Victoria (1 = very good idea to 4 = very bad idea). The third question was if participants will be more likely to cycle more in the future after the construction of the AAA network is complete. Participants responded with either yes ("1") or no ("0"). The survey also asked about preferences for active transportation infrastructure was measured by asking participants how comfortable they would feel biking in six different places. These places included a separated path, quiet residential street, quiet residential street with traffic calming, major urban street with no bike lanes, major urban street with a striped bike lane and major urban street with a protected bike lane. Participants responded on a scale from one (very uncomfortable) to 4 (very comfortable).

3.5.2 Overall Physical Activity

The primary outcome in this study is overall physical activity levels, which was measured by two ways: the self-report data from the online survey, and the accelerometer data from the Sensedoc. Participants reported their past seven days of physical activity using a modified version of the IPAQ (*International Physical Activity Questionnaire*, 2002). The IPAQ has been found to be a reliable and valid tool for measuring self-reported physical activity across multiple countries (Bauman et al., 2009; Craig et al., 2003; Maria Hagströmer et al., 2006). There were three main categories of physical activity (walking, moderate and vigorous) that were used to calculate overall physical activity. INTERACT's modified IPAQ does not include walking at work or moderate physical activity at work. This modified version of the IPAQ also does not include the domestic and garden work section which included moderate inside and outside yard chores and vigorous outside yard chores. There hasn't been any analysis completed to determine if these changes will affect the reliability and validity of the IPAQ. However, the HELENA study modified the IPAQ for adolescents and found it to be valid for adolescents aged 15-17 (M Hagströmer et al., 2008). Overall physical activity was calculated as described below:

Total walking Metabolic Equivalent of Task (MET) minutes of physical activity was calculated by combining transport walking and leisure walking using formula 1.

$$
\begin{aligned}
&Walking\ MET - minutes\ of\ physical\ activity \\
&\qquad = (3.3\ X\ walking\ minutes\ X\ walking\ days\ for\ transportation) \\
&\qquad + (3.3\ X\ walking\ minutes\ X\ walking\ days\ in\ leisure)
\end{aligned}
$$

Formula 1:

Total moderate MET-minutes of physical activity was calculated by combining cycling for transport and moderate-intensity leisure activities using formula 2.

$$Moderate\ MET - minutes\ of\ physical\ activity$$
$$= (6.0\ X\ cycling\ minutes\ X\ cycling\ days\ for\ transportation)$$
$$+ (4.0\ X\ moderate - intensity\ activity\ minutes\ X\ moderate$$
$$- intensity\ days\ in\ leisure)$$

Formula 2:

Total MET-minutes of physical activity was calculated by combining vigorous activities at work and vigorous-intensity leisure activities using formula 3.

$$Vigorous\ MET - minutes\ of\ physical\ activity$$
$$= (8.0\ X\ vigorous - intensity\ activity\ minutes\ X\ vigorous$$
$$- intensity\ days\ at\ work) + (8.0\ X\ vigorous$$
$$- intensity\ activity\ minutes\ X\ vigorous$$
$$- intensity\ days\ in\ leisure)$$

Formula 3:

Total MET-minutes of physical activity was calculated by combining walking MET-minutes, moderate MET-minutes, and vigorous MET-minutes using formula 4.

$$Total\ MET - minutes\ of\ physical\ activity$$
$$= Walking\ MET - minutes + Moderate\ MET - minutes$$
$$+ Vigorous\ MET - minutes$$

Formula 4:

An objective measure of physical activity was assessed using the Sensedoc, mobile sensing device. The Freedson, Melanson, and Sirand (1998) physical activity cut points developed for adults were used for my data analysis.(Freedson et al., 1998) Using the cut points, accelerometer-based physical activity was classified into two categories: moderate and vigorous (Freedson et al., 1998). These results were combined with the GPS data to calculate minute by minute location-based physical activity data (Sabia et al., 2014; van Hees et al., 2013).

3.6 Exposure

The GPS data from each participant was analyzed to determine their level of exposure to the AAA Cycling Network. Each participant's exposure was determined by examining their GPS traces and its intersection with the Pandora separated cycle track. I used the GPS trace to create "activity spaces" for each participant. Horton and Reynolds (1971), define activity spaces as the "subset of all urban locations with which the individual has direct contact as the result of day-to-day activities" (p.37). Activity space is an individualized measure of spatial behaviour and includes where the participant lives, works, studies and other places that are important to the participant (Hirsch et al., 2014). A systematic review of activity spaces defines activity spaces as "dynamic measure of mobility" and provides insights on using activity spaces to strengthen causal inference (Smith et al., 2018).

The specific activity space measure I used was daily path mobility. Daily path mobility takes all of the trips completed by a participant using the GPS coordinates and buffers them by a set distance, which is a concept adapted from Kwan's daily potential path area (Hirsch et al., 2014; Kwan, 1999; Zenk et al., 2011). Similar studies have used buffers ranging from 200 metres to 800 metres (Hirsch et al., 2014; Zenk et al., 2011).

Since daily path mobility buffers routes that are travelled by participants, it is a good measure for examining the places participants pass throughout the day (Hirsch et al., 2014).

I calculated exposure to the AAA Cycling Network using daily path mobility. A buffer of 200 metres was used for daily path mobility space. Since I are only interested in exposure to the Pandora cycle track, I buffered the cycle track by 200 metres and then determined how many GPS points for each participant were located inside the 200-metre buffer. Exposure is expressed as the percentage of a participants' total GPS points that are within this buffer. This is a continuous measure and can be interpreted as a "dose".

3.7 Confounding and Effect Modification

Throughout my literature review, I have identified several potential confounders that could influence the results of my study. Confounding is defined as the "mixing of effects between an exposure, an outcome, and a third extraneous variable known as a confounder (Rothman et al., 2008). It is important to identify and control for confounding variables to attempt to have unbiased estimates. I have identified several potential confounders in my study, including, age, gender, ethnicity, income and weather. All of the potential confounders were measured using the online survey as discussed above. Weather data from each day of data collection was retrieved from Environment Canada and included as a covariate in the statistical models. Appendix A contains the specific survey questions addressing each of the potential confounding variables.

3.8 Data Analysis

Data analysis was conducted using R and R Studio. Descriptive statistics were calculated for the total sample and the subset of participants who wore a Sensedoc. I calculated descriptive statistics to determine support for the AAA Cycling Network. A multiple linear regression and random intercepts regression were used to examine the association between exposure to the Pandora protected cycle track and total physical activity measure using self-report surveys and hip worn accelerometers, respectively. I conducted a stratified analysis by gender to determine differences in exposure and overall self-report and accelerometer physical activity levels.

3.8.1 Exposure and outcome

From the mobile sensing device, I used the GPS data to determine participants exposure and accelerometer data to objectively measure physical activity. Exposure to the Pandora protected cycle track was determined using daily path mobility with a 200-metre buffer. For each participant, exposure was expressed as a percentage of the number of points in the Pandora buffer divided by the number of total GPS points. This allowed for exposure values to be relative and could be compared among participants who had different numbers of total GPS points. Three participants had high exposure values of 47.0%, 52.2% and 62.6%. These exposure values were considered outliers and were removed from the analysis. Figure 1 illustrates a map of the exposure values greater than 45% which were considered to be outliers. Based on the map, I assume that participants with high exposure either lived or worked along the bike lane.

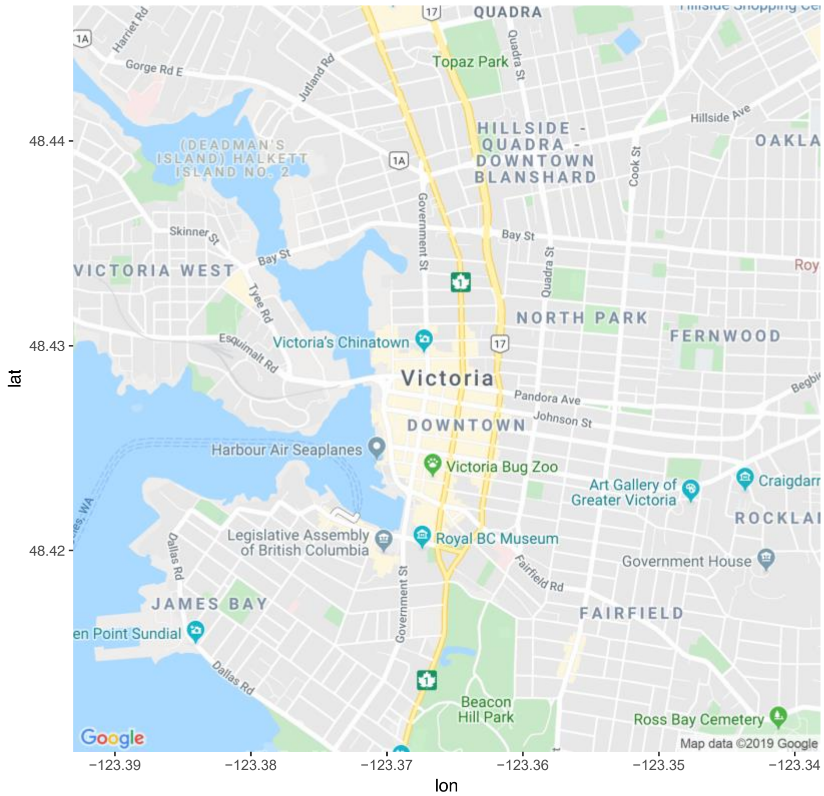

Figure 1: Map of outlier participants with greater than 45% exposure to the Pandora Bike Lane.

The primary outcome in this study is overall physical activity. Physical activity was measured using self-report and accelerometer data collected from each participant. Participants reported their past seven days of physical activity using a modified version of the IPAQ. There were four outliers' for total MET-minutes of physical activity per week. Participants who had greater than 20000 MET-minutes of physical activity per week were considered outliers. Using the participant with the highest self-report physical activity value less than 20000 as a base score, each outlier was recoded to be one higher than this score while also maintaining rank order. For example, the participant's score of 20786.0

was recoded to 18897, 22308.0 was recoded to 188898.0, 25470.0 was recoded to 18899.0 and 29622.0 was recoded to 18900.0.

The accelerometer data was processed and summarized into minute-level activity counts using the R activityCounts package. The activity counts were classified into sedentary, light, moderate or vigorous activity based on cut-points developed by Troiano et al. (2008). Sedentary behaviour was classified as 0-99 counts per minute (CPM). Minute-level activity counts ranging between 100- 2019 CPM were classified as light activity, Moderate activity as between 2020 – 5998 CPM and any counts per minute over 5999 were classified as vigorous activity. Counts greater than 10,000 were removed from the data as they do not represent plausible physical activity values. Activity counts that were classified as sedentary or light (less than 2019 CPM) were excluded from the analysis because this analysis focused on MVPA.

3.8.2 Weather data

Weather data was retrieved from Environment Canada from the Victoria International Airport for each day of data collection. The entire data collection period was over a 7 month period from May 19, 2017, to November 30, 2017. Participants wore Sensedoc devices for 10 days with the data collection period. There could be considerable variable in daily weather patterns during the data collection period. I calculated the mean daily temperature and total amount of precipitation per day was matched to each valid day that a participant wore the Sensedoc. For each participant, I calculated (a) the mean temperature and (b) total amount of precipitation in millimetres (mm) over their data collection period was calculated. The weather data was included in the regression models as a confounder.

3.8.3 Regression analysis

To examine the association between exposure to the Pandora separated cycling track and self-report MVPA I used a linear regression model, controlling for confounders. I used a negative binomial regression models to examine the associations between exposure to the AAA Cycling Network and overall physical activity, controlling for confounders. The trans and gender non-binary group was excluded from the regression analysis due to the small group size (n = 3).

3.8.4 Confounders

Each potential confounding variable was examined by comparing the effect size between bivariate and fully adjusted models of the association between the confounder and outcome. If there was a greater than 10% difference between the bivariate and fully adjusted models, then the variable was considered a confounder (Aschengrau & Seage, 2014). Each variable meeting this criteria was added into the final model. Additional potential confounding variables identified with less than 10% difference were included in final models based on the existing literature. Based on this, variables with less than 10% difference that is still conceptually a confounder, was included in the model.

Chapter 4: Results

4.0 Total Sample

The total sample size for this study was 281 participants. See Table 1 for participant demographic information. To summarize, participants mean age was 44.2 years old (SD = 13.4). Just over half (51.9%) of the sample were women (n = 146), and three participants identified as trans or gender non-binary (1.1%). The majority of participants (86.8%, n = 244) identified as Caucasian. The majority of participants (76.5%, n = 215) had incomes greater than $50,000 per year.

4.1 Subsample

4.1.1 Sensedoc Subsample

A subset of the sample (n = 149) wore a Sensedoc for 10 days which collected GPS and accelerometer data (Table 1). The sociodemographic characteristics of these participants did not differ substantially from the entire sample. The demographic data for each group is presented along with the support for the AAA cycling network and cycling behaviours (Table 1). Since there are no differences between the two groups, the total sample will be used when discussing the data collected using the survey.

4.1.2 Gender Subsample

When analyzing the total sample (*N* = 281), I had a slightly higher percentage of participants who identified as women (51.9%) than men (46.9%). The average age of women and men in this study was 42.9 years (*SD* = 12.9) and 45.8 years (*SD* = 13.9), respectively. Participants who identified as trans or gender non-binary had an average age of 44.0 years old (*SD* = 12.2) and men had the highest average age of 45.7 years old (*SD* = 13.9). All other sociodemographic characteristics of this sample did not differ substantially between genders.

Table 1: Participant demographics from the INTERACT cohort, a sample of residents who cycled at least once a month in Victoria, Canada.

	Total Sample (N = 281)	SenseDoc Participants (n = 149)
Age		
Mean (*SD*)	44.2 (13.4)	45.7 (13.7)
Range	(21, 79)	(22, 79)
Gender		
% Women	51.9	51.6
% Men	46.9	47.0
% Trans or gender non-binary	1.1%	**
Ethnicity		
% Caucasian	86.8	88.6
% Aboriginal	1.4	1.3
% Asian	6.4	7.4
% Latin American	1.4	0.7
% Middle Eastern	0.3	0
% Unknown	3.5	2.0
Born in Canada		
Yes	74.4	70.5
No	25.6	29.5
Income		
$49,999 or less	16.4	16.8
$50,000 to $99,999	38.1	34.9
$100,000 to $149,999	23.1	24.8
$150,000 or more	15.3	15.4
I don’t know/Prefer not to answer	7.1	8.0
Marital Status		
Married (or common law)	71.9	74.8
Separated or divorced	8.2	8.0
Single (never married)	19.2	14.8
Widowed	0.7	1.3
Health Status		
Poor/Fair/Good	26.2	23.5
Very Good	49.1	47.6
Excellent	24.5	28.8
Children		
% Yes	53.7	53.0
% No	46.3	46.9
Car Access		
% Yes	90.7	92.5
% No	6.4	7.5

Note. ** Excluded in regression analysis due to small sample size

4.2 Support for the All Ages and Abilities Cycling Network

Support for the AAA Cycling Network was measured with three variables. See Table 2 for supporting information. The majority of participants (67.3%) were familiar with the AAA Cycling Network. Almost all participants (97.5%) thought that the AAA network was a very good or somewhat good idea. Just over three- quarters of participants (78.6%) intend to cycle more once the AAA Cycling Network is constructed. Support for the AAA Cycling Network did not differ between genders.

Table 2: Support for the All Ages and Abilities Cycling Network in Victoria, British Columbia, Canada

	Full Sample (n = 281)	SenseDoc Participants (n = 149)
Familiarity with the AAA		
% Yes	67.3	71.1
% No	32.7	28.8
AAA is a good idea		
% Very Good Idea	86.5	88.6
% Somewhat good idea	11.0	9.4
% Somewhat bad idea	1.1	1.3
% Very bad idea	0.03	0.7
% I don't know	1.1	0
Would like to cycle more in the future when AAA is constructed		
% Yes	78.6	76.5
% No	21.3	23.5

4.3 Cycling Frequency and Preference for Active Transportation Infrastructure

Table 3 describes the cycling behaviour of the participants and their preference for different types of active transportation infrastructure. The majority of survey participants perceived cycling in Victoria to be either somewhat or very safe (67.6%). Participants were asked how many days they cycle during each season out of a total of 90 days. All participants were required to cycle at least once a month in order to participate in the study, however, many participants cycled much more. On average, participants in this study cycled 60.0 days in the fall (*SD* = 22.7), 48.2 days in the winter (*SD* = 27.4), 62.6 days in the spring (*SD* = 22.2) and 67.9 days in the summer (*SD* = 19.9). The number of days cycled during each season differed by gender as illustrated in Figure 2. In each season, women on average, cycled six to eight days less than men.

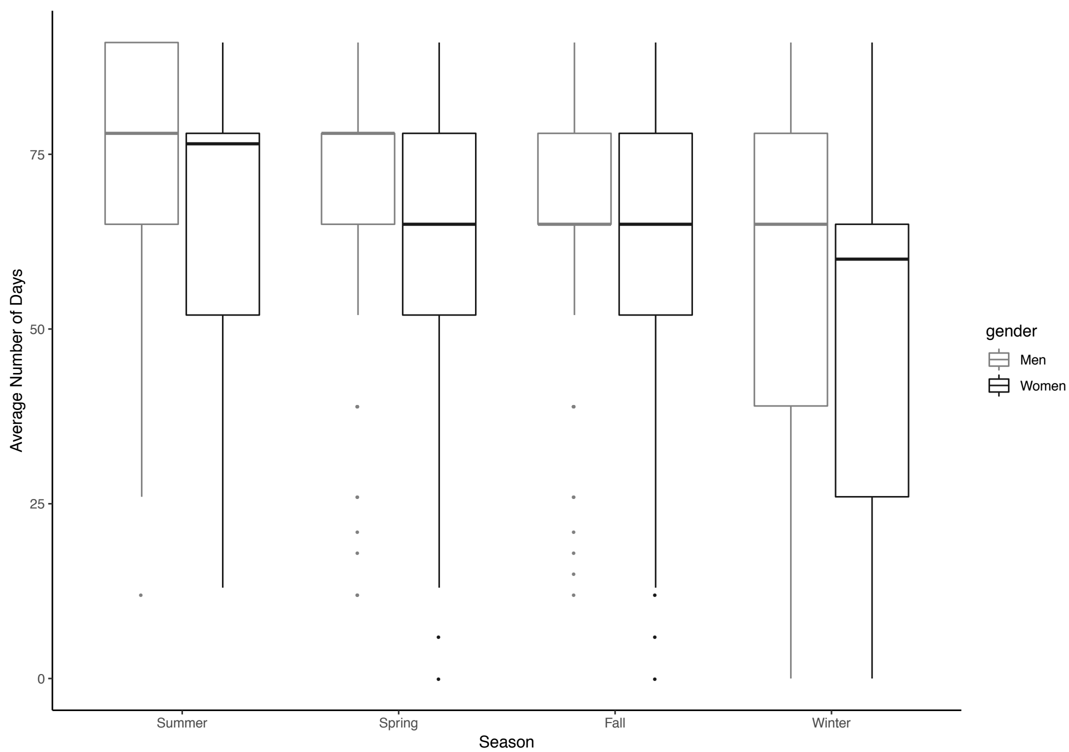

Figure 2: Average number of days cycling during each season by gender

Participants in this study felt more or less comfortable on certain types of cycling infrastructure which is illustrated in Figure 3. The majority of participants (86.1%) felt very comfortable cycling on a path or trail separated from the street. Of the participants who responded with very comfortable, women had a slightly higher preference for bicycle paths (51.7%) than men (47.1%).

Just over half of participants were very comfortable (54.4%) and 30.9% somewhat comfortable cycling on a quiet, residential street with motorized traffic speeds of 30-40 kilometres per hour. A higher percentage of participants who choose somewhat comfortable were women (63.2%) than men (36.8%). In contrast, a higher percentage of men chose very comfortable (55.6%) than women (42.5%).

Almost all participants (90.4%) were either very comfortable or somewhat comfortable on a quiet residential street with a 30 kilometres per hour speed limit, bicycle route markings, wide speedbumps and other things that slow down and discourage car traffic. Of the participants who selected very comfortable, 52.6% were women and 46.0% were men.

On a major urban or suburban street with four lanes, on-street parking, motorized traffic speeds of 50-60 kilometres per hour, and no bike lane, only 3.2% of participants were very comfortable and 13.9% were somewhat comfortable. Almost half of the participants (45.2%) would be very uncomfortable. Of these participants, double the number of women (66.1%) chose very uncomfortable than men (33.1%).

Adding a striped bike lane to a major urban or suburban street with four lanes, on-street parking and motorized traffic speeds of 50-60 kilometres per hour increased the percentage of participants who felt very comfortable to 13.9% or somewhat comfortable to

45.5%. However, almost half of participants (40.6%) were either somewhat or very uncomfortable in this situation. There was a greater gender difference from the participants who reported being somewhat uncomfortable (31.7%). From this group, 56.2% of participants were women and 41.6% were men.

Approximately two-thirds of participants (67.9%) felt very comfortable and 20.6% felt somewhat comfortable cycling on a wide bike lane physically separating the cyclists from a major street with four lanes of motorized traffic and speeds of 50-60 kilometres per hour with either a raised curb, planters or parked cars. Preference for the separated cycling lane was almost equally balanced among genders with a slightly higher percentage of women selecting very comfortable or somewhat comfortable (89.7%) than men (87.1%).

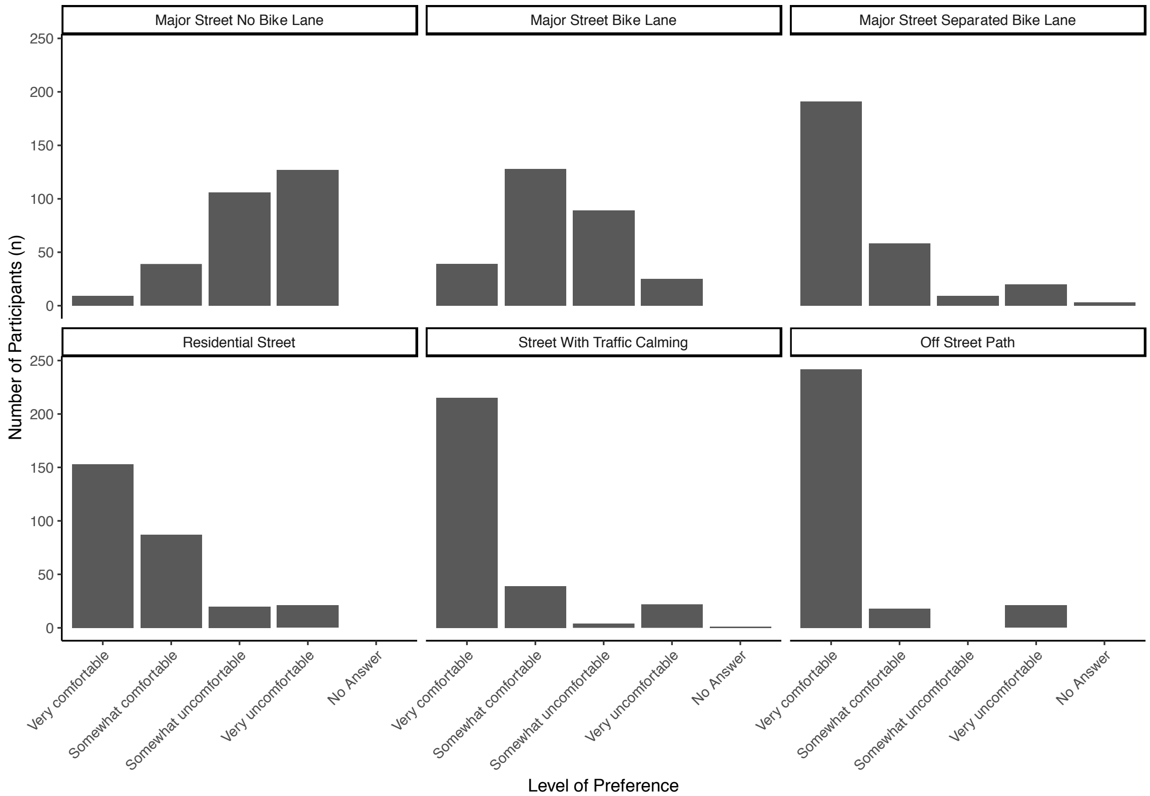

Figure 3: Preference for six different types of active transportation infrastructure. Participants had four options to rate their level of preference: very uncomfortable, somewhat uncomfortable, somewhat comfortable or very comfortable.

Table 3: Cycling Behaviour and Preference for Active Transportation Infrastructure in Victoria British Columbia, Canada

	Full Sample (n = 281)	SenseDoc Participants (n = 149)
Perceived Cycling Safety		
Very safe	8.2	8.7
Somewhat safe	59.4	59.7
Neither safe nor unsafe	11.4	13.4
Somewhat dangerous	19.6	17.4
Very dangerous	1.4	0.7
Bike Frequency by season – Days – Mean (*SD*)		
Fall: Mean (*SD*)	60.0	63.9
Winter: Mean (*SD*)	48.2	53.5
Spring: Mean (*SD*)	62.6	66.1
Summer: Mean (*SD*)	67.9	70.5
Preference for types of cycling infrastructure		
Separated Path		
% Very comfortable	86.1	87.9
% Somewhat comfortable	6.4	6.0
% Somewhat uncomfortable	0	0
% Very uncomfortable	7.5	6.0
Residential Street		
% Very comfortable	54.4	55.0
% Somewhat comfortable	30.9	32.2
% Somewhat uncomfortable	7.1	5.4
% Very uncomfortable	7.5	7.4
Residential Street with traffic calming		
% Very comfortable	76.5	81.9
% Somewhat comfortable	13.9	8.7
% Somewhat uncomfortable	1.4	1.3
% Very uncomfortable	7.9	7.4
% I don't know	0.3	0.7
Major street with no bike lane		
% Very comfortable	3.2	3.3
% Somewhat comfortable	13.9	15.4
% Somewhat uncomfortable	37.8	36.2
% Very uncomfortable	45.2	44.9
Major street with striped bike lane		
% Very comfortable	13.9	13.4
% Somewhat comfortable	45.5	46.9
% Somewhat uncomfortable	31.7	28.8
% Very uncomfortable	8.9	10.7
Separated Cycling Infrastructure		
% Very comfortable	67.9	67.1
% Somewhat comfortable	20.6	19.5
% Somewhat uncomfortable	3.2	4.0
% Very uncomfortable	7.1	8.0
% I don't know	1.1	1.3

4.4 Mobile Sensing Device Wear Time

Participants were instructed to wear the Sensedocfor 10 days and go about their normal routine. On average, participants wore the Sensedoc for 9.2 days (*SD* = 1.6, range 2-13). Participants wore the Sensedoc for an average of 8.2 hours per day (*SD* = 2.4) and wear time ranged from 2.4 to 14.0 hours per day.

4.5 Exposure

Exposure was defined as the percentage of total GPS points that fall within 200 metres of the Pandora protected cycle track. After removing outliers, the mean exposure was 4.0% (*SD* = 6.3) and ranged from 0% to 37.1%. This means that on average 4% of participant's total GPS points were on or within 200 metrs of the Pandora protected cycle track throughout their data collection period. Figure 4 illustrates participants' exposure to the Pandora protected cycle track. When analyzing differences in exposure between men and women, women had slightly higher exposure; an average of 4.4% (*SD* = 6.8) compared to 3.5% (*SD* = 5.6) for men.

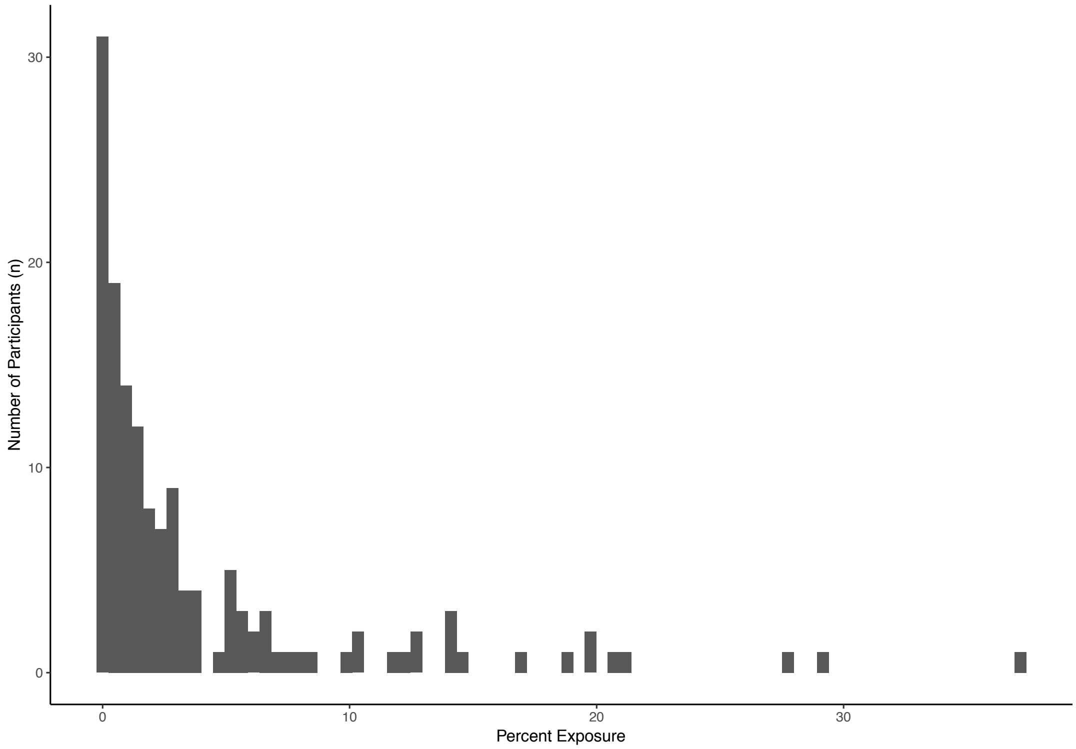

Figure 4: Histogram of participant exposure to the Pandora Protected Cycle Track (Exposure variable) (M = 4.0, SD = 6.3, SE = 0.5 n = 146)

4.6 Outcome

Physical activity was measured using self-report and accelerometer data for each participant. On average, participants reported 4861 total MET-minutes of physical activity per week (*SD* = 4521, range 408 to 22309). Figure 5 illustrates participants total MET-minutes of physical activity per week. Men reported much higher levels of physical activity than women; an average of 5520 total MET-minutes of physical activity per week (*SD* = 4788) compared to 4270 total MET-minutes of physical activity per week (*SD* = 4212) for women.

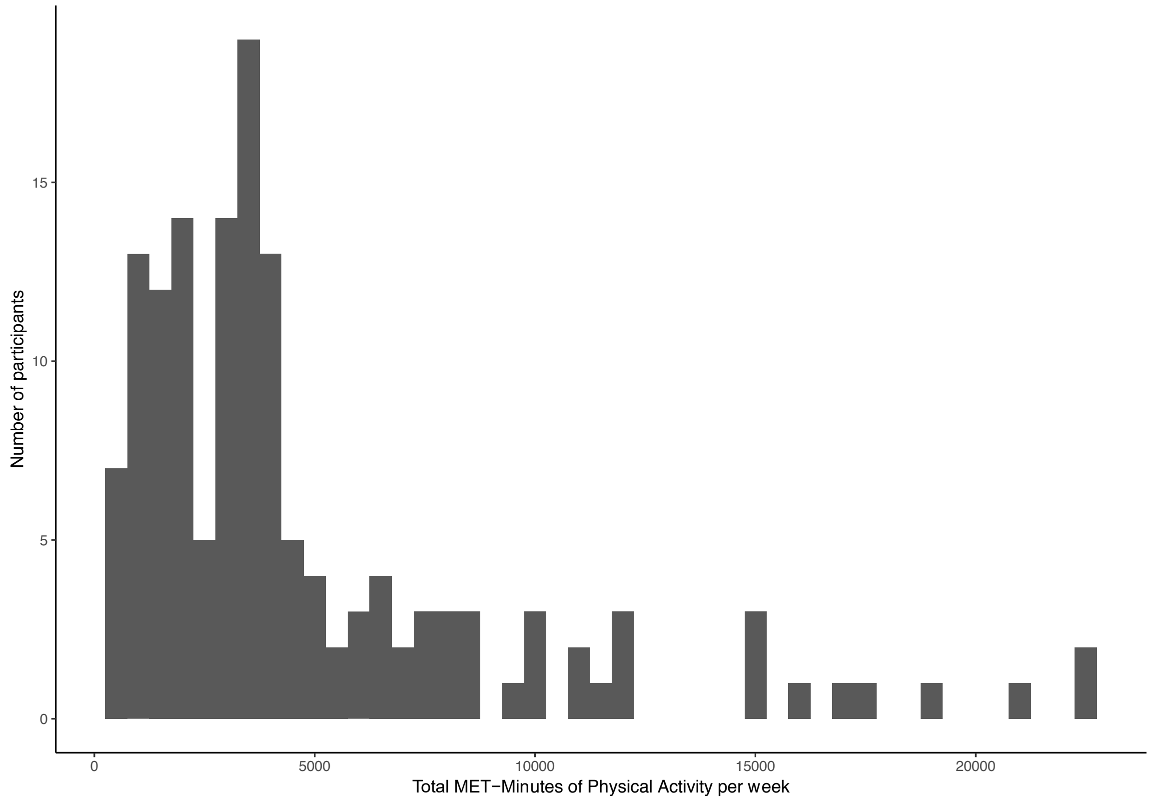

Figure 5. Histogram of Participant's Total MET-minutes of Physical Activity per week measured using the International Physical Activity Questionnaire (M = 4861, SD = 4521, SE = 374, n = 146)

In addition to self-report physical activity, physical activity was measured using the accelerometer data. As mentioned above, the accelerometer data was processed and converted from CPM and labelled as sedentary, light, moderate and vigorous physical activity. Moderate and vigorous physical activity was included in this analysis. Figure 6 illustrates participants moderate physical activity per day. On average, participants recorded 121.4 minutes of moderate physical activity per day (*SD* = 56.5, range 3 to 319). Figure 7 illustrates participants vigorous physical activity per day. On average, participants recorded 12.93 minutes of vigorous physical activity per day (*SD* = 24.2, range 0 to 182).

Men recorded a slightly higher number of moderate physical activity minutes per day. For men, the average number of moderate minutes of physical activity was 125.1 (*SD* = 59.9) and for women, the average number of moderate minutes of physical activity was 117.9 (*SD* = 52.7). Similar with moderate activity, men recorded a slightly higher number of vigorous physical activity minutes per day. For men, the average number of vigorous minutes of physical activity was 15.9 (*SD* = 28.92) and for women, the average number of vigorous minutes of physical activity was 10.1 (*SD* = 18.2). This relationship is consistent with men who self-reported higher levels of physical activity. The difference between men and women is not as large for the accelerometer based physical activity compared to the self-report physical activity.

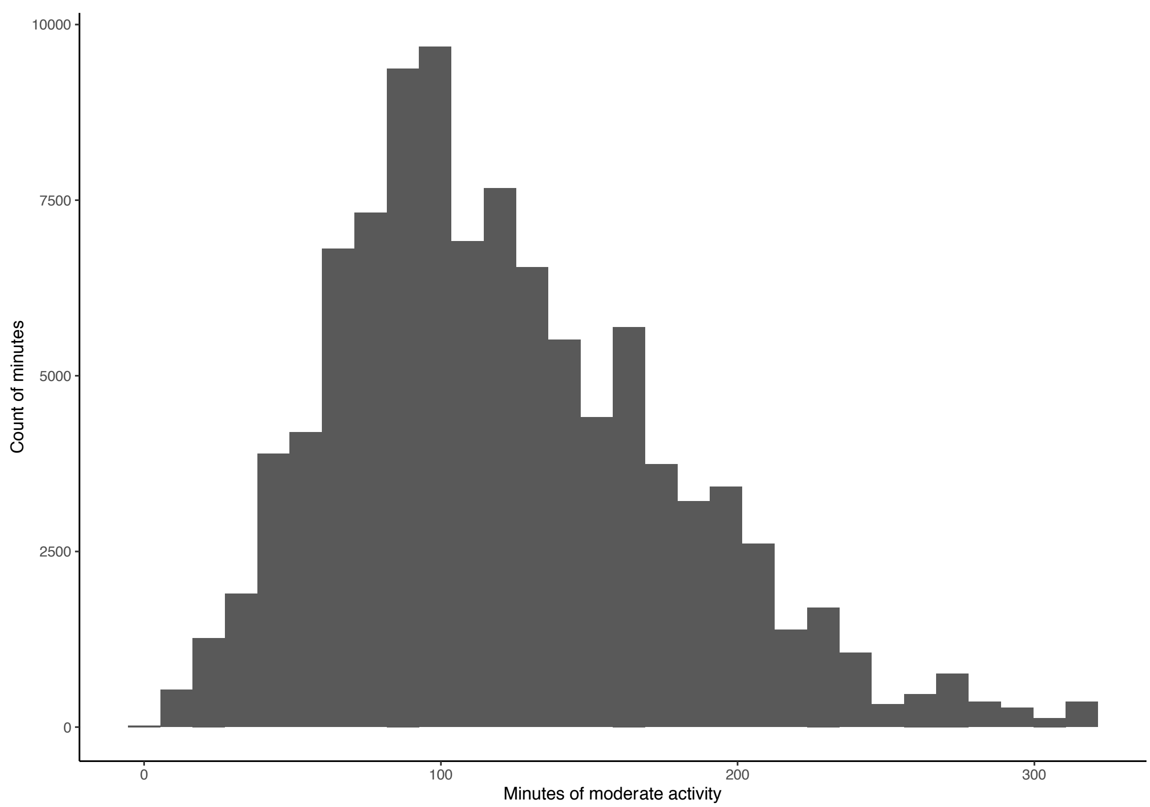

Figure 6: Histogram of minutes per day of moderate physical activity measured with accelerometery (M = 121.4, SD = 56.5, SE = 0.18)

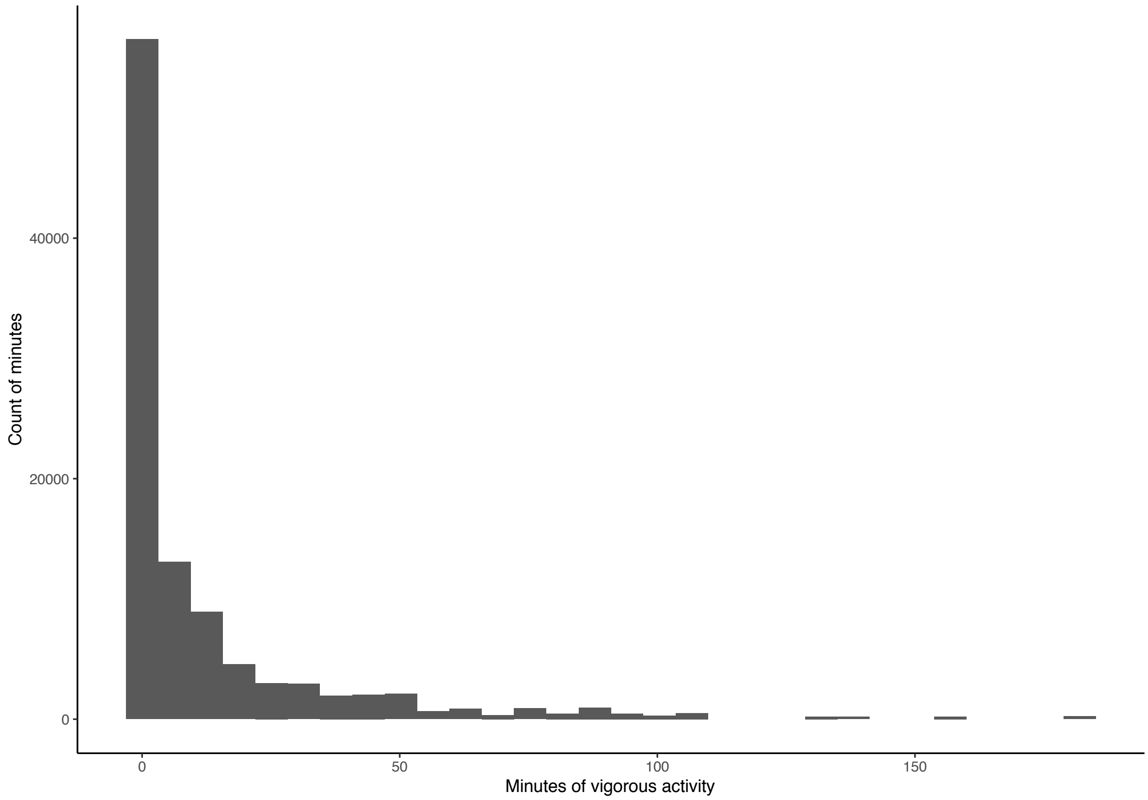

Figure 7: Histogram of minutes per week of vigorous physical activity measured with accelerometery (M = 12.93, SD = 24.2, SE = 0.08)

4.7 Multiple Linear Regression – Total MET-minutes of Physical Activity per week (Self-report)

A multiple linear regression was used to examine the association between exposure to the Pandora protected cycle track and total MET-minutes of self-report physical activity per week (Table 4). Overall, the model accounted for 16.6% of the variance in total MET-minutes of physical activity per week (R^2 = .166, R_{adj}^2 = .076). The model is a significant fit of the data ($F_{(14,131)}$ = 1.87, p = 0.03). Since the majority of the predictors have very large confidence intervals and non-significant results, I conclude that there is no association between exposure to the Pandora protected cycle track and self-reported physical activity.

Table 4: Multiple Linear Regression Self-Report Physical Activity Model Table

Predictor Variable	Estimate (95% CI)
Exposure to Pandora	-231.9 (-552.1 to 88.4)
Gender	
Men	Reference
Women	-1118.7 (-2598.6 to 361.2)
Age Category	
20 - 29	Reference
30 – 39	-294.1 (-2925.9 to 2337.8)
40 – 49	-612.0 (-3425.1 to 2200.9)
50 – 59	1329.0 (-1660.8 to 4318.9)
60+	1333.2 (-1378.1 to 4044.4)
Ethnicity	
Caucasian	Reference
Racialized	286.2 (-2087.9 to 2660.3)
Income	
$49,999 or less	Reference
$50,000 to $99,999	-2460.8* (-4700.2 to -221.3)
$100,000 to $149,999	-3569.1* (-6063.3 to – 1074.9)
$150,000 or more	-2990.6* (-5810.9 to -170.2)
Missing	-3666.2* (-6945.5 to -386.8)
Mean Temperature	33.7 (-243.9 to 311.4)
Total precipitation (mm)	-4.9 (-45.0 to 35.3)

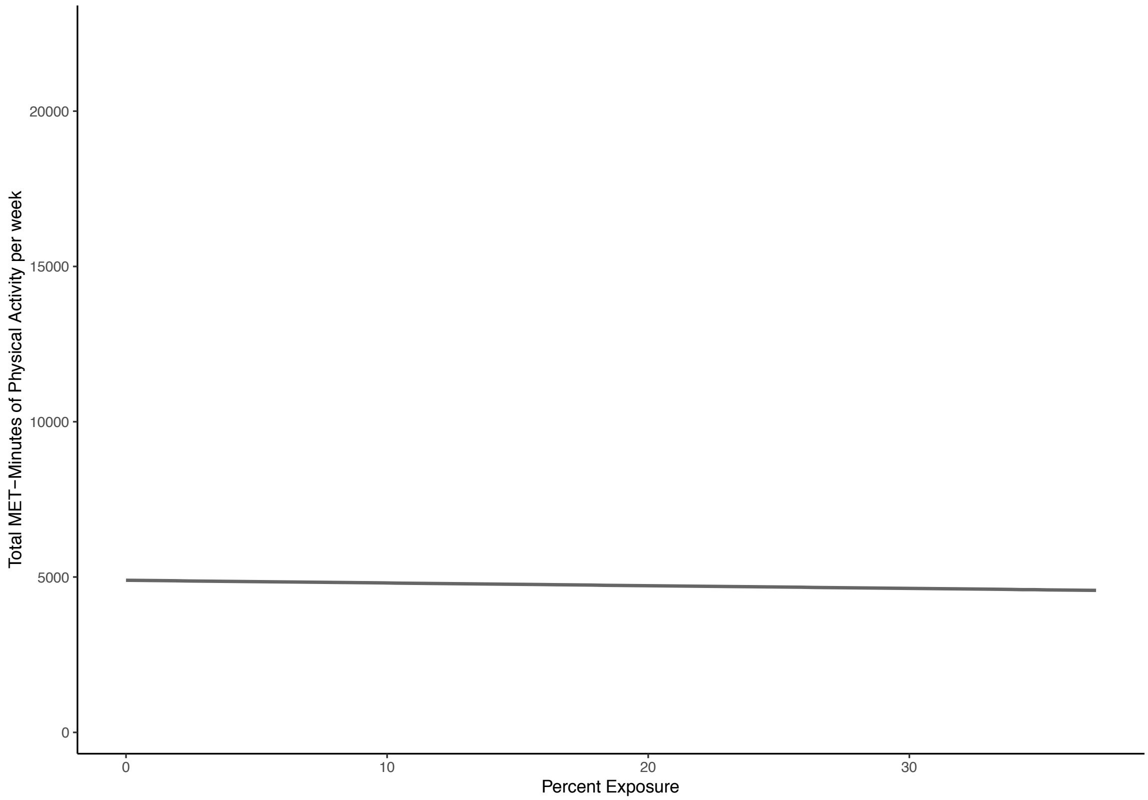

Figure 8: Regression Model illustrating the association between exposure to the Pandora protected cycle track and total MET-minutes of physical activity per week

4.8 Random Intercepts Regression – Moderate Physical Activity (Accelerometer)

A random intercepts regression with days (n = 101561) nested in participants (n = 146) was used to examine the association between exposure to the Pandora protected cycle track and the number of moderate physical activity minutes per day (Table 5). Overall, the model accounted for 50.2% (conditional R_2) of the variance in total MET-minutes of physical activity per week. Due to the large confidence intervals, there is no association between exposure to the Pandora protected bike lane and the number of moderate minutes of physical activity per day.

Table 5: Random Intercepts Regression Moderate Physical Activity Model Table

Predictor Variable	Estimate (95% CI)
Exposure to Pandora	-0.07 (-10.2 to 10.1)
Gender	
Men	Reference
Women	-53.4 (-180.2 to 73.1)
Age Category	
20 - 29	Reference
30 – 39	11.1 (-212.8 to 234.9)
40 – 49	72.8 (-165.6 to 311.1)
50 – 59	237.2 (-9.0 to 483.6)
60+	37.8 (-190.2 to 265.9)
Ethnicity	
Caucasian	Reference
Racialized	30.5 (-171.9 to 232.8)
Income	
$49,999 or less	Reference
$50,000 to $99,999	-203.0 (-394.0 to -11.9)
$100,000 to $149,999	-194.6 (-408.1 to 18.8)
$150,000 or more	-137.1 (-377.9 to 103.6)
Missing	-153.3 (-428.9 to 122.1)
Mean Temperature	18.7 (-5.0 to 42.4)
Total precipitation (mm)	2.0 (-1.4 to 5.5)

Note. Estimates are multiplied by 10. They should be interpreted as a 10% change in exposure.

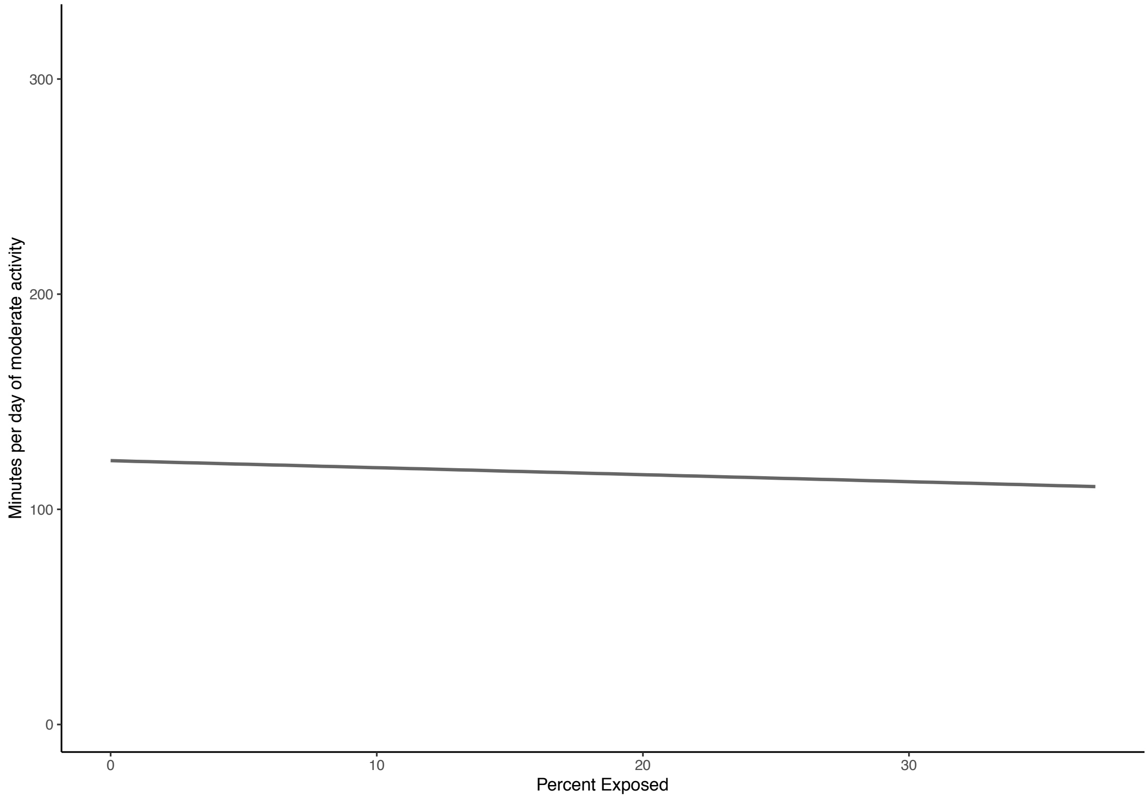

Figure 9: Regression Model illustrating the association between exposure to the Pandora protected cycle track and number of moderate physical activity minutes per day

4.9 Random Intercepts Regression – Vigorous Physical Activity (Accelerometer)

A random intercepts regression with days (n = 101561) nested in participants (n = 146) was used to examine the association between exposure to the Pandora protected cycle track and the number of vigorous physical activity minutes per day (Table 6). Overall, the model accounted for 39.9% (conditional R_2) of the variance in total MET-minutes of physical activity per week. The large confidence intervals from this model suggest that there is no association between exposure to the Pandora protected bike lane and the number of vigorous minutes of physical activity per day.

Table 6: Random Intercepts Regression Vigorous Physical Activity Model Table

Predictor Variable	Estimate (95% CI)
Exposure to Pandora	3.0 (-0.4 to 6.4)
Gender	
Men	Reference
Women	-24.7 (-67.3 to 17.8)
Age Category	
20 - 29	Reference
30 – 39	-33.5 (-108.7 to 41.7)
40 – 49	-41.6 (-121.8 to 38.4)
50 – 59	17.9 (-64.9 to 100.6)
60+	-53.0 (-129.6 to 23.6)
Ethnicity	
Caucasian	Reference
Racialized	-60.0 (-128.0 to 7.9)
Income	
$49,999 or less	Reference
$50,000 to $99,999	-2.89 (-67.1 to 61.3)
$100,000 to $149,999	26.8 (-44.9 to 98.5)
$150,000 or more	23.7 (-57.1 to 104.7)
Missing	104.9 (12.4 to 197.5)
Mean Temperature	2.2 (-5.8 to 10.2)
Total precipitation (mm)	0.73 (-0.4 to 1.9)

Note. Estimates are multiplied by 10. They should be interpreted as a 10% change in exposure.

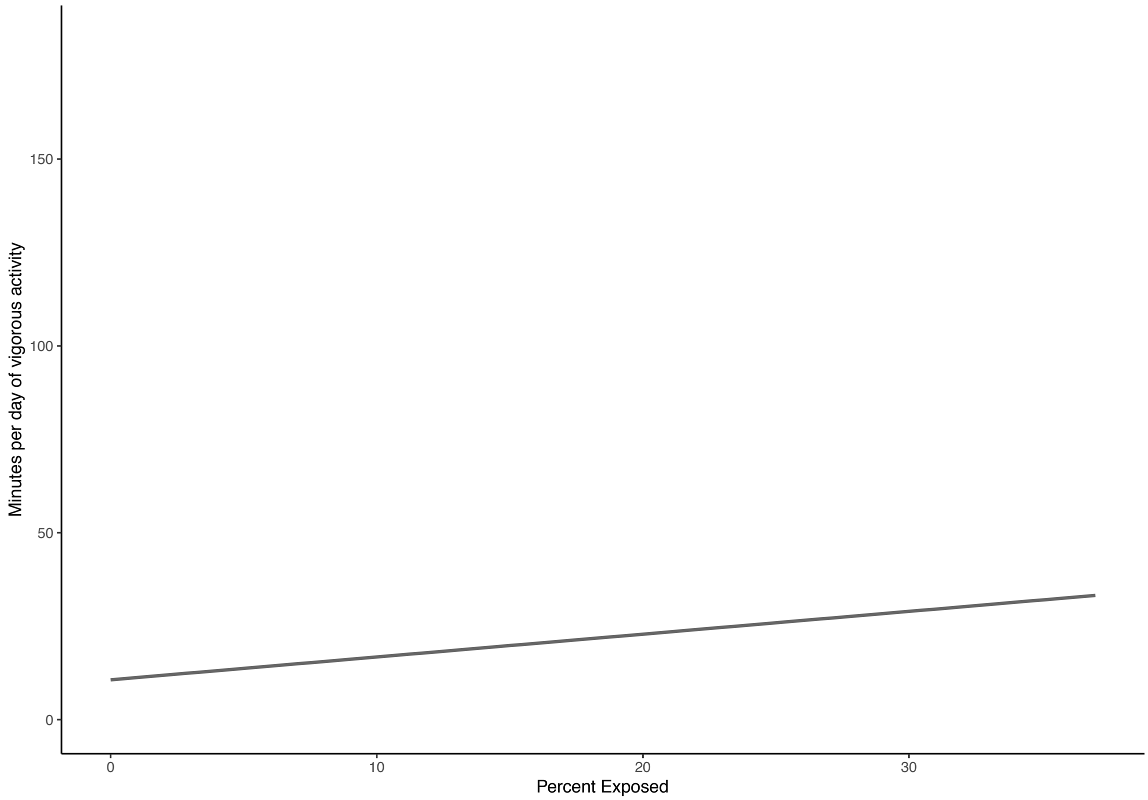

Figure 10: Regression Model illustrating the association between exposure to the Pandora protected cycle track and number of vigorous physical activity minutes per day

Chapter 5: Discussion

5.0 Main Discussion

There were three main objectives for this thesis. The first objective was to determine whether the participants in the sample supported the AAA Cycling Network. The second objective was to examine if overall physical activity levels changed depending on exposure to the Pandora protected cycling track. The third objective was to determine differences in gender by conducting a stratified gender analysis.

It was hypothesized that participants in this study would support the AAA Cycling Network. The results showed that the majority of participants support the AAA Cycling

Network as determined through three main variables. The majority of participants were familiar with the AAA Network, believe it is a very good idea and intend to cycle more once construction is complete. There were no differences in support for the AAA Cycling network between genders. When examining the preference for active transportation infrastructure, the majority of the participants felt very comfortable on an off-road path or separated bike lane. In contrast, the majority of participants felt somewhat or very uncomfortable on a major street with no bike lane.

One explanation may be that maximal separation from motorized traffic and increased perceptions of safety are reasons why the majority of participants support the AAA Network and prefer off-road paths and separated bike lanes. Previous research has found that users prefer separation from motorized traffic, off-road paths, and routes that are easy to travel (Garrard et al., 2008; Heesch et al., 2012; Winters et al., 2011). In 2012, Heesch et al. examined gender differences in cycling and route preference by surveying 1862 cyclists. Overall, the authors showed that few participants preferred cycling on-road, but men were more likely to prefer cycling on the road and women were more likely to prefer cycling off-road. Garrard et al. (2008) observed 6589 cyclists and found that female cyclists preferred off-road paths instead of either on-road bicycle lanes or roads without any cycling infrastructure. Both of these studies are consistent with my participants with whom the majority preferred off-road paths and separated cycling lanes. Also, this study found the same gender differences, with two times the number of women in this study reporting feeling very uncomfortable on a major road without bike lanes than men. Winters et al. (2011) surveyed potential and current cyclists from Vancouver, British Columbia, and found that the top motivators to cycle included routes that were away from motor traffic and easy to cycle. Similarly, the main deterrents for cycling were unsafe surfaces and interactions with motor vehicles. Previous research supports these findings because both off-road paths and separated cycling lanes provide increased separation from motorized traffic compared to other types of cycling facilities. Overall, these results are consistent with previous studies and suggest that cyclists prefer cycling paths or protected lanes instead of no infrastructure or painted bicycle lanes.

It was hypothesized that exposure to the Pandora protected cycle track would increase overall physical activity levels of participants who cycled in Victoria. Three regression analyses were conducted to examine associations between either self-report or moderate and vigorous accelerometer-based physical activity and exposure to the Pandora protected cycle track.

Similar studies found no associations between the implementation of cycling infrastructure and increased cycling or overall physical activity levels (Brown et al., 2016; Dill et al., 2014). In 2014, Dill et al. found no associations between living in near a newly implemented bicycle boulevard (treatment area) and minutes of moderate to vigorous physical activity. In 2016, Brown et al. found non-significant increases in cycling duration following a complete street intervention in Salt Lake City, Utah.

Both studies collected data pre and post-construction of the cycling infrastructure (Brown et al., 2016; Dill et al., 2014). This study only has one data collection period, which took place just after the Pandora protected cycle track opened. All three studies used the same data collection methods, including GPS, accelerometer, and survey data. However, GPS and accelerometer wear time differed in each study. Brown et al. (2016) had 536 participants who wore the device for three days with at least ten or more hours of valid wear time per day. Dill et al. (2014) had 353 participants who had five consecutive days of wear time, which included one weekend day. The current study had 146 participants who had an average wear time of nine days, with eight hours per day. This study has the smallest number of participants but the longest GPS and accelerometer data collection period. The interventions for all three studies differed. Brown et al. (2016) examined complete street interventions, which included a new bike lane and other improvements while Dill et al. (2014) examined the implementation of neighborhood bicycle boulevards. Dill et al. (2014) had a treatment group who lived on a street with one of the new bicycle boulevards and a control group who lived on similar streets without the intervention. I examined a new protected cycle track on a busy downtown street in Victoria, British Columbia.

Several reasons may explain why the results of this study differ from previous research. First, participants' exposure was measured using daily path mobility with a buffer of 200 metres. On average, 5% of participants total GPS points were within 200 metres of the Pandora protected track. Participants' time spent along the Pandora corridor was a relatively small proportion of their total GPS recorded time, expectedly. The Pandora protected cycle track is approximately 1.0 kilometre in length. Since the cycle track is only a small segment of downtown and participant exposure was low on average that could partially explain why the association between exposure and overall physical activity only appears to occur at sufficiently high exposure level (15-20%). Second, the Pandora protected cycle track opened in early May 2017 and data collection began in late May 2017. The cycle track was only open for a few weeks before data collection began. Participants may not have changed or adjusted their cycling behaviour this soon after the implementation and may require months or years to change their behaviour. This may explain the effect I observed in this study. Dill et al. (2014) encountered a similar problem in their study, where data collection began immediately after construction occurred, and some of their projects were not fully complete when data collection for their study ended. Dill et al. (2014) hypothesized that inadequate time between installation and data collection did not allow for participants to change their behaviour and thus could be a reason why they found no association. I believe that the short time period in this study between installation and data collection may have affected the results as well.

Overall, this study and previous research suggest that there is not a clear established relationship between the implementation of cycling infrastructure and increases in physical activity, at the individual level. Brown et al. (2016), Dill et al. (2014), and the present study found no significant associations between cycling infrastructure and physical activity for cyclists in the area. However, many studies using self-report data have found positive relationships between exposure to cycling infrastructure and increases in physical activity (Frank et al., 2019; Goodman et al., 2014; Panter et al., 2016; Rissel et al., 2015). It is possible that the size and scale of the implementation may influence the association, with studies examining infrastructure that covers more area, are better connected, and implemented in a shorter time period being more likely to show a positive association.

It was hypothesized that women would have lower levels of overall physical activity than men regardless of exposure status. This hypothesis was confirmed, as I found substantial gender differences in self-report physical activity, where men reported 1250 more total MET-minutes of physical activity per week than women, on average. A similar relationship was observed when examining accelerometer based moderate and vigorous physical activity. In terms of cycling-specific activity, women cycled on average six to eight days less than men in each of the four seasons. Some of the results from this study agree with previous research that has found lower physical activity levels and cycling frequency in women (Butler et al., 2007; Heesch et al., 2012; Pucher & Buehler, 2008; Ramage-Morin & Statistics Canada, 2017). Two studies using the Canadian Community Health Survey found that although the prevalence of cycling is increasing, women report cycling less than men (Butler et al., 2007; Ramage-Morin & Statistics Canada, 2017). Heesch et al. (2012) found an increased percentage of male cyclists in both transport and recreational cycling. However, there was no difference in MET minutes of transport physical activity between genders (Heesch et al., 2012). The results of my thesis showed that women reported cycling less and have much lower self-report levels of physical activity than men. This study also determined that the majority of participants, especially women, are comfortable on protected cycling infrastructure. One possible way to increase cycling in women and ultimately, physical activity levels is by implementing more protected cycling infrastructure in communities.

5.1 Limitations

Similar to all research studies, the current study has limitations. The first limitation is the potential for sample bias. All participants were required to bike at least once a month in the City of Victoria to be included in this study. The population the study generalized to was the cycling community in Victoria. On average, the participants in this study were middle-aged adults with the majority who identified as Caucasian, had incomes greater than $50,000 per year, were married and reported either very good or excellent health. It is not clear whether the sample in this study is representative of the cycling community in

Victoria due to the lack of sociodemographic information for this group. However, multiple other studies have reported sample characteristics similar to this sample population (Heesch et al., 2012; Heesch & Langdon, 2016; Ramage-Morin & Statistics Canada, 2017).

The second limitation is this is cross-sectional data, as the study only used the first of three planned waves of data collection from a longitudinal study. These results will be used to compare changes across the second and third data collection periods.

The third limitation is the data only provides a snapshot of participants behaviour; 10 days of mobile sensing data. Previous research has determined that less than two weeks of GPS data is necessary to determine participants activity space (Stanley et al., 2018). This study had a longer data collection period than past work (Dill et al. (2014) Brown et al. (2016)). However, longer data collection period may have allowed us to characterize more typically activity spaces.

The fourth limitation is the use of a modified IPAQ. In this study, I found that women had much lower levels of self-reported physical activity. Traditionally, women have been responsible for domestic work which was not accounted for on this version of the IPAQ. It is difficult to be certain whether there was a true difference in the level of self-reported physical activity between genders or if it is due to the methodology.

The final limitation is potential for around the Hawthorne effect, where participants change their behaviour as a result of being in a study (Portia & International Epidemiological Association, 2014). In this study, there was potential for participants to change their behaviour because they were wearing a mobile sensing device. Since the participants knew that the SenseDoc tracked their physical activity, they may have increased their physical activity beyond their routine.

5.2 Future Studies

INTERACT will continue to study the AAA Cycling Network in Victoria until 2021. With two additional data collection periods in 2019 and 2021, INTERACT researchers will conduct interrupted time series analysis to further examine the relationship between exposure to the AAA Cycling Network and physical activity. Some of the subgroups in the sample had small sample sizes (e.g., trans and gender non-binary group, certain income categories, and ethnicities other than Caucasian). I recommend that future studies conduct purposeful sampling or use oversampling techniques to target these groups. Additionally, studies could be conducted examining specific subgroups including ethnicity or income to better understand socioeconomic differences in cycling.

5.3 Conclusion

This study found that there is not a clear association between exposure to the Pandora protected cycle track and overall levels of physical activity. Due to the mixed body of literature in this field, more studies are needed to establish the relationship between exposure to cycling infrastructure and physical activity levels. Overall, the participants support the AAA Cycling Network and have a general preference for separated cycling infrastructure. Gender differences were present in this study with women achieving lower levels of physical activity and preferring cycling infrastructure that maximized separation from motor vehicle traffic. Implementing additional protected cycle tracks in the City of Victoria will promote cycling and physical activity for all residents.

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Appendix 1:

MEMORIAL UNIVERSITY

Interdisciplinary Committee on Ethics in Human Research (ICEHR)

St. John's, NL Canada A1C 5S7
Tel: 709 864-2561 icehr@mun.ca
www.mun.ca/research/ethics/humans/icehr

ICEHR Number:	**20192531-HK**
Approval Period:	January 18, 2018 – January 31, 2020
Funding Source:	CIHR (RGCS: 20180446)
Responsible Faculty:	Dr. Daniel Fuller School of Human Kinetics and Recreation
Title of Project:	*Examining the association between cycling infrastructure and cycling: Baseline Results from INTERACT Victoria*

Title of Parent Project:	*Interventions, Research and Action in Cities Team (INTERACT): Impact of the Bus Rapid Transit (BRT) in Saskatoon*
ICEHR Number:	*20180761-EX*

January 18, 2019

Ms. Melissa Tobin
School of Human Kinetics and Recreation
Memorial University of Newfoundland

Dear Ms. Tobin:

Thank you for your submission to the Interdisciplinary Committee on Ethics in Human Research (ICEHR) seeking ethical clearance for the above-named research project. The Committee has reviewed the proposal and agrees that the proposed project is consistent with the guidelines of the *Tri-Council Policy Statement on Ethical Conduct for Research Involving Humans* (TCPS2). *Full ethics clearance* is *granted to* January 31, 2020. ICEHR approval applies to the ethical acceptability of the research, as per Article 6.3 of the *TCPS2*. Researchers are responsible for adherence to any other relevant University policies and/or funded or non-funded agreements that may be associated with the project.

The *TCPS2* **requires** that you submit an Annual Update to ICEHR before January 31, 2020. If you plan to continue the project, you need to request renewal of your ethics clearance and include a brief summary on the progress of your research. When the project no longer involves contact with human participants, is completed and/or terminated, you are **required** to provide an annual update with a brief final summary and your file will be closed. If you need to make changes during the project which may raise ethical concerns, you must submit an Amendment Request with a description of these changes for the Committee's consideration prior to implementation. If funding is obtained subsequent to approval, you must submit a Funding and/or Partner Change Request to ICEHR before this clearance can be linked to your award.

All post-approval event forms noted above can be submitted from your Researcher Portal account by clicking the ***Applications: Post-Review*** link on your Portal homepage. We wish you success with your research.

Yours sincerely,

Russell J. Adams, Ph.D.
Chair, Interdisciplinary Committee on
Ethics in Human Research
Professor of Psychology and Pediatrics
Faculties of Science and Medicine

RA/lw

cc: Supervisor – Dr. Daniel Fuller, School of Human Kinetics and Recreation
Director, Research Grant and Contract Services