Understanding Physical Activity Behaviour in Ontario, Canada: A Cross-Sectional Cohort Analysis of Carrot Rewards App Users

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Abstract

Little device-measured data are available to describe the physical activity (PA) of rural-dwelling individuals living with chronic disease. **PURPOSE**: From accelerometer data collected using a smartphone app ('Carrot Rewards'), we sought to provide mean daily step counts for app users in general and by age and gender for those living in rural/urban areas and those self-reporting a chronic disease or not. **METHODS**: This cross-sectional cohort study used device-assessed data from Ontario app users (i.e., PA data collected over a 7-day period for each user) who completed an in-app chronic disease survey from December 2018 to April 2019. A series of ANCOVAs controlling for date were conducted. **RESULTS**: Overall, 11,162 users (M_{age}=34.7) accumulated 5,342 steps per day (*SE*=33.41). Chronic disease status, gender and age bracket significantly influenced ($p<.001$) mean daily step count, whereas rural/urban status did not ($p=.367$). Post hoc testing suggested females living with chronic disease(s) were more likely to have insufficient PA. **CONCLUSION**: Using smartphone-assessed daily step count data, we describe PA behaviours in several population subgroups in Ontario and add to the existing PA surveillance literature.

Keywords

Physical Activity, Public Health, Chronic Disease, Rural/Urban, Step Counts, mHealth

Summary for Lay Audience

Regular physical activity (PA) can reduce the rate and severity of many chronic diseases. Possibly because of lower PA levels, rural-dwelling (vs. urban) individuals are at higher risk of developing preventable chronic diseases. Those living with chronic disease may also be less active than their healthy peers, worsening their conditions. To date, little objective data are available to describe PA and inform interventions for these higher-risk populations. This study looked at the daily step counts of Ontario users from a popular Canadian smartphone app called Carrot Rewards. Our objective was to provide daily step counts for app users in general and by gender and age as well as those living in urban versus rural areas and those self-reporting a chronic disease or not. Overall, users took approximately 5,342 steps per day. Males took more steps than females, and there were step differences between 6 of 13 age brackets. Individuals who self-reported having at least one chronic disease took fewer steps per day than healthy individuals. There was no difference in daily step counts between individuals living in rural or urban settings. This study provides a unique perspective on the PA behaviours of Ontarians. Our data may help public health policy makers to better understand, target, and specialize interventions for specific subsets of the population.

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Table of Contents

List of Tables

List of Figures

List of Appendices

Chapter 1: Introduction

1.1 *Physical Activity, Inactivity, and Global Guidelines*

The World Health Organization (WHO) defines physical activity (PA) as “any bodily movement produced by skeletal muscles that requires energy expenditure” and may include activity that is related to work, leisure, or transportation (WHO, 2020). Physical inactivity can be defined as insufficient moderate-to-vigorous physical activity (MVPA) or a PA level that does not meet physical activity guidelines (Tremblay et al., 2017). Global and Canadian PA guidelines have different recommendations based on age. Global guidelines suggest youth 5-17 years of age should accumulate at least 60 minutes of MVPA per day. Adults 18-64 and over 65 years of age should accumulate 150-300 minutes of moderate or 75-150 minutes of vigorous intensity PA per week (World Health Organization, 2020). Canadian PA guidelines are similar to global guidelines and recommend that youth 5-17 years of age accumulate at least 60 minutes of MVPA per day, whereas adults 18-64 and 65+ should get at least 150 minutes of MVPA per week (Ross & Tremblay, 2020). Unfortunately, at least 25% of adults (18+ years of age) worldwide do not meet global PA guidelines (Guthold et al., 2018). In addition, an estimated four out of five adolescents (11-17 years of age) are not meeting PA guidelines internationally (Guthold et al., 2019).

1.2 *Health Benefits of Physical Activity*

The potential of PA to confer health benefits has been studied for decades (Morris et al., 1953; Morris and Heady, 1953; Paffenbarger et al., 1978; Paffenbarger and Hale, 1975). Research has demonstrated that consistent PA yields musculoskeletal benefits including the strengthening of muscles and ligaments, improvements in vascular health as well as balance and flexibility (Curtis et al., 2017; Myers., 2003; Seco et al., 2013). Along with musculoskeletal benefits, consistent PA can also support other aspects of health such as neurological health, cognitive function, mental health, and sleep hygiene (Biddle et al., 2016; Briguglio et al., 2020; Di Liegro et al., 2019; Loprinzi et al., 2011; Mandolesi et al., 2018). PA has demonstrated efficacy as both a preventative and protective measure against dementia and Alzheimer's, particularly when employed early in life (Tsai et al., 2017). It has also been used as a tool to help improve executive functioning/control and to slow the rate of decline in at-risk older adults and persons with mild cognitive impairment (Colcombe and Kramer, 2003). PA also may act as a moderator during periods of high stress and reduce common stress-related adverse effects on health outcomes including poor mental well-being and sleep quality (Wunsch et al., 2017). There are many benefits of PA but there are also numerous risks associated with physical inactivity, the most important of which is the development of chronic disease (Booth et al., 2012).

Physical inactivity is an influential and modifiable chronic disease risk factor (Diaz et al., 2017; Ekelund et al., 2019; Erikssen et al., 1998; Lee et al., 2012). Data from the *Canadian Community Health Survey* (2003) suggests that physical inactivity is more prevalent (i.e., about 54%) than any other modifiable risk factor for chronic disease like being overweight (i.e., about 45%) or tobacco use (i.e., about 22%). Lee et al. (2012) further supported this finding utilizing data from around the world with the *Lancet Physical Activity Series Working Group*. Specifically, Lee et al. determined that physical inactivity has at least the same level of risk as a chronic disease risk factor as obesity and tobacco. Other risk factors for chronic disease development including high blood pressure and cholesterol also contribute significantly to the global disease burden (Ezzati, 2002). Many of the risk factors for chronic disease development can be attenuated with increased PA participation (Diaz & Shimbo., 2013; Lee et al., 2012; Williams and Thompson, 2013). In addition to managing risk factors, PA can also prevent and manage chronic disease. For example, Warburton et al. (2006) suggested that there is a positive linear relationship between PA and overall health and that consistent PA has utility as both a primary and secondary prevention mechanism against several chronic diseases (cancer, cardiovascular disease and diabetes mellitus). Booth et al. (2012) looked at a broad spectrum of 35 chronic diseases and concluded that PA is a primary management tool that can be used to prevent or at least impede chronic disease development. Furthermore, the study by Lee et al. (2012) suggests that major chronic diseases like type 2 diabetes, several cancers, depression, and dementia are less prevalent in persons who are regularly active. Despite the overwhelming body of evidence for PA as a primary preventative and secondary management measure against chronic disease, there is still insufficient attention being placed on PA promotion (Booth et al., 2012; Ding et al., 2018; Durstine et al., 2013).

1.3 *Physical Inactivity and Chronic Disease in Canada*

Data from the 2016-17 *Canadian Health Measures Survey* indicates that 84% of adults and 61% of youth are not meeting national PA guidelines (Centre for Surveillance and Applied Research, 2020). These findings differ from the global findings of Guthold et al. (2018; 2019) which suggested 75% of adults and approximately 20% of youth are meeting PA guidelines. In addition, about 30% of Canadians over the age of 20 have been diagnosed with at least one of the five major chronic diseases (i.e., cancer, diabetes, cardiovascular diseases, chronic respiratory disease, and mood/anxiety disorders; Canadian Chronic Disease Indicators, 2017). In Ontario, Canada's most populated province, major chronic diseases are responsible for nearly 75% of all deaths (Public Health Ontario, 2019). Cancer, diabetes, cardiovascular diseases, and chronic respiratory diseases alone are responsible for 64% of all deaths (Public Health Ontario, 2019).

In the most recent *Canadian Chronic Disease Indicators (CCDI)* report (2017), 84.7% of Canadians surveyed reported having or engaging in at least one of the four modifiable chronic disease risk factors: physical inactivity, unhealthy eating, smoking, or excessive use of alcohol (CCDI, 2017). Risk factor management is essential. There is a growing body of evidence that suggests younger people (i.e., 15-59 years of age) are also at-risk of developing chronic disease (Nikolic et al., 2011; World Health Organization, 2005). Public Health Ontario (2019) suggests that modifiable (or behavioural) chronic disease risk factors such as physical inactivity are more prevalent in groups known to experience poorer health (e.g., rural-dwelling adults, adults with chronic disease). In addition, physical inactivity represents a total annual economic burden (direct and indirect healthcare costs) of $2.6 billion CAD (Public Health Ontario, 2019). Addressing these risk factors could reduce the human and economic burden of chronic disease in Ontario.

1.4 *Determinants of Physical Activity and Physical Activity Inequalities*

Plotnikoff et al. (2004) was one of the first to explore the correlates of PA in specific population subgroups (e.g., age, gender, and rural/urban living setting). Two of the correlates they evaluated were education level and employment status which are frequently included in the literature as measures of socioeconomic status (Baker, 2014). Age, gender, rural/urban and socioeconomic status have been recognized as important determinants of both PA and health (Giles-Corti et al., 2002; Marmot et al., 2005;

Myers et al., 1989). The manner in which physical inactivity is influenced by various determinants of health including environmental (i.e., urban/rural status), personal factors (e.g., socioeconomic status, age and gender) and their interplay on health status (i.e., chronic disease diagnosis) is complex (Giles-Corti et al., 2002; Stringhini et al., 2017). This may be attributed to the fact that many of the determinants of health that influence socioeconomic status and overall health also influence physical inactivity and are not mutually exclusive (Giles-Corti et al., 2002; Stringhini et al., 2017). Stringhini et al. (2017) used data from 1.7 million individuals from around the world to evaluate whether socioeconomic status with key risk factors was related to premature mortality (i.e., high alcohol consumption, smoking, physical inactivity, hypertension, diabetes, and obesity). They concluded that socioeconomic status was associated with premature mortality to a similar level as the other factors listed above which were targeted by the *World Health Organization* in their "25x25" initiative to reduce premature mortality due to chronic disease 25% by 2025. Furthermore, Stringhini et al. (2017) concluded that second only to smoking, physical inactivity (together with low socioeconomic status) resulted in the highest number of life years lost.

Socioeconomic status, which includes factors such as income and education, is a key determinant of PA participation, chronic disease risk (cardiovascular disease) and all-cause mortality (Beenackers et al., 2012; Gidlow et al., 2006; Havranek et al., 2015; Laine et al., 2019; Veronesi et al., 2017). However, it is important to note that the relationship between socioeconomic status and PA has been studied extensively in youth and adults and has been found to be multidirectional (e.g., PA level can also predict socioeconomic status, chronic disease risk and all-cause mortality; Allen et al., 2017; Hankonen et al., 2017). O'Donoghue et al. (2018) found that persons who experience socioeconomic disadvantage are much more likely to be physically inactive than the general population. Kestilä et al. (2015) used a sample of approximately 2,000 young adults/youth (18-29 years of age) to understand the influence socioeconomic status had on PA in early adulthood. They found that for individuals whose parents had an education level less than secondary (high school) were more likely to be inactive and have inactive children themselves than those whose parents had completed secondary education or higher. Interestingly, for the young adults/youth in this study, this finding differed by gender. Low parental education and physical inactivity were only correlated for males. For females, only long-term financial difficulties were associated with physical inactivity (Kestilä et al., 2015). An individual's own education level was determined to be the strongest predictor of PA level in early adulthood (Kestilä et al., 2015).

Gender and age are well understood influencers of PA level and participation across the lifespan as well (Azevedo et al., 2007; Bauman et al., 2012; Trost et al., 2002; Wenjun et al., 2017). Recent large-scale data has suggested that gender-based PA inequality is an important predictor of health outcomes such as obesity (Althoff et al., 2017). Inequalities in PA participation exist between males and females in Canada with approximately 18% of males meeting physical activity guidelines and only 15% or females (Centre for Surveillance and Applied Research, 2020). In Canada, this pattern of inactivity has been quite stable over time. Juneau and Potvin (2010) utilized six nationally representative surveys spanning from 1994-2005 and found that while leisure time PA and PA as a method for active transportation increased, the increases were proportional between males and females, thereby maintaining the preexisting gender PA disparity. This pattern of gender-based PA inequality has been noted consistently in other countries and differs minimally by PA domain (occupational, housework and transportation; Azevedo et al., 2007; Livingstone et al., 2001). A variety of reasons for these PA differences have been proposed and include differing motivations to participate in PA and environmental factors (e.g., facility type), among others (Coen et al., 2018; Craft et al., 2014). Recently, the PA literature has started to include studies examining PA behaviours in transgender persons or individuals who do not identify with their biological sex. Jones et al. (2018), for instance, found that transgender individuals participate in less PA than their cisgender counterparts. In Jones et al. (2018), participants scored their PA frequency on a scale of items with binary response options (yes or no) based on whether certain statements about PA applied to them. The cumulative score was then calculated from 1-7. The questions were rank ordered and corresponded with a level of PA (i.e., if the highest question that participants responded 'yes' to was 4, they would be given a PA score of 4). In this scale, a higher number corresponded to a higher PA frequency with scores under 6 considered insufficient PA. Cisgender individuals scored an average of 5.33 which was significantly higher than transgender individuals at 4.73. Systematic reviews examining the experiences of transgender persons in sport and PA indicate that their experiences can often be negative which may be driving the lower PA levels (Jones et al., 2016; Muchicko et al., 2014). This is particularly problematic as transgender individuals are known to be at higher risk for mental illness which regular PA participation may help manage (Arcelus et al., 2016; McMahon et al., 2017).

PA patterns change over the life course with older age groups typically less active than younger adults and youth (Hirvensalo and Lintunen, 2011; Hughes et al., 2008; Johannsen et al., 2008). However, PA among youth is concerningly low with an estimated four out of five youth not meeting PA guidelines, globally (Guthold et al., 2019). Tudor-Locke et al. (2011) looked at the average steps per day between youth adults, and older adults. Adults walked an average of 4,000-18,000 steps per day, whereas youth had notable gender differences with boys taking 12,000-16,000 steps per day compared to 10,000-13,000 for girls (Tudor-Locke et al., 2011). Older adults in their study averaged 2,000-9,000 steps per day, which is 2,000-8,000 steps less than their younger counterparts when comparing only the lowest thresholds for each age group, youth and adults, respectively (Tudor-Locke et al., 2011). There is further evidence to suggest age-related PA decline may begin in early adulthood. Leslie et al. (2001) determined that for moderate-to-vigorous PA, individuals 18-19 years of age were up to 15% more active than individuals in the 20-24 and 25-29 year old age groups. Targeting PA promotion towards young people is essential as PA behaviours become more stable with age meaning poor habits in youth may lead to inactivity in adulthood (Lounasallo et al., 2019; Telama et al., 2005).

It has been suggested that those living in rural settings may be at a higher risk of developing chronic diseases than their urban-dwelling counterparts, possibly because of higher rates of physical inactivity (DesMeules et al., 2006; Patterson et al., 2004). Patterson et al. (2004) determined that PA was 4% lower in rural individuals compared to their urban counterparts and irrespective of ethnicity, rural-dwelling individuals were at higher risk of obesity. However, a more recent study by Stevenson et al. (2016) reported that people living in densely populated urban regions have lower PA levels and higher chronic disease rates, possibly due to the conveniences of their built environments, such as greater access to motorized transport. In the most motorized cities, changing to a compact and more walkable city design could increase PA between

56-72%. As well, individuals living with chronic diseases such as cancer, diabetes, hypertension, cardiovascular disease, and dyslipidemia have demonstrated reduced adherence to PA recommendations (Forechi et al., 2018; Hair et al., 2014; Janevic et al., 2012; Valero et al., 2016). Less than 18% of participants with chronic disease (ages 35-74) in the study by Forechi et al. adhered to PA guidelines. Out of the chronic disease included in the study, people with diabetes reported the lowest adherence at less than 14%.

1.5 *Physical Activity Measurement Methods*

For the last several decades, PA surveillance in Canada and worldwide has primarily relied on self-reported survey data (Colley et al., 2011; Dyrstad et al., 2014; Hallal et al., 2012; Macera & Pratt., 2000; Simpson et al., 2003). Self-reported surveys are an efficient way of measuring PA on a population scale. However, limitations such as recall (difficulty drawing accurate information from memory) and social desirability (less likely to report low PA and instead exaggerate level of PA to maintain positive perceptions) biases reduce the validity of self-reported PA behaviours (Loney et al., 2011). In their seminal work, Prince et al. (2008) determined that self-reported PA measures both over- and under-report PA behaviour when compared to objective measures (e.g., pedometers). Similarly, in a more recent study conducted by Colley et al. (2018), researchers found that the correlation between self-reported and objective (e.g., accelerometers) PA measures was low (r = .15). While accelerometry is considered the gold-standard method of measuring free-living PA behaviours, it also has its own unique set of limitations. For example, accelerometry studies are often limited by cost, sample size, response (likelihood of answering questions misleadingly), and selection (population sample may not by representative) biases (Bassett et al., 2010; Colley et al., 2011, Pedišić &

Bauman., 2015; Sullivan et al., 2014, Troiano et al., 2008). In the first large Canadian PA surveillance project to use accelerometry (*Canadian Health Measures Survey*; Colley et al., 2011), only 42.2% of the 2,832 Canadians recruited to participate had complete accelerometry data sets (i.e., 4 out of 7 days and at least 10 hours/day of wear time). Interestingly, non-respondents (individuals who completed less than the minimum days (4) and hours (10/day) of wear time) tended to be younger, more obese, and potentially less physically active (Colley et al., 2011). This response bias may have resulted in an overestimation of step counts and highlights a potential issue in contemporary PA surveillance in Canada: population sampling. While many population surveys use statistical weighting techniques to address this issue (e.g., Colley et al., 2011), these data may be biased toward healthy respondents and those from urban centres and, therefore, may not sufficiently describe the PA behaviours of certain potentially higher risk population subgroups (e.g., less healthy, rural dwelling adults; Martin et al., 2005). However, it is important to note that in sampling the *Canadian Health Measures Survey*, Colley et al. (2011) were only able to provide national level estimates, not provincial or territorial. Both objective (e.g., accelerometer) and self-reported methods of PA surveillance are important but have different limitations which must be considered when interpreting and using this information for PA program/policy development.

1.6 *Measuring Physical Activity using Smartphone Devices*

Commercial mobile health applications (mHealth apps) using ‘built-in’ smartphone accelerometers offer a practical platform to examine PA behaviours on a large scale, while addressing some traditional surveillance study limitations. The smartphone is an accessible and convenient tool for health research (Dorsey et al., 2017). Recent literature has shown that ‘built-in’ smartphone accelerometers have high internal validity and moderate external validity (Amagasa et al., 2019; Case et al., 2015; Duncan et al., 2017). Hekler et al. (2015) determined that smartphones are a "comparable" method for tracking PA behaviours when compared to gold standard triaxial (i.e., movement measured in three planes) accelerometers in both lab-based and free-living contexts. Hekler et al. (2015) concluded that in comparing smartphones to ActiGraph accelerometers, smartphones were moderately and strongly correlated, respectively, when tracking both sedentary (ρ=.44, p<.001) and moderate-vigorous physical activity (MVPA, ρ=.67, p<.001) in a free-living environment. However, only a weak correlation was reported for light physical activity (ρ=.38, p<.001). In lab environments, smartphones were strongly correlated overall (ρ=.90, p<.001) to ActiGraph PA data across activity intensities (Hekler et al., 2015). Case et al. (2015) reported that smartphone accelerometers/mobile applications evaluated in a lab context differed from observed step counts by -6.7 to +6.2%. While smartphones are highly accessible, they do have several limitations when used outside of a lab/controlled environment (Amagasa et al., 2019; Hekler et al., 2015). In free-living contexts many PA surveillance studies are limited by the inability to fully control for wear time. Recently, Amagasa et al. (2019) determined that smartphone accelerometers employed in free-living conditions might underestimate step counts by up to 12%, possibly due to not carrying/wearing the device on one's person (e.g., leaving on desk, carrying in purse). This information is essential for anyone looking to appropriately contextualize study findings that utilize smartphone accelerometers to track PA. However, smartphone usage and by association, wear time, is rapidly changing. A digital research team, dscout, in a report titled *Mobile Touches*, examined the number of phone interactions per day in a group of average American consumers. They recruited 94 diverse participants (52% female; 5 broad ethnic classifications; 69% between 25-44 years of age) and discovered that people touch their phones an average of 2,617 times each day (dscout, 2016). Therefore, with specific population subgroups in mind, it is important to consider the utility of different PA collection devices, which groups need to be targeted, and where gaps in data exist. The PEW Research Centre (2015) reported that persons who are younger, less educated, lower-income and non-Caucasian tend to be more smartphone dependent. This is an extremely important consideration as these cohorts are frequently underserviced/understudied (Sampselle, 2007). Using smartphone-assessed data may provide a more accurate depiction of PA behaviours in ways that self-reported PA data have not been able to do previously, particularly in these potentially at-risk populations. Advancing and prioritizing PA surveillance in public health will facilitate the design and delivery and more effective and efficient PA programming (Ding, 2018).

1.7 *Step Counts and Physical Activity: Clinical Implications and Thresholds*

Walking is one of the most common forms of PA and allows people who may not be able to participate in higher-intensity exercise (e.g., running, playing team sports) to still experience health benefits (Tremblay et al., 2011). The Canadian Physical Activity Guideline (CPAG)/24-hour Movement Guidelines provides PA recommendations in minutes of MVPA per week, as it is the advised intensity at which the most beneficial dose-response relationships have been observed (Ross & Tremblay, 2020; Tremblay et al., 2011). More recent evidence suggests that light PA can still confer important health benefits (reduction is all cause-mortality and cardiometabolic risk factors) and reduce the negative health impacts of excessive sedentary time (premature mortality; Amagasa et al., 2018; Diaz et al., 2019). In addition, there is a growing literature base that suggests step counts are an equally effective method of setting PA goals and tracking physical activity patterns (Baker et al., 2011).

Tudor-Locke (2011) examined the congruency between steps per day in an adult population and suggestions from the CPAG and determined that there is a strong relationship between step cadence and intensity. Tudor-Locke (2011) proposed that 10,000 daily steps was sufficient for the average adult to meet both 150 minutes of weekly MVPA, while accommodating the recommendation that activity should occur in bouts of 10 minutes or more. However, more recent evidence suggests that 10,000 steps may not be required for health benefits. Kraus et al. (2019) determined that 7,000-9,000 steps per day may provide a similar level of health benefit that 150+ minutes (guideline recommendations) of PA would confer. While these thresholds are beneficial for health adults, they may not be appropriate for clinical populations. Tudor-Locke and Basset (2004) developed a daily step count classification scheme for levels of PA: <5,000 (Sedentary), 5,000-7,499 (Inactive), 7,500-9,999 (Moderately Active), ≥10,000 (Physically Active), ≥12,500 (Very Active). Schmidt et al. (2009), utilizing cardiometabolic risk as the health indicator, found the lowest (<5,000) and highest step count thresholds (≥12,500) were points where the most distinct health benefits were obtained (i.e., ≤75th percentile for waist circumference, systolic blood pressure, blood glucose, and triglycerides, or >25th percentile for HDL cholesterol and a lower Framingham risk score). Individuals who walked greater than 5,000 and 12,500 steps per day had significantly lower prevalence for cardiometabolic health indicators than the respective groups above and below (less than 5,000, less than 12,500; Schmidt et al., 2009). These step differences equated to an approximately 20% and 9% reduction, respectively, moving from less than 5,000 (sedentary) to greater than 5,000 steps (low active), and from active (10,000-12,499) to very active (greater than 12,5000 steps), in the prevalence of cardiometabolic health indicators (Schmidt et al., 2009).

1.8 *Carrot Rewards Smartphone Application*

Widespread smartphone usage in Canada (~90% of Canadians own a smartphone with 'built-in' accelerometers; Canadian Radio-television and Telecommunications Commission, 2019) offers an opportunity to collect PA data on a large scale. The Carrot Rewards app, developed by Carrot Insights Inc. in partnership with the Public Health Agency of Canada in 2015, was a popular Canadian mHealth app that rewarded users with loyalty points (i.e., that could be redeemed for commercial products like gas or groceries) to engage in healthy behaviours such as walking. Users were able to track their daily step counts and were rewarded for accomplishing daily 'goals' based on their daily step count averages, assessed weekly, using aggregated data from the built-in smartphone accelerometer. With more than 1.3 million Canadian downloads, 614,287 registered users and 442,286 monthly active users in Ontario alone (as of January 2019), the app held plenty of promise as a surveillance tool (Mitchell et al., 2017, 2018). Accordingly, Arim and Schellenberg (2019) conducted a study to examine whether Carrot Rewards app users were representative of the broader Canadian population. Specifically, when comparing Carrot Rewards user responses to adapted *Canadian Community Health Measures Survey* questions with those of Canadians in general, Arim and Schellenberg (2019) concluded that the samples were in fact different. Specifically, Carrot Rewards users were on average younger, more likely to be female, university educated, living in an urban centre, and less healthy (e.g., less active, poorer mental health) than the general Canadian population. Despite the demographic and health characteristic differences between Carrot Rewards users and Canadians in general, we sought to complement current PA surveillance efforts by examining PA behaviours of Carrot Rewards users acknowledging that the generalizability of our findings to Canadians and Ontarians in general may be limited.

1.9 *Study Objectives*

We performed a cross-sectional cohort study to examine PA levels (i.e., daily step counts) of Carrot Rewards users living in Ontario, Canada. This study had one main purpose and two secondary objectives (herein referred to as objectives 1, 2 and 3). The main purpose of this study (objective 1) was to provide and compare device-assessed mean daily step counts (i.e., PA for each user was assessed over a 7-day period) for Ontario Carrot Rewards users who responded to an in-app chronic disease questionnaire. Daily step counts were compared in general, by gender and age, and across independent sub-groups (with vs. without self-reported chronic disease, rural vs. urban). One of our secondary objectives (objective 2) was to compare the combined group influence of rural/urban and chronic disease status, together, on mean daily step counts (i.e., rural-dwelling with and without a chronic disease vs. urban-dwelling with and without a chronic disease). Another secondary objective (objective 3) was to report PA levels in different regions of the province to identify high- and low-active areas. This unique data set should not replace but rather be considered a useful complement to existing PA surveillance data while addressing some PA surveillance literature limitations. Most importantly, this work starts to address the lack of device-assessed PA in Ontarians in general, and key sub-groups.

Chapter 2: Methods

2.1 *Setting and Study Design*

This cross-sectional cohort study included new Carrot Rewards users living in Ontario, Canada. Participants (aged 13 years or older) must have downloaded the free app from the ‘App Store’ on iPhone devices or ‘Play Store’ (Google Play) on Android devices between December 7th, 2018 and April 30th, 2019. Upon app download (Day 1), demographic (i.e., age, gender [male, female, other], postal code) data were collected. Subsequently, device-assessed PA data were collected over a 7-day period (Day 1 to Day 7, starting from whenever the participant downloaded the app over the 23-week period). The app drew daily step count data from the HealthKit (iOS), Google Fit (Android), or FitBit apps. Carrot Rewards users were also able to voluntarily complete short health behaviour and demographic surveys through the app interface. The data for this study were stored electronically. Participants consented to have this information collected for research purposes. Data collection for this study was conducted in partnership with the research team at Carrot Rewards. During the study, Carrot Insights Inc. declared bankruptcy which influenced our data collection and precluded certain analyses including our ability to distinguish between smartphone and FitBit devices. This produced several limitations and constraints which will be discussed throughout this document. This study (REB #113909; see letter of approval, Appendices A) was approved by the Health Sciences Research Ethics Board at Western University and follows the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines for cross-sectional studies (von Elm et al., 2007; see Appendix B).

2.2 *Inclusion Criteria*

To be included, new Ontario Carrot Rewards users must have completed the ‘chronic disease’ question, “Do you have any of the following chronic illnesses or conditions?” in one of the short health surveys (launched December 7^{th}, 2018, see Appendix C; study flow chart in Figure 1). Secondly, participants must have had a phone-registered Ontario forward sortation area code (FSA code, or the first three postal code digits). A single FSA may contain between 0 and 60,000 households (Simon Fraser University, 2020). Ontario has 513 unique FSA codes, the most of any province or territory in Canada (Statistics Canada, 2016). Thirdly, and specific to internal Carrot Rewards data collection protocols, users must have had at least five ‘valid’ days of daily step count data (i.e., between 1,000 and 40,000 steps) during the 7-day PA collection period. Individuals who walked less than 1,000 steps or greater than 40,000 steps per day were considered to have insufficient phone wear time or be experiencing a technological error, respectively. These minimum and maximum step count thresholds have been used previously and are distinct features of the Carrot Rewards app (Mitchell et al., 2020). The 7-day PA collection interval is consistent with other recent Carrot Rewards studies and with daily step count literature more broadly (Katzmarzyk et al., 2013; Mitchell et al., 2020; Schmidt et al., 2009). We acknowledge that it is possible that some individuals with chronic disease may walk less than 1000 steps per day on account of their medical condition which may be a study limitation. For example, older adults in Cochrane et al. (2017) after receiving a health education intervention took an average of 2281 steps per day with a standard deviation of 1450 after 24-months, meaning there were some individuals walking less than 1000 steps per day. Further, as wear time is frequently a limitation in PA surveillance works, we attempted to mitigate this by providing wear time reminders (Hekler et al., 2015). A recent study utilizing FitBit devices demonstrated that reminders may increase wear time by almost 20% when compared to participants who did not receive reminders (Polgreen et al, 2018). Participants in our study received prompts throughout the 7-day PA collection period to ‘wear’ their smartphone or wearable device as much as possible (Figure 2).

Figure 1. *Study flow chart.*

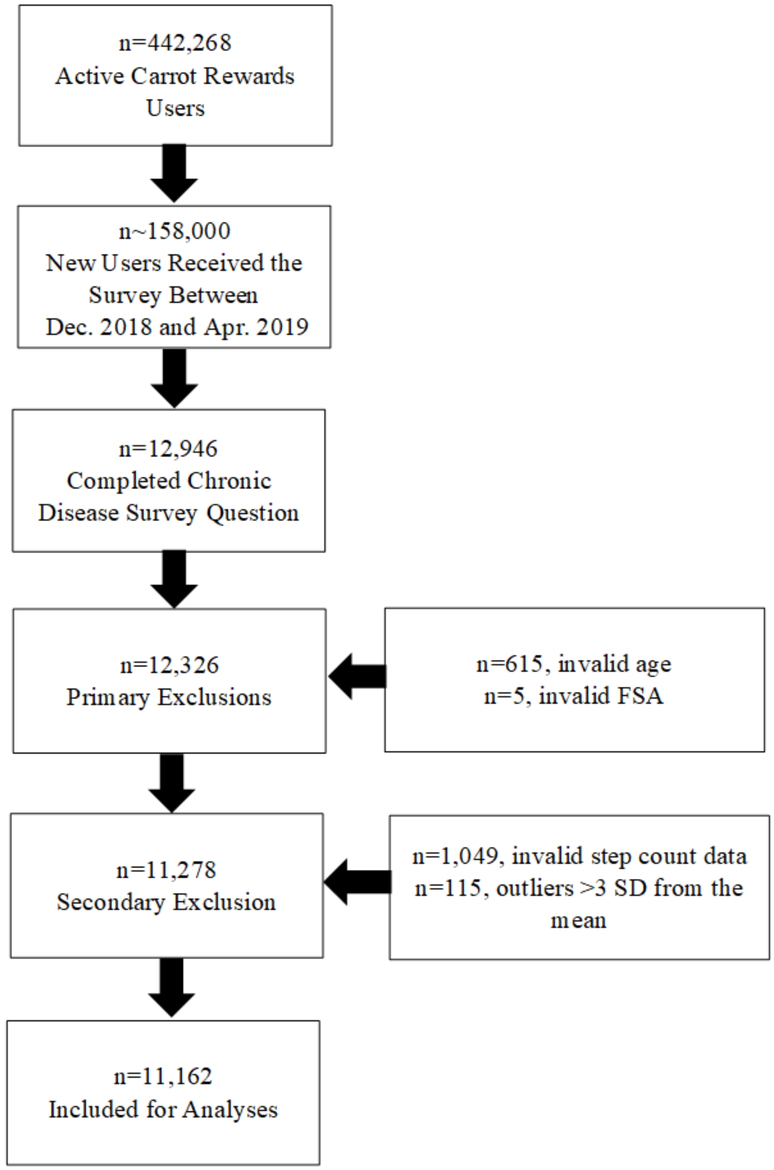
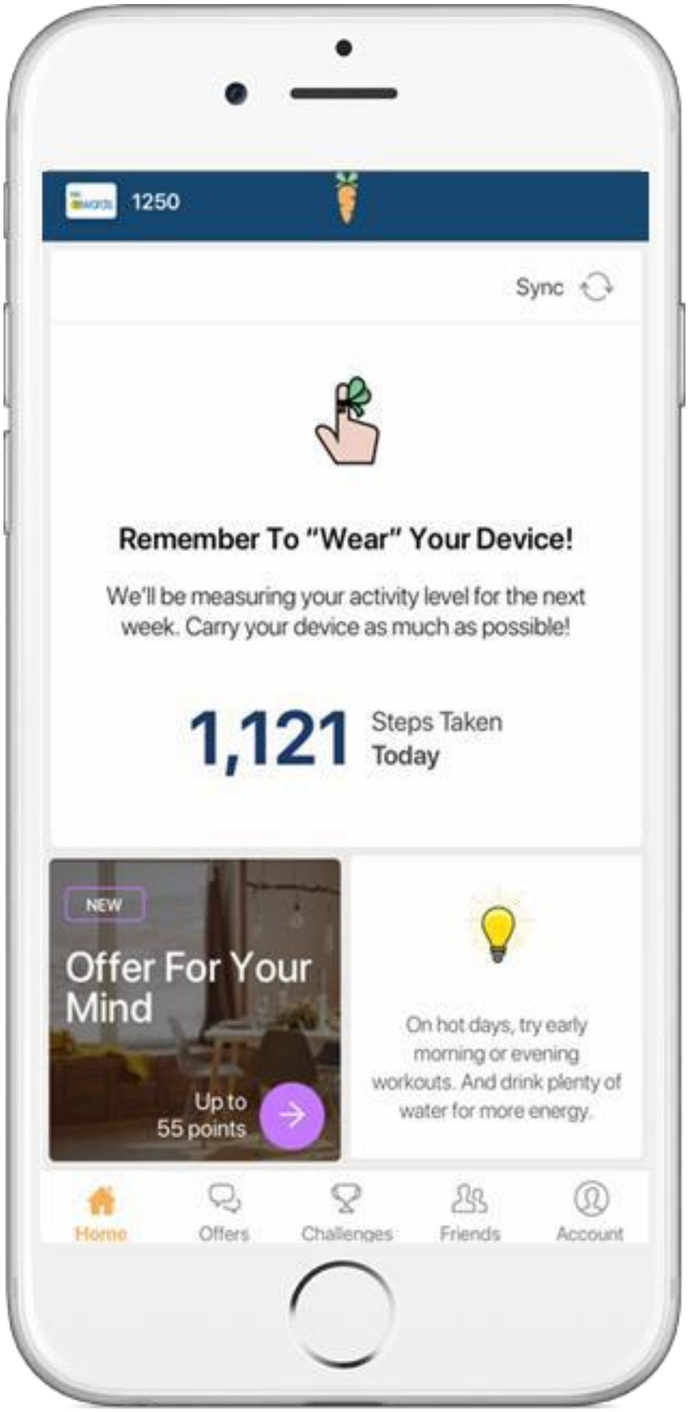


Figure 2. *Screenshot of the wear time reminder Carrot Rewards users received during the baseline daily step count collection period.*



2.3 *Selection and Development of the Independent Variables*

Participants completed two health-related questionnaires/demographic surveys. These surveys were developed by the Carrot Insights Inc. research team and were offered through the app to exclusively new Ontario Carrot Rewards users in December 2018 which isolated our cohort for this study. The questions contained in each survey were adapted from the *Canadian Community Health-Measures Survey* (CCHS) to fit the Carrot Rewards user interface. Participants could self-report information related to specific health behaviours and personal demographics. Most questions contained several multiple-choice response options, including options to abstain and skip questions. For exact questions and multiple-choice response options see Appendix C. Due to time constraints, an interrupted data collection interval (only had 23 weeks, whereas our minimum goal was 26), the limited existing literature, identified gaps in this space for Ontario, and variables previously identified as important predictors of PA participation (Plotnikoff et al., 2004), we elected to use only the broadest subgroup strata (chronic disease status, rural/urban status, age and gender) to form the research questions for this study. While we collected a significant amount of demographic data, only select questions from each survey (to form a sufficiently holistic image of our cohort) were included for use in study objective 3.

The first survey titled “Please Stand Up” focused on participant demographics and specific health behaviours. It included questions such as “What is the highest certificate, diploma or degree that you've completed?” and “What is your annual pre-tax household income?”. The second survey titled “Our Burning Questions” again focused on demographic questions, but importantly, also included a question about chronic disease diagnosis. Questions from this second survey included, “Do you have any of the following chronic illnesses or conditions? These are conditions diagnosed by a health professional that are expected to last or have already lasted 6 months or more. (Scroll and select all that apply)”.

There were four important independent variables that were drawn from the surveys/registration information to be utilized in this study, namely, chronic disease status, rural/urban status, age, and gender. For chronic disease status, participants were able to self-report one or more of the following chronic disease diagnoses: cancer, cardiovascular disease, chronic obstructive pulmonary disease (COPD), type 2 diabetes, mood/anxiety disorders, or another chronic illness not listed. These chronic diseases are the ‘major five’ listed by the *Canadian Chronic Disease Indicators* report from the Public Health Agency of Canada (CCDI, 2017). Users could also select ‘None of the above’ or ‘Rather not say’ as well. We used FSA codes to determine ‘urban’ or ‘rural’ status, in accordance with Government of Canada designations to ensure reporting consistency with our rural/urban subgroup as well as to formally identify grouping regions for our third study objective. FSA codes containing a ‘0’, as a second digit are designated ‘rural’ areas (Statistics Canada, 2015). The specific definition of ‘rural’ has been contested in the literature (Olsen et al., 2013). We used the Statistics Canada 2016 definition of ‘rural’: areas/communities of less than 1000 people. As part of the registration process with the app, participants had to disclose their age. These age data were then grouped into age brackets using the Arim and Schellenberg (2019) scheme. Finally, our gender variable was defined as male, female and other; the other option provided individuals an opportunity to identify with something other than biological characteristics. This information was provided to us by Carrot Rewards and we did not have any input into the creation of our gender variable. Finally, for study objective 3, we structured descriptive demographic variables based on key socioeconomic comparisons from Arim and Schellenberg (2019). Unfortunately, there was insufficient data for any robust comparative analyses study objective 3. Accordingly, we proceeded with a descriptive analysis and variables were grouped to facilitate a basic feasibility/proof-of-concept descriptive analysis. Arim and Schellenberg (2019) highlighted key comparisons of educational level and income status which are well known influencers of PA and chronic disease incidence. To provide general contextualization to our sample we used two socioeconomic variables for each respective FSA. The two socioeconomic variables were percent higher education (bachelor's degree or above) and percent low household income (less than $60,000/year in Ontario; Ministry of Finance, 2020). We also reported age and gender distributions for this analysis. Further, due to the limited scope of data we were able to collect for this objective (limited number of FSAs with a sufficient number of participants), we utilized a logic-based convenience sample approach to inform our group sizes of (n<90) for urban FSAs and (n<30) for rural FSAs taking into account the inherent regional population size and density differences (Simon Fraser University, 2020).

2.4 *Outcomes*

The primary outcome was mean daily step count as assessed by 'built-in' smartphone accelerometers, or any FitBit device over the 7-day PA collection period. Participants received wear time reminders during the 7-day PA data collection period to reduce reporting discrepancies that have been identified with smartphone platforms (Figure 2; Amagasa et al., 2019; Case et al., 2015; Duncan et al., 2017).

2.5 *Data Analyses*

Prior to beginning analyses, the data were evaluated to look for outliers or leverage points that may have skewed our results. A potential outlier was defined as any user with a mean daily step count greater than three standard deviations from the overall group mean based on studentized residuals (Osborne & Overbay, 2008). All potential outliers were individually inspected, identified, and removed, as necessary. Normality was assessed by visual inspection of the studentized residual plots using Q-Q Plots and was determined to be approximately normal, thereby meeting the assumption of one- and two-way ANOCOVA's. While Kolmogorov-Smirnov and Shapiro-Wilk's test are useful to test for normality, they are extremely susceptible to over-sensitivity with large sample sizes, therefore a graphical approach is preferred (Keppel and Wickens, 2004). Further, Elliot and Woodward (2007), utilizing Central Limit Theorem, state that even if normality is not present, when using large sample groups (n>40), the use of parametric tests is reasonable. All other analysis of covariance (ANCOVA) assumptions were met and we proceeded with our analysis.

Our first objectives were to calculate baseline daily step counts for: (a) all study participants, (b) 'healthy' versus those self-reporting at least one chronic disease diagnosis, and (c) those living in rural versus urban settings. Analytic groups were further stratified by age and gender. A series of one-way and two-way ANCOVAs (with post-hoc Bonferroni corrections for multiple comparisons) controlling for data collection date were conducted to examine sub-group differences in mean daily step count.

Previous literature has suggested there is a potential moderating effect of season (i.e., date) on PA in Canada and worldwide (Chan et al., 2006; Merchant et al., 2007; Tucker & Gilliland., 2007). Before including date as a covariate in our analyses, we first recoded our total sample into 23 week-by-week sub-groups based on date of baseline PA collection week from December 7th, 2018 to April 30th, 2019 to explore the possible impact of date on mean daily step count. Week-by-week sub-group daily step count means were compared using a one-way ANOVA. Overall, we found that there was a significant effect of weeks on mean daily step counts, $F(22, 11255)=5.215$, $p<.001$, and so study week was included as a covariate in all analyses.

Next, using a two-way ANCOVA we examined whether mean daily step count differences existed across rural and urban settings for persons living with chronic disease when compared to their ‘healthy’ counterparts. Lastly, we listed higher and lower active FSAs, adjusting for the effect of date (study week). Only FSAs meeting our operational definition of ‘sufficient’ participants were included (i.e., at least 90 and at least 30 users in urban and rural FSA’s, respectively). This operational threshold differed for rural/urban FSAs because of inherent population density differences (Simon Fraser University, 2020). Mean daily step counts and socio-demographics (i.e., age, chronic disease diagnosis, low-income and higher education percentages) are provided. Data were analyzed using IBM SPSS Statistics version 26.0.

Chapter 3: Results

3.1 *Participant Characteristics*

From a total possible sample of 12,946, 11,162 Ontario Carrot Rewards users ultimately met our inclusion criteria (mean age [M_{age}]=34.7, standard deviation (*SD*)=13.63, range 13-100; female: 63.2%; rural: 8.5%; self-reporting at least one chronic disease diagnosis: 37.7%; see Tables 1 and 2). Our cohort was demographically different than the general Ontario population (2016 Canadian Census Report) and Ontario Carrot Rewards users in general (Arim & Schellenberg, 2019). Compared to the general Ontario population, for example, our cohort was younger (M_{age}=34.7 vs. 41.0 years), more likely to be female (63.2% vs. 51.2%) and less likely to live in a rural area (8.5% vs. 10.4%). They were also more educated (34.2% vs. 26.0% with bachelor's degree or above) and reported higher household incomes (37.8% vs. 44.2% under $60,000 CAD).

Table 1. Socio-demographics of study sample, Carrot Rewards users, and Ontarians in general.

Variable	Ontarian Residents (Census, 2016)	Carrot Rewards (Arim & Schellenberg, 2019)	Study Sample
Gender			
Women (%)	51.2	68.5	63.2
Age			
Mean	41.0	33.7[a,b]	34.4
Highest Education Level			
Bachelor's Degree or Above (%)	26.0	41.2	34.2
Immigration Status			
Born outside Canada (%)	29.1	27.3	29.9
Household Income			
Less than $60,000 (%)	44.2	47.2	37.8
Urbanicity			
Rural (%)	10.4	9.2	8.5

a. Mean age for Ontario was not evaluated by Arim & Schellenberg (2019) or any other publication using Carrot Rewards data.
b. Mean age included from Mitchell et al. (2020) using data from British Columbia and Newfoundland and Labrador.

Table 2. Proportion self-reporting one or more chronic diseases and daily step count mean for each.

Status	%	Average Daily Step Count
None of the above (*n*=6140)	55.0	*M*=5575[a] SE=44.93
Mood/Anxiety Disorders (*n*=3042)	27.3	*M*=5003[a] *SE*=63.90
Chronic Disease not listed (*n*=769)	6.9	*M*=5096[a] *SE*=127.29
Cancer (*n*=752)	6.7	*M*=5072[a] *SE*=128.72
Rather not say (*n*=602)	5.4	*M*=5271[a] *SE*=143.87
Cardiovascular Disease (*n*=452)	4.0	*M*=5147[a] *SE*166.04
Type 2 Diabetes (*n*=342)	3.1	*M*=4884[a] *SE*=190.84
COPD[b] (*n*=196)	1.8	*M*=5129[a] *SE*=252.18

a. Adjusted for effect of date.
b. Chronic Obstructive Pulmonary Disease.

3.2 *Overall Mean Daily Step Counts*

Results are presented as mean (*M)* and 95% confidence interval (95% CI) throughout unless otherwise stated. Overall, study participants accumulated an average of 5,342 steps per day (95% CI: [5276.46, 5407.45]; see Table 3). There was a significantly different mean daily step count for gender (Males, *M*=5844, 95% CI [5734.25, 5953.95], Females, *M*=5080, 95% CI [4997.60, 5161.44], Other, *M*=4690 95% CI [4179.78, 5199.91]), $F(2, 11162) = 63.00$, $p<.001$, partial $\eta^2 = .011$. Due to the significantly different mean daily step counts for gender, we conducted Bonferroni adjusted post hoc testing to identify where the differences were and found that males had significantly more steps ($p<.001$) than their counterparts, female and other. Males accumulated about 800 more steps per day, or 5,600 more steps per week, compared to females and 1,200 steps per day, or 8,400 step per week compared to other (see Table 3, and Appendix D for full post hoc results). The one-way ANCOVA examining the overall effect of age (13 age brackets, e.g., 13-19 years, 20-24 years, 25-29 years, etc.) on mean daily step counts was statistically significant, $F(12, 11162)=7.31$, $p <.001$, partial $\eta^2 = .008$. Post hoc analyses were performed with a Bonferroni adjustment and found that mean daily step counts were significantly different ($p<.001$) in six of 13 age brackets when compared to the youngest cohort, 13-19 years (see Appendix D for full post hoc results). An examination of study sample means by age group suggest users under the age of 25 years, and over the age of 65 years, accumulated fewer steps per day when compared to users 25 to 64 years of age (Appendix E).

Table 3. Mean daily step counts for overall study sample, by gender.

Group	Overall	Gender		
		Male	*Female*	*Other*
All	*M*=5342[a] *SE*=33.41 [5276.46, 5407.45][b] *n*=11162	*M*=5844[a] *SE*=56.04 [5734.25, 5953.95][b] *n*=3924	*M*=5080[a] *SE*=41.79 [4997.60, 5161.44][b] *n*=7056	*M*=4690[a] *SE*=260.21 [4179.78, 5199.91][b] *n*=182
Healthy	*M*=5548[a] *SE*=42.21 [5465.66,5631.14][b] *n*=6955	*M*=5966[a] *SE*=70.63 [5827.31, 6104.19][b] *n*=2456	*M*=5328[a] *SE*=52.81 [5224.92, 5431.96][b] *n*=4393	*M*=4995[a] *SE*=339.98 [4328.39, 5661.21][b] *n*=106
Chronic Disease Diagnosis	*M*=5001[a] *SE*=54.27 [4894.27,5107.04][b] *n*=4207	*M*=5641[a] *SE*=91.36 [5461.50, 5819.65][b] *n*=1468	*M*=4669[a] *SE*=67.83 [4535.93, 4801.85][b] *n*=2663	*M*=4265[a] *SE*=401.51 [3477.56,5051.61][b] *n*=76
Rural	*M*=5441[a] *SE*=114.35 [5216.47, 5664.75][b] *n*=953	*M*=6239[a] *SE*=227.06 [5794.05,6684.19][b] *n*=239	*M*=5192[a] *SE*=132.30 [4933.07, 5451.72][b] *n*=704	*M*=3831[a] *SE*=1110.03 [1654.66, 6006.36][b] *n*=10
Urban	*M*=5333[a] *SE*=34.94 [5264.26, 5401.23][b] *n*=10209	*M*=5818[a] *SE*=57.83 [5705.13, 5931.83][b] *n*=3685	*M*=5067[a] *SE*=44.04 [4980.68, 5153.34][b] *n*=6352	*M*=4740[a] *SE*=267.65 [4215.17, 5264.45][b] *n*=172

a. Adjusted for effect of date.
b. 95% confidence interval.

3.3 *Mean Daily Step Counts for Users With and Without a Chronic Disease Diagnosis*

There was a statistically significant effect of chronic disease status (at least one chronic disease, *M*=5001, 95% CI [4894.27, 5107.04], vs. without, *M*=5548, 95% CI [5465.66, 5631.14]), $F(1, 11162) = 63.46$, $p<.001$, partial $\eta^2 =.006$ on mean daily step count with a mean group difference of 548 steps more per day favouring healthy individuals compared to those with chronic disease (95% CI [412.97, 682.53], $p<.001$; see Table 3). The two-way ANCOVA, examining chronic disease status by gender (Males, *M*=5641, 95% CI [5462, 5819.65], Females, *M*=4669, 95% CI [4535.93, 4801.85], Other, *M*=4265, 95% CI [3477.56, 5051.61], with at least one chronic disease, Males, *M*=5966, 95% CI [5827.31, 6104.19], Females, *M*=5328, 95% CI [5224.92, 5431.96], Other, *M*=4995, 95% CI [4328.39, 5661.21], without chronic disease) was not significantly different, $F(2, 11162)=2.762$, $p=.063$, partial $\eta^2 =.000$ (see Table 3). Normally, it would not be appropriate to conduct post hoc testing on gender-based differences without a statistically significant ANCOVA interaction. However, because there was a simple main effect of chronic disease and the test was approaching significance, we proceeded with post hoc testing. All post hoc testing was performed with a Bonferroni adjustment (see Appendix F for post hoc results). Notably, we observed in Table 3 the mean daily step count difference between healthy users and those with a chronic disease diagnosis appears to be approximately two-times greater for females (i.e., 660 daily steps) than males (i.e., 325 daily steps). In addition, mean daily step counts for chronic disease diagnoses were not significantly influenced by age bracket, $F(12, 11162)=1.517$, $p=.110$, partial $\eta^2 = .002$. Interestingly, examination of mean daily step counts by age group suggested the greatest disparity in daily step counts among users with and without chronic disease was in the 55 to 59 and 60 to 64-year age groups (i.e., 1052 and 1647 steps per day, respectively; Appendix E).

3.4 *Mean Daily Step Counts for Rural versus Urban Users*

Overall, there was no statistically significant effect of rural/urban status (Rural, *M*=5441, 95% CI [5216.47, 5664.75], Urban, *M*=5333, 95% CI [5264.26, 5401.23]) on mean daily step counts, $F(1, 11162)=.814$, $p=.367$, partial $\eta^2=.000$ (see Table 3 and Appendix F). Furthermore, there was no significant effect of rural/urban status by gender (Rural males, M=6239, 95% CI [5794.05,6684.19], Rural females, *M*=5192, 95% CI [4933.07, 5451.72], Rural other, *M*=3831, 95% CI [1654.66, 6006.36], Urban males, *M*=5818, 95% CI [5705.13, 5931.83], Urban females, *M*=5067, 95% CI [4980.68, 5153.34], Urban other, *M*=4740, 95% CI [4215.17, 5264.45]) on mean daily step count, $F(2, 11162)= 1.055$, $p=.348$, partial $\eta^2 = .000$ (Table 3). As well, the one-way ANCOVA evaluating participants by age bracket for effect of rural/urban status on mean daily step count did not reach statistical significance, $F(12, 11162)=.743$, $p=.710$, partial $\eta^2 = .001$. Overall, there were no statistically significant mean daily step count differences between rural and urban Ontarians, irrespective of age and gender sub-groups. An examination of group means suggests the mean daily step count difference between males and females is greater in rural (1047 steps) versus urban (751 steps) settings (Table 3).

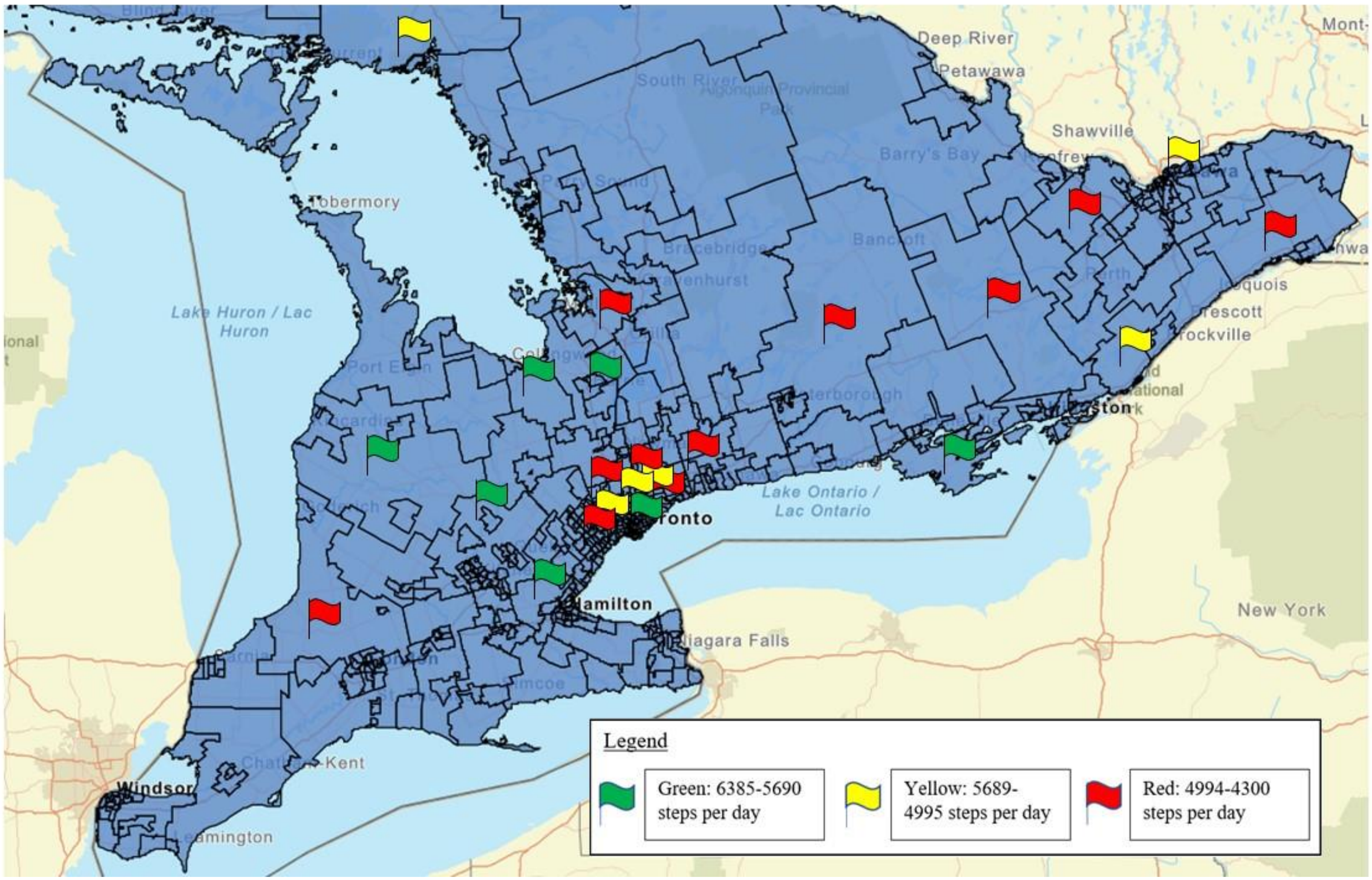
3.5 *Two-way Analyses of Rural/urban Status by Chronic Disease Status on Mean Daily Step Count*

The two-way ANCOVA examining rural/urban and chronic disease status (Urban, with at least one chronic disease, *M*=5011, 95% CI [4899.81, 5121.87], Urban, without, *M*=5529, 95% CI [5442.00, 5615.23], Rural, with at least one chronic disease, *M*=4887, 95% CI [4515.00, 5258.00], Rural, without, *M*=5755, 95% [5475.20, 6034.87]) did not have a significant interaction, $F(1, 11162)=2.00$, $p=.157$, partial $\eta^2 = .000$ (see Appendix G). Due to the significant one-way effect of chronic disease status, we proceeded with post hoc testing. Post hoc comparisons revealed that there was a statistically significant mean daily step count difference for both rural and urban environments, independently of chronic disease status (see Appendix H for post hoc results).

3.6 *Overall Mean Daily Step Count by Forward Sortation Area*

We ranked a total of 23 Forward Sortation Area (FSA) with sufficient data codes in terms of their mean daily step counts (from highest to lowest; see Appendix I). FSA N0G, representing the rural region of Southern Bruce and Huron County, had the highest overall mean daily step count (*M*=6385, 95% CI [5144.12, 7626.46]). The second highest mean daily step count and the highest for an urban FSA was M5V, representing the downtown core in Toronto (*M*=6360, 95% CI [5686.14, 7034.84]). FSA L3R representing Southwest Markham had the lowest overall mean daily step count, (*M*=4300, 95% CI [3554.78, 5045.02]). The lowest mean daily step count for a rural FSA, and overall, was K0C, representing the Cornwall/Stormont, Dundas and Glengarry United Counties, (*M*=4364, 95% CI [3284.95, 5443.46]). Figure 3 illustrates the geographic dispersion across Ontario of our 23 Forward Sortation Areas including their step count averages, presented in tertiles. The FSAs had a range of 4230-6385 steps per day with tertiles of 695 steps. Twenty-two of 23 regions included for reporting were in eastern, central, or southern Ontario. We only had one region that was classified as northern, P0M (Sudbury).

Figure 3. *Daily step count means of 23 Ontario Forward Sortation Areas, by tertile (high, midrange, and low).*



c. Green: High Step Count Average based on available data.
d. Yellow: Midrange Step Count Average based on available data.
e. Red: Low Step Count Average based on available data.

Chapter 4: Discussion

4.1 *Principal Findings*

In this cross-sectional cohort study, we used smartphone data collected by a popular Canadian mhealth app to describe PA levels for over 11,000 app users in Ontario, Canada. We had a least one user from all 513 Ontario FSAs, demonstrating widespread use across the province. Study participants were younger, more likely to be female, and more likely to live in urban areas than the general Ontario population. Nearly 40% of participants self-reported at least one chronic disease diagnosis. Overall, our study participants accumulated 5,342 steps per day, at least 2000 steps per day lower than the Tudor-Locke et al. (2011) recommendations that suggested individuals needed to walk 7500-9999 steps per day to be moderately active and 10000 steps per day to be considered physically active. Further, Kraus et al. (2019) recommend that 7000-9000 steps per day is sufficient to exceed PA guidelines which is 1500 to 3500 steps higher than the overall step count average found here. Based on the Tudor-Locke and Bassett (2004) classification, and acknowledging the limitations of our design (e.g., wear time may not have been optimized) our study participants would be considered physically inactive. In our study, participants self-reporting a chronic disease diagnosis took about 550 fewer steps per day, or nearly 4000 steps per week (about 40 walking minutes), compared to those with no chronic disease, despite the well-established benefits of PA as a chronic disease self-management tool (e.g., better glycemic control, mental health, etc.; American College of Sports Medicine, 2018). This difference between those with and without chronic disease existed for rural and urban participants alike. Notably, there were no mean daily step count differences between participants living in rural versus urban areas.

There were also several age and gender-based findings. First, PA in our study appears to vary by age group, with people under 25 years and over 65 years accumulating less steps per day when compared to users 25 to 64 years. Second, females accumulated about 800 fewer steps per day, or 5600 fewer steps per week (about an hour of walking), compared to males. This gender gap appears to be exacerbated with a chronic disease diagnosis. For instance, the difference between healthy users and those with a chronic disease were two-times greater in females (i.e., 660 steps) compared to males (i.e., 325 steps). Additionally, the gender gap may be even wider in rural areas (i.e., about 1100 steps/day difference between males and females, vs. 800 steps/day in urban areas).

Lastly, we have started to describe the great disparity in PA across the province with a more than 2000 step per day average difference between our most and least active FSAs (with sufficient data for analysis in this study). Physical inactivity hotspots were also identified as a proof-of-concept, potentially informing the future delivery of more targeted, effective, and efficient PA interventions in Ontario. While our results do not describe PA for Ontarians in general, they do help overcome some of the limitations of PA surveillance studies to-date, namely recall bias (for subjective measures) and limited sampling in population subgroups such as those living in rural settings with chronic disease (for traditional objective measures).

4.2 *Similar Studies*

Our findings generally align with those of Althoff et al. (2017) who similarly used smartphone accelerometer data to characterize PA behaviours in countries around the world, including Canada. Participants in our study accumulated 5342 steps per day, compared to the Canadians described by Althoff et al. (2017) who accumulated 4891 steps per day. Data from over 25,000 participants spread across all of Canada were used to calculate the Canadian daily step count average in the Althoff et al. (2017) study, whereas we analyzed data from over 11,000 users in Ontario alone, possibly explaining the roughly 500 step per day difference between studies. On the contrary, our study tells a different story than Guthold et al. (2018) who collected *self-reported* PA data from 168 countries with 1.9 million total participants (representing 96% of the world's population) and found that approximately 75% are meeting PA guidelines. Our smartphone-based approach may be less vulnerable to the over-reporting that is characteristic of traditional PA surveillance methods. One of the most important contributions to PA surveillance in Canada to-date by Colley et al. (2011) utilizing the *Canadian Health Measures Survey* reported objectively assessed PA among a representative sample of 2800 Canadians. They found that Canadian adults accumulated, on average, 8965 steps per day—much higher than the 5342 steps/day average reported here. A couple of reasons may help explain this discrepancy, including: (a) under-sampling of Canadians at-risk of insufficient PA by Colley et al. or (b) the possibility that not all participant steps were recorded by smartphones in our study owing to insufficient wear time (i.e., device not carried on person all waking hours).

Regarding the influence of chronic disease status on daily step counts in the current study, our findings are similar to Moy et al. (2015), for example, who concluded from a sample of 134 American adults (over 40 years of age) that individuals with COPD take 5680 steps per day on average (as assessed by ankle-worn accelerometer), though their study sample was predominantly male (98%). Our study was also similar to Yates et al. (2014) who aimed to understand the influences of daily step count increases on cardiovascular events (e.g., congestive heart failure, coronary artery disease, cerebrovascular disease, etc.). Over 9,000 participants from 40 countries utilized had their daily PA evaluated using a pedometer which resulted in a median of 5892 steps. Importantly, the researchers concluded that every 2000 step per day average increase from baseline to 12-months resulted in a 10% reduction in risk for a cardiovascular event. The finding of Yates et al. was only approximately 800 steps different than our subgroup self-reporting a chronic disease. Siddiqui et al. (2018) assessed daily step counts in a South African population living with type 2 diabetes. Participants (95) in this study were split into two arms (control and active). Active participants were considered those who had the highest step counts during the baseline period as well as those who indicated they would be willing to increase their daily step count to 7,000. The control group were instructed to do nothing beyond their normal routine. During the baseline evaluation period, males and females in the control group walked 3,358 and 2,727 steps whereas males and females in the active group walked 4,682 and 4,573, respectively. Interestingly, the findings of Siddiqui et al. are below the daily step counts reported for individuals self-reporting type 2 diabetes in our study with 4,884 steps. This step count difference may be due to the fact that the mean age of our participants is 20 years younger than Siddiqui et al. Jefferis et al. (2019) reported in a study of over 1,500 British men (mean age=78 years) without pre-existing cardiovascular disease or heart failure and determined that they take an average 4,938 steps per day. Importantly, they concluded that each 1000 step per day difference resulted in a 15% reduction is all-cause mortality risk. Further, our study was also similar to Schmidt et al. (2009). They evaluated cardiometabolic risk factors in relation to daily step count and determined that individuals who walked greater than 5,000 and 12,500 steps per day had a significantly lower prevalence of cardiometabolic events than those who walked above and below those increments. Schmidt et al. concluded that <5000 steps per day was an appropriate threshold to mitigate cardiometabolic risk associated with inactivity. Participants who self-reported a chronic disease diagnoses in our study had a daily step count mean of 5,001 steps per day which is directly on the threshold for reducing cardiometabolic risk (>5000) as outlined by Schmidt et al. (2009). Lee et al. (2019) examined the minimum number of steps per day required to reduce mortality risk and found that any increase in steps, even small increases, reduces all-cause mortality risk up to approximately 7500 steps. In their study, taking even 4,400 steps per day reduced mortality risk by over 40% compared to individuals walking less than 3,000 steps per day. This is an important consideration as 10,000 steps per day as a goal may discourage individuals who are not or are barely attaining half of that goal, such as the individuals who self-reported a chronic disease in our present study. Any increase in steps per day may be useful to confer some health benefit and reduce risks up to certain thresholds. Our 5,001 step per day finding is also similar to the computer-generated modelling recommendations from Tudor-Locke et al. (2011) that suggested a reasonable step goal for individuals living with chronic disease or persons part of a special population is 5,500 steps per day or 4,600 steps per day in a free-living environment. Our participants self-reporting a chronic disease fall in the middle of that recommendation which supports the suggestion that any increase in steps per day may provide health benefits and perhaps a 10,000 step per day goal is not realistic acknowledging the potential physical limitations of persons living with chronic disease or other special population.

Anxiety and mood disorders were the most pervasive chronic disease reported by our study participants. The American Psychiatric Association (2013) has identified that mental illnesses or conditions can be caused or influenced by other existing medical conditions. It is well documented that living with a chronic condition can cause or worsen mental health issues and disorders (Chapman et al., 2005). This is an important consideration in the context of one of our gender subgroups: individuals who chose to identify as neither male or female and selected ‘other’. There is very limited literature that uses accelerometry/device-measured PA using a gender classification other than binary sex characteristics (male and female). The evidence is further limited when looking at PA in non-binary (i.e., transgender) population also living with a chronic disease. Our study, to the best of our knowledge, may be the first to use a smartphone to assess PA in non-binary individuals self-reporting a chronic disease. Compared to the overall mean for individuals self-reporting a chronic disease, individuals who identified as 'other' walked almost 800 steps per day fewer. This is particularly concerning as transgender individuals are known to be at higher risk for mental illness, symptoms of which can be attenuated with consistent PA (Arcelus et al., 2016; McMahon et al., 2017). For higher risk groups such as transgender individuals living with chronic disease, our data suggest that inequalities may 'stack-up' and further reinforce existing disparities.

Our study used a comparable subgroup selection as Plotnikoff et al. (2004). Their study used a random sample of over 20,000 Canadians with the aim of understanding the correlates of PA across men and women, by geography (urban and rural) and specific age groups (18-25, 26-45, 46-59 and 60+). Plotnikoff et al. determined that higher education level was associated with higher PA level across all subgroups except for age. In their study, for individuals in the youngest age cohorts (<45 years of age), lower education level was associated with higher PA level. Plotnikoff et al. were surprised by these findings, however, as occupation has been noted as a potential confound when looking at the correlates of PA (Smith et al., 2016). Fukishima et al. (2018) used accelerometer measured PA and determined that blue-collar workers were more physically active than white-collar workers. Even though white-collar workers get more leisure time activity, it is insufficient to combat sedentary work time (Fukishima et al., 2018). The pattern of higher physical activity among blue-collar workers is consistent in the literature (Bennie et al., 2010; Kirk et al., 2011). This is potentially an important implication for the subgroups in our study as the distribution of blue-collar workers and occupation more broadly, could influence PA distribution in rural and urban settings and should be a consideration in future works.

Our finding suggesting rural/urban status does not influence daily step count is interesting. Previous literature has noted that conveniences of the built environment (Stevenson et al., 2016) in urban areas, or lack of traditional PA resources (Patterson et al., 2004) in rural areas, may limit respective PA participation. While our findings suggest there are no significant PA differences based on rural/urban status and gender, they are nonetheless intriguing. Coen et al. (2016) described traditional PA resources like gym facilities to be highly gendered spaces which often reduce the enjoyment of PA experiences for women. This may account for the 300 step per day difference observed between rural-dwelling males and females (1,100 step per day difference) between urban-dwelling males and females (800 step per day difference). The smartphone as a collection instrument, and mHealth apps like Carrot Rewards as an ‘intervention’ tool, may bridge the previously existing resource gaps that were suggested to have existed in rural populations due to limited traditional PA resources by providing women a platform to assess and improve their PA using non-traditional resources (thereby moving the posited rural-urban and gender-based PA disparities towards equilibrium). In addition, Martin et al. (2005) have suggested that rural versus urban PA differences are not automatic and very much regional, consistent with our results. Taken together and considered in the context of the broader PA surveillance literature, our findings suggest different PA measurement methods may be required to more effectively assess and address PA behaviours in a variety of population subgroups in Ontario and Canada. Indeed, surveys, hip-worn accelerometers, and ‘built-in’ smartphone accelerometers may complement each other in this regard.

4.3 *Bridging the Gender Gap*

Althoff et al. (2017) suggested that gender-based disparities in PA are a more reliable predictor of a country's obesity incidence than PA participation in general. Guthold et al. (2018) and Azevedo et al. (2007) also determined that females accumulate less PA than males overall. It is essential to understand gender-based PA differences as they have important public health considerations. Krueger et al. (2014) determined that reducing physical inactivity (i.e., the proportion of individuals accumulating <5,000 steps per day) by even 1% in Canada could substantially reduce the economic burden related to chronic disease risk factors over the next two decades. This is an interesting consideration as noted above, females in our study accumulated significantly fewer steps per day (800) and approximately 5,600 fewer steps per week (about an hour of walking), compared to males. In the context of a single day, 800 steps may appear menial, however 800 steps per day could contribute significantly to bridging this PA gender gap and move more women above the 5,000 step per day threshold, potentially helping to reduce the chronic disease burden. Further, considering the finding of Althoff et al. (2017), gender disparities in PA was a better predictor of a country's obesity incidence than total PA level raises an important economic question. A comprehensive study from Anis et al. (2010), for example, suggested that Canada's total economic burden associated with overweight/obesity was $6 billion CAD. Similarly, a recent report from the Organization for Economic Cooperation and Development (OECD) in 2019 determined that Canada spends nearly 11% of its total annual healthcare budget on overweight-/obesity-related complications (OECD, 2019). These figures are concerning, especially because obesity incidence is on the rise, placing individuals at increased risk of developing costly chronic disease later in life (Kelsey et al., 2014). Given the demonstrated PA gender gap around the world by Althoff et al. (2017), and now potentially in Ontario in particular, it may make more sense from a chronic disease prevention and management perspective to invest in bridging the gap (e.g., investing in PA programs for females specifically) rather than aiming to increase PA overall.

4.4 *Limitations*

Several limitations must be considered when interpreting the results of this study. First, this is a cross-sectional study of Carrot Rewards users in Ontario, therefore the data may not be generalizable to the general Ontario population or the wider Carrot Rewards user base. Another limitation is our PA measurement method – several studies have demonstrated that smartphone accelerometry can underreport daily step count due to inadequate wear time (Bassett et al., 2017). During our PA assessment, however, participants received prompts to wear their smartphone as much as possible to help manage this wear time concern. Further, reduced wear time may disproportionately affect the daily step counts of women who may be more likely to carry their smartphone in a handbag, for example, which could result in additional undercounting. Nonetheless, our findings supporting gender-based PA disparities are consistent with the literature using similar measurement tools (e.g., Althoff et al., 2017). A third limitation is that we were unable to distinguish between smartphone and FitBit device users for analysis. A fourth limitation is that we had a low number of older adults compared with our younger age brackets as evidenced by large error variances on some statistical analyses and therefore should be interpreted with caution. In addition, given the younger average age of our participants, and because our chronic disease data were self-reported, there is likely some underestimation of the actual chronic disease incidence numbers within our cohort. While a very common technique in the literature, using FSA to determine rural/urban status, we lose a level of specificity (i.e., metropolitan, suburban, rural, remote, etc.). In addition, while FSA data helps to standardize the classification, it only describes where people live and maybe not where they work which could influence health behaviours and PA data. A fifth limitation is how we collected our gender data (male, female, other), in that the “other” selection option may not be as robust as it could be to represent individuals who do not identify as male or female and could include persons who simply did not want their gender data collected. To increase the robustness of this variable, individuals should have been allowed to self-identify instead of being grouped in a generic category (other). A sixth limitation is that components of our self-report chronic disease question were somewhat generic such as how we defined cardiovascular disease, which encompasses a wide spectrum of conditions. Season is consistently a limitation for all PA surveillance data collected outside of the spring/summer months in Canada; particularly, data that encompasses the winter holiday breaks as ours did. However, we adjusted for this across all analyses using a 23-week grouping. Individuals were grouped according to the week of the study that they began their 7-day PA collection interval. It was included in all ANCOVA models as a covariate and was used to adjust the PA data for all descriptive analyses as it is possible there were larger proportions of individuals in specific subgroups who were began their collection interval during the winter or holiday season where PA may have been lower, even though week-week recruitment was quite consistent throughout the 23-week study duration. As noted above, there were also a couple of limitations that were directly related to Carrot Insights Inc.’s bankruptcy during our data collection period. The first related limitation is that we were unable to draw the data required to analyze non-responders which may have provided useful contextualization for our results. Second, due to our limited data collection time period we were unable to complete any robust analysis for our third study objective (very limited number of FSA included). Therefore, the analysis was presented as a feasibility/proof-of-concept.

4.5 *Future Directions*

In the future, researchers should engage the resources of private sector companies (e.g., health apps) who collect PA data across Canada in an effort to expand and improve upon the work started here. Larger-scale and continual up-to-date data will enable interventions to be informed with the best available evidence.

Furthermore, future studies should prioritize the collection of valid health and sociodemographic variables to increase confidence in sub-group findings. As well, future studies should include sociodemographic and socioeconomic variables in large models to help control for potential variances in PA that are not attributed to population subgroup membership alone. This will help to delineate the correlates of PA across complex subgroups. As well, future works should make every effort to collect participants from as many FSAs as possible to complete our objective 3 goals. This would provide potentially useful data to public health policy makers who are interested in regional specific programming and policy. Finally, as smartphone accelerometry continues to improve, there will be more opportunity to leverage this technology to assess a variety of population sub-groups including specific clinical populations. Purswani et al. (2018) identified that there is lack of studies that utilize step/day metrics in cancer patients. These data may prove to be a cornerstone for further surveillance studies examining gender disparities in PA participation in Ontario and Canada. Scaling these data and ensuring effective knowledge translation may provide the rationale for further prioritization and targeting of identified groups at higher risk of physical inactivity including women, those living with chronic disease, and younger adults.

4.6 *Conclusion*

This surveillance study is, to the best of our knowledge, the first to use novel smartphone technology to assess PA in Ontario on a large scale. Our focus on a variety of population subgroups, particularly urban/rural and individuals living with chronic disease was also a strength of this study. By using daily step counts, we were able to complement existing PA surveillance literature and describe daily PA in several population subgroups. This new information, while not representative of Ontarians in general, may nonetheless increase understanding among public health decision makers, facilitating the targeting and tailoring of interventions for specific subsets of our population; namely females living with a chronic illness in rural parts of Ontario, Canada's most populous province.

4.7 *Funding and Conflict of Interest*

The author and project supervisors declare no conflict of interest. The author and project supervisors received no financial support for the research, writing, or publication of this thesis.

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Appendices

Appendix A: Health Sciences Research Ethics Board Application Approval Letter

Western Research

Date: 28 May 2019

To: Professor Marc Mitchell

Project ID: 113909

Study Title: Understanding Physical Activity Behaviour in Ontarian's Living with Chronic Disease

Application Type: HSREB Initial Application

Review Type: Delegated

Meeting Date / Full Board Reporting Date: 04/Jun/2019

Date Approval Issued: 28/May/2019

REB Approval Expiry Date: 28/May/2020

Dear Professor Marc Mitchell

The Western University Health Science Research Ethics Board (HSREB) has reviewed and approved the above mentioned study as described in the WREM application form, as of the HSREB Initial Approval Date noted above. This research study is to be conducted by the investigator noted above. All other required institutional approvals must also be obtained prior to the conduct of the study.

Documents Approved:

Document Name	Document Type	Document Date
Evaluation Quizzes - Carrot - Sheet1	Online Survey	28/Jun/2019
Privacy Policy - Carrot Insights Inc.	Written Consent/Assent	28/Jun/2019

Documents Acknowledged:

Document Name	Document Type
CIHI., 2006	References
Colley et al., 2011	References
Duncan et al., 2017	References
Hekler et al., 2015	References
Mitchell et al., 2017	References
Mitchell et al., 2018	References
Prince et al., 2008	References

No deviations from, or changes to, the protocol or WREM application should be initiated without prior written approval of an appropriate amendment from Western HSREB , except when necessary to eliminate immediate hazard(s) to study participants or when the change(s) involves only administrative or logistical aspects of the trial.

REB members involved in the research project do not participate in the review, discussion or decision.

The Western University HSREB operates in compliance with, and is constituted in accordance with, the requirements of the TriCouncil Policy Statement: Ethical Conduct for Research Involving Humans (TCPS 2); the International Conference on Harmonisation Good Clinical Practice Consolidated Guideline (ICH GCP); Part C, Division 5 of the Food and Drug Regulations; Part 4 of the Natural Health Products Regulations; Part 3 of the Medical Devices Regulations and the provisions of the Ontario Personal Health Information Protection Act (PHIPA 2004) and its applicable regulations. The HSREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000940.

Please do not hesitate to contact us if you have any questions.

Sincerely,

Daniel Wyzynski, Research Ethics Coordinator, on behalf of Dr. Joseph Gilbert, HSREB Chair

Note: This correspondence includes an electronic signature (validation and approval via an online system that is compliant with all regulations).

Appendix B: STROBE Checklist for Cross-sectional Studies

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract (pg. i)
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found (pg. ii)
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported (pg. 1-13)
Objectives	3	State specific objectives, including any prespecified hypotheses (pg. 13-14)
Methods		
Study design	4	Present key elements of study design early in the paper (pg. 15-17)
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection (pg. 15)
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants (pg. 16)
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable (pg. 21-23)
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group (pg. 16-24)
Bias	9	Describe any efforts to address potential sources of bias (pg. 16-17)
Study size	10	Explain how the study size was arrived at (pg. 18)
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why (pg. 20-23)
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding (pg. 23-25)
		(*b*) Describe any methods used to examine subgroups and interactions (pg.23-25)
		(*c*) Explain how missing data were addressed (N/A)
		(*d*) If applicable, describe analytical methods taking account of sampling strategy (N/A)
		(*e*) Describe any sensitivity analyses (N/A)
Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed (pg. 17-19)
		(b) Give reasons for non-participation at each stage (pg. 17-19)
		(c) Consider use of a flow diagram (pg. 19)
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders (pg. 26)
		(b) Indicate number of participants with missing data for each variable of interest (N/A)
Outcome data	15*	Report numbers of outcome events or summary measures (pg. 26-35, 67-77)
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included (pg. 26-35).
		(*b*) Report category boundaries when continuous variables were categorized (pg. 17)

		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period (N/A)
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses (pg. 26-35, 67, 71, 73)
Discussion		
Key results	18	Summarise key results with reference to study objectives (pg. 36-37)
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias (pg. 44-45)
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence (pg. 36-44)
Generalisability	21	Discuss the generalisability (external validity) of the study results (pg. 44)
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based (pg. 47)

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

Appendix C: Demographic Health Surveys

Health Survey 1: Please Stand Up

Question #	Question Statement	Response Options
1	Today, let's reflect. We're going to ask you a series of questions about your health that will help us share future information that best suits your lifestyle. Are you ready?	Introduction Statement
2	It's recommended that adults get at least 2.5 hours of moderate-to-vigorous physical activity each week. In the past 7 days, how much time did you spend on activities that made you breathe harder and sweat at least a little bit? (Only count activities that lasted 10 minutes or longer.)	a) Less than 60 min (not very active) b) Between 60 min and 2.5 hrs (fairly active) c) More than 2.5 hrs (very active)
3	Incorporating physical activity into your routine comes with many benefits including an increased fitness level. What area of your personal fitness would you like to improve the most over the next 6 months?	a) Endurance (brisk walk, jog, yard work, dancing) b) Strength (weight and/or resistance training) c) Flexibility (yoga, Pilates) d) Balance (fall prevention exercises, tai chi) e) I don't want to improve in any of these areas
4	Fruit and vegetables add color, texture, and flavour to your meal. Canada's Food Guide recommends that they fill 50% of your plate. How many times did you have fruit and vegetables yesterday?	a) 1 time b) 2 times c) 3 times d) 4 time e) 5 or more times

5	You are what you eat! What healthy eating behaviour would you like to implement the most within the next six months?	a) Portion control b) Meal preparation c) Incorporate more fruit and vegetables d) Reduce consumption of sugar-sweetened beverages e) Reduce consumption of pre-packaged foods f) Eat together with friends and/or family g) I don't want to implement any of these behaviours
6	Did you know that health is holistic? Mental well-being is a critical component of your overall health. In general, where would you place your mental health at the moment?	a) Excellent b) Very good c) Good d) Fair Poor e) Rather not say
7	Social factors like education and household income can also impact your overall sense of health and well-being. We're going to dive a little deeper to get a better understanding of who you are so we can offer you relevant health information.	Transition Prompt
8	Education is one of the most important tools at your disposal. Some go the traditional route and others forge their own path. What is the highest certificate, diploma or degree that you've completed?	a) Less than high school b) High school or equivalent c) Trade certificate d) College, CEGEP or other non-university certificate e) University certificate below bachelor's level Bachelor's degree (B.A., B.Sc., LL.B.)

		f) University degree above bachelor's level g) Don't know h) Rather not say
9	Let's talk money. What is your annual pre-tax household income?	a) Less than $20,000 b) Between $20,000 - $39,999 c) Between $40,000 - $59,999 d) Between $60,000 - $79,999 e) Between $80,000 - $99,999 f) Between $100,000 - $149,999 g) Over $150,000 h) Don't know i) Rather not say
10	Canada is one of the most multicultural countries in the world (and proudly so). Where on this green earth were you born?	a) In Canada b) Outside Canada: Arrived 2018 to present c) Outside Canada: Arrived 2012 to 2017 d) Outside Canada: Arrived 2006 to 2011 e) Outside Canada: Arrived 2005 or earlier f) Don't know g) Rather not say
11	Thanks for sharing. We look forward to guiding you along your wellness journey with content that matters to you.	Conclusion Statement

Health Survey 2: Our Burning Questions

Question #	Question Statement	Response Options
1	Today, we'll talk about your home, preferred methods of transportation, consumption habits, and immunization history. Sound a little random? These seemingly disparate topics overlap and influence your health in distinct ways. Let's get started!	Introduction Statement
2	Canadian communities run the gamut from cozy towns to large metropolitan cities. Which of these options best describes the area you live in?	a) Remote (0 to 10,000 people) b) Rural (10,001 to 40,000 people) c) Urban/Rural (40,001 to 190,000 people) d) Metropolitan (190,001+ people)
3	Do you currently own or rent the home that you live in?	a) I do not own or rent my home b) I own my home c) I rent my home
4	Do you currently own or lease a vehicle?	a) I do not own or lease a vehicle b) I own a vehicle c) I lease a vehicle
5	Active transportation is any form of human-powered transportation (like walking or cycling) that gets you to and from where you need to go. Did you use active transportation in the last 7 days (e.g. to school, work or the bus stop)?	a) Yes b) No
6	Do you currently smoke cigarettes?	a) Daily b) Occasionally c) Not at all

7	If you smoke, are you seriously considering quitting smoking in the next 6 months?	a) I do not smoke b) Yes c) No
8	After years of debate, cannabis consumption is now legal in Canada. Do you use cannabis?	a) Yes, for medical purposes b) Yes, for non-medical purposes c) No, I do not use cannabis d) Rather not say
9	Think back over the past week – how many alcoholic drinks did you consume in total? (Scroll and select all that apply)	a) None, zero, zilch b) 1 to 3 drinks during the past week c) 4 to 6 drinks during the past week d) 1 drink per day e) 2 drinks per day f) 3 drinks per day g) 4 drinks per day h) 5 or more drinks per day i) Rather not say
10	Let's talk flu. When was your last flu shot?	a) I've never had a flu shot b) Less than a year ago c) 1 to 2 years ago d) 2 years ago or more
11	Do you have any of the following chronic illnesses or conditions? These are conditions diagnosed by a health professional that are expected to last or have already lasted 6 months or more. (Scroll and select all that apply)	a) Anxiety or mood disorders b) Cancer c) Cardiovascular disease d) Chronic obstructive pulmonary disease (COPD) e) Type 2 diabetes f) Another chronic illness not listed here g) None of the above h) Rather not say

12	You did it! The information you provided will help us tailor your Carrot journey with information that's relevant to you.	Conclusion Statement

Appendix D: Overall Mean Daily Step Counts, Post Hoc Results

Post hoc analyses were performed with a Bonferroni adjustment and revealed that males took significantly more steps than females (764.58, 95% CI [597.20, 931.96], $p<.001$) and other (1154.25, 95% CI [516.93, 1791.58], $p<.001$). Post hoc testing was also performed with a Bonferroni adjustment for age and found that age brackets 20-24 (449.41, 95% CI [7.34, 891.49], $p=.041$), 25-29 (699.97, 95% CI [257.29, 1142.66], $p<.001$), 30-34 (676.52, 95% CI [208.58, 1144.46], $p<.001$), 35-39 (1008.48, 95% CI [519.58, 1497.38], $p<.001$), 40-44 (776.28, 95% CI [250.59, 1301.97], $p<.001$), 45-49 (972.04, 95% CI [418.57, 1525.51], $p<.001$), 50-54 (700.07, 95% CI [133.51, 1266.63], $p=.002$), and 55-59 (641.551, 95% CI [13.37, 1269.74] $p=.038$) age groups when compared to the youngest bracket, 13-19 years (M=4732.07, 95% CI [4533.91, 4930.23]). In addition, the 35-39 cohort had significantly more steps than the 20-24 (559.07, 95% CI [116.20, 1001.93], $p=.001$), 65-69 (1177.09, 95% CI [237.21, 2116.97], $p=.001$), and 70-74 (1660.86, 95% CI [119.80, 3201.91], $p=.018$) age brackets. The same significantly different groups were observed in the 45-49 as the 35-39 age bracket. The 45-49 age bracket also completed significantly more steps than the 20-24 (522.04, 95% CI [9.37, 1035.89], p=.040), 65-69 (1140.65, 95% CI [165.62, 2115.68], $p=.005$), and 70-74 (1624.42, 95% CI [61.67, 3187.16], $p=.030$) age brackets (see Appendix E).

Appendix E: Mean Daily Step Counts by Age Bracket

Group	*All*	*Healthy*	*Chronic Disease Diagnosis*	*Rural*	*Urban*
Age Cluster					
13-19	*M*=4732[a] *SE*=101.09 [4533.91, 4930.23][b] *n*=1211	*M*=4733[a] *SE*=146.27 [4446.21, 5019.63][b] *n*=576	*M*=4731[a] *SE*=139.29 [4458.29, 5004.37][b] *n*=635	*M*=4525[a] *SE*=357.26 [3824.93, 5225.52][b] *n*=97	*M*=4750[a] *SE*=105.42 [4543.44, 4956.73][b] *n*=1114
20-24	*M*=5181[a] *SE*=80.88 [5022.95, 5340.02][b] n=1892	*M*=5356[a] *SE*=115.21 [5129.73, 5581.40][b] *n*=928	*M*=5014[a] *SE*=113.04 [4792.33, 5235.49][b] *n*=964	*M*=4843.50[a] *SE*=313.46 [4229.06, 5457.94][b] *n*=126	*M*=5206[a] *SE*=83.73 [5041.48, 5369.72][b] *n*=1766
25-29	*M*=5432[a] *SE*=81.16 [5272.95, 5591.14][b] *n*=1879	*M*=5629[a] *SE*=106.306 [5420.30, 5837.05][b] *n*=1090	*M*=5160.30[a] *SE*=124.96 [4915.36, 5405.24][b] *n*=789	*M*=5623[a] *SE*=319.88 [4996.30, 6250.32][b] *n*=121	*M*=5419[a] *SE*=83.92 [5254.37, 5583.37][b] *n*=1758
30-34	*M*=5409[a] *SE*=92.520 [5227.23, 5589.94][b] *n*=1449	*M*=5606[a] *SE*=114.30 [5382.18, 5830.28][b] *n*=943	*M*=5038[a] *SE*=156.49 [4731.14, 5344.64][b] *n*=503	*M*=5038[a] *SE*=329.55 [4391.86, 5683.79][b] *n*=114	*M*=5440[a] *SE*=96.41 [5251.33, 5629.30][b] *n*=1132
35-39	*M*=5741[a] *SE*=101.39 [5541.81, 5939.29][b] *n*=1204	*M*=5900[a] *SE*=122.34 [5660.19, 6139.81][b] *n*=823	*M*=5396[a] *SE*=179.82 [5043.51, 5748.47][b] *n*=381	*M*=6071[a] *SE*=357.26 [5370.29, 6770.88][b] *n*=97	*M*=5712[a] *SE*=105.76 [5504.32, 5918.93][b] *n*=1107

40-44	*M*=5508[a] *SE*=116.11 [5280.75, 5735.95][b] *n*=918	*M*=5661[a] *SE*=134.89 [5396.39, 5925.20][b] *n*=677	*M*=5080[a] *SE*=226.08 [4637.04, 5523.35][b] *n*=241	*M*=5967[a] *SE*=345.03 [5290.69, 6643.33][b] *n*=104	*M*=5450[a] *SE*=123.33 [5208.02, 5691.49][b] *n*=814
45-49	*M*=5704[a] *SE*=126.70 [5455.76, 5952.47][b] *n*=771	*M*=5903[a] *SE*=146.11 [5616.12, 6188.93][b] *n*=577	*M*=5114[a] *SE*=252.02 [4619.82, 5607.83][b] *n*=194	*M*=5813[a] *SE*=381.64 [5065.29, 6561.46][b] *n*=85	*M*=5691[a] *SE*=134.34 [5427.23, 5953.90][b] *n*=686
50-54	*M*=5432[a] *SE*=131.57 [5174.24, 5690.04][b] *n*=715	*M*=5591[a] *SE*=152.60 [5291.68, 5889.92][b] *n*=529	*M*=4981[a] *SE*=257.35 [4476.69, 5485.58][b] *n*=186	*M*=5706[a] *SE*=401.02 [4919.96, 6492.09][b] *n*=77	*M*=5399[a] *SE*=139.31 [5126.02, 5672.17][b] *n*=638
55-59	*M*=5374[a] *SE*=153.71 [5072.33, 5674.92][b] *n*=524	*M*=5661[a] *SE*=179.83 [5308.46, 6013.46][b] *n*=381	*M*=4609[a] *SE*=293.51 [4033.37, 5184.03][b] *n*=143	*M*=5674[a] *SE*=474.45 [4744.25, 6604.26][b] *n*=55	*M*=5338[a] *SE*=162.50 [5019.88, 5656.92][b] *n*=469
60-64	*M*=5458[a] SE=197.60 [5070.40, 5845.05][b] *n*=317	*M*=5884[a] *SE*=228.95 [5435.14, 6332.72][b] *n*=235	*M*=4236.60[a] *SE*=387.58 [3476.87, 4996.33][b] *n*=82	*M*=6110[a] *SE*= 513.24 [5104.04, 7116.11][b] *n*=47	*M*=5344[a] *SE*= 214.14 [4924.43, 5763.93][b] n=270
65-69	*M*=4563[a] *SE*=255.90 [4061.86, 5065.07][b] *n*=189	*M*=4607[a] *SE*=310.22 [3999.06, 5215.22][b] *n*=128	*M*=4472[a] *SE*=449.38 [3591.07, 5352.78][b] *n*=61	*M*=4812[a] *SE*= 733.72 [3373.92, 6250.35][b] *n*=23	*M*=4529[a] *SE*= 273.094 [3993.70, 5064.32][b] *n*=166
70-74	*M*=4080[a] *SE*=439.77 [3217.67, 4941.72][b] *n*=64	*M*=4083[a] *SE*=529.11 [3045.97, 5120.27][b] *n*=44	*M*=4073[a] *SE*=784.87 [2534.52, 5611.48][b] *n*=20	*M*=3488[a] *SE*= 1759.31 [38.97, 6936.08][b] *n*=4	*M*= 4119[a] *SE*= 454.27 [3228.76, 5009.67][b] *n*=60

75+	*M*=4555[a] *SE*=621.97 [3335.80, 5774.15][b] *n*=32	*M*=4600[a] *SE*=716.49 [3195.91, 6004.78][b] *n*=24	*M*=4421[a] *SE*=1240.89 [1988.82, 6853.53][b] *n*=8	*M*=4711[a] *SE*= 2031.66 [728.81, 8693.65][b] *n*=3	*M*=4539[a] *SE*= 653.52 [3257.89 5819.91][b] *n*=29

a. Adjusted for effect of date.
b. 95% confidence interval.

Appendix F: Mean Daily Step Counts for Users With and Without a Chronic Disease Diagnosis, Post Hoc Results

Males with and without chronic disease walked significantly more steps than females (972, 95% CI [699.25, 1244.11], *p*<.001), and other (1376, 95% CI [390.09, 2361.90], *p*=.003), females (637, 95% CI [426.16, 848.46], p<.001), other (971, 95% CI [139.56, 1802.34], *p*=.016) (with and without, respectively). In addition, males who self-reported a chronic disease diagnosis had significantly fewer steps than those who were healthy (325.18, 95% CI [136.76, 631.06], *p*=.005). Females who self-reported a chronic disease also had significantly fewer steps than those who were healthy (659.55, 95% CI [491.03, 828.06], *p*<.001; Table 3).

Appendix G: Mean Daily Step Counts for Chronic Disease Status and Rural/Urban Status

Rural/Urban Status	Chronic Disease Status	
	With	Without
Urban	M=5011[a] SE=56.64 [4899.81, 5121.87][b] n=3896	M=5529[a] SE=44.18 [5442.00, 5615.23][b] n=6427
Rural	M=4887[a] SE=189.52 [4515.00, 5258.00][b] n=348	M=5755[a] SE=142.76 [5475.20, 6034.87][b] n=615

a. Adjusted for effect of date.
b. 95% confidence interval

Appendix H: Two-way Analyses of Rural/urban Status by Chronic Disease Status on Mean Daily Step Counts, Post Hoc Results

Urban-dwelling individuals without a chronic disease completed significantly more steps (517.78, 95% CI [376.96, 658.60], $p<.001$) than their urban counterparts self-reporting a chronic disease. Rural-dwelling individuals without a chronic disease also completed significantly more steps than those self-reporting a chronic disease (868.53, 95% CI [403.41, 1333.66], $p<.001$) (Appendix G).

Appendix I: Describing Regions of Ontario by Forward Sortation Area

Forward Sortation Area Code (FSA)	Mean Daily Step Count	Mean Age	Chronic Disease Incidence (%)	Gender Distribution (Female %)	Education Level Bachelor + (%)	Household Income < 60K (%)
FSA Rank Based on Mean Daily Step Count						
N0G	M=6385[a] SE=633.19 [5144.12, 7626.46][b]	M=35.84 SD=12.93	32.3	71.0	20.0	40.7
M5V	M=6360[a] SE=344.02 [5686.14, 7034.84][b]	M=32.87 SD=9.57	29.5	62.9	62.2	26.3
L4N	M= 6129[a] SE=371.59 [5400.31, 6857.06][b]	M=36.58 SD=12.24	35.6	65.6	24.7	42.5
K0K	M=6106[a] SE=447.76 [5228.78, 6984.14][b]	M=36.97 SD=14.05	35.5	67.7	11.5	62.7
N0B	M=5895[a]	M=38.62	36.2	74.5	29.5	26.8

	SE=514.20 [4887.39, 6903.24][b]	SD=13.98				
L0R	M=5799[a] SE=430.75 [4954.42, 6643.11][b]	M=35.37 SD=13.42	31.3	79.1	21.2	35.6
L0M	M=5737[a] SE=623.30 [4515.21, 6958.79][b]	M=37.22 SD=13.04	37.5	59.4	19.4	26.9
P0M	M=5421[a] SE=613.67 [4217.60, 6623.40][b]	M=35.82 SD=12.60	27.3	81.8	25.0	38.7
M2N	M=5403[a] SE=389.30 [4639.96, 6166.17][b]	M=35.70 SD=12.23	36.6	57.3	60.8	44.1
M2J	M=5244[a] SE=377.96 [4503.48, 5985.21][b]	M=33.40 SD=12.48	37.9	62.0	42.9	49.3
K0E	M=5142[a] SE=691.35 [3787.13, 6497.45][b]	M=32.88 SD=13.26	50.0	69.2	16.0	36.4

L6Y	M=5097[a] SE=309.19 [4490.55, 5702.69][b]	M=27.15 SD=10.25	51.5	50.0	25.0	56.4
K1A	M=5053[a] SE=211.51 [4638.33, 5467.52][b]	M=39.62 SD=11.39	30.0	68.2	50.5	15.7
K0L	M=4955[a] SE=525.50 [3925.41, 5985.57][b]	M=37.24 SD=15.52	31.1	71.1	13.3	33.3
M1B	M=4844[a] SE=377.96 [4102.90, 5584.64][b]	M=31.52 SD=14.68	44.8	63.2	23.5	63.4
K0A	M=4829[a] SE=479.83 [3888.76, 5769.85][b]	M=39.74 SD=13.29	31.5	77.8	44.2	23.3
L6R	M=4813[a] SE=382.43 [4063.04, 5562.28][b]	M=29.73 SD=11.10	47.1	52.9	31.7	56.9
N0M	M=4804[a]	M=40.08	38.9	72.2	31.4	35.7

	SE=587.53 [3652.50, 5955.83][b]	SD=16.90				
L6C	M=4611[a] SE=380.16 [3865.89, 5356.27][b]	M=41.17 SD=16.73	24.4	52.3	40.2	40.0
L5M	M=4490[a] SE=354.32 [3795.91, 5184.95][b]	M=33.89 SD=14.92	29.3	60.6	39.6	44.8
K0H	M=4410[a] SE=666.31 [3104.42, 5716.57][b]	M=44.07 SD=15.17	39.3	82.1	14.8	54.2
K0C	M=4364[a] SE=550.59 [3284.95, 5443.46][b]	M=36.15 SD=10.64	31.7	75.6	15.0	58.8
L3R	M=4230[a] SE=380.13 [3554.78, 5045.02][b]	M=37.80 SD=16.73	36.0	62.8	37.3	51.4

Forward Sortation Area’s with a ‘0’ in the second digit position are considered rural.

a. Adjusted for effect of date.
b. 95% confidence interval.

Curriculum Vitae

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Abstract Publication: McHugh, D., Wilk, P., Stranges, S., Prapavessis, H., Mitchell, M. (2020). Understanding Physical Activity Behaviour in Canadians Living with Chronic Disease: A Retrospective Cohort Study. *Medicine & Science in Sports & Exercise*. 52(7S), 419-420.

Poster Presentation (cancelled): "Understanding Physical Activity Behaviour in Canadians Living with Chronic Disease: A Retrospective Cohort Study"
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