Physiological Responses to Pedal-Assist E-bike Use in Older Adults

by

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The above committee determined that the thesis is acceptable in form and content and that a satisfactory knowledge of the field covered by the thesis was demonstrated by the candidate during an oral examination. A signed copy of the Certificate of Approval is available from the School of Graduate and Postdoctoral Studies.

ABSTRACT

Pedal-assist electric bicycles (pedelecs) have been found to elicit moderate-to-vigorous intensity physical activity (MVPA) in younger adults, however, it is unknown if pedelec riding elicits MVPA in older adults or if loading the pedelec changes the level of e-assist used, and thus the intensity of the activity completed. Participants (n=21, mean age 70.1 ± 5.1) completed a maximal exercise test followed by two 6.25km outdoor pedelec rides at a self-selected comfortable pace, once with 20kg of load added and once without, in random order. Nearly all participants (19/21) achieved a mean intensity of MVPA. Mean intensity from unloaded and loaded rides was 76% HRmax and 75% HRmax, respectively. No differences were observed when comparing HRavg, HRpeak, POavg or POpeak between unloaded and loaded pedelec rides. Older adults self-select at least MVPA while riding pedelecs on a closed course. The added load did not change the intensity of pedelec riding.

Keywords: aging; physical activity; e-bike(s); pedelec(s); exercise intensity

AUTHOR'S DECLARATION

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________________________________ Michael Jenkins

STATEMENT OF CONTRIBUTIONS

The manuscript included in Chapter 3 was performed in the Human Performance Laboratory and the Office of Campus Infrastructure and Sustainability at Ontario Tech University, and will be submitted for publication. Co-authors of the manuscript include Dr. Shilpa Dogra, Nicholas O'rourke, and Lucio Lustosa. Data collection was conducted by myself with the assistance of Nicholas O'rourke and Lucio Lustosa. Dr. Shilpa Dogra provided guidance as I, the first author, performed all data synthesis, statistical analyses, primary interpretations and writing of results.

I hereby certify that I am the sole author of this thesis and that no part of this thesis has been published or submitted for publication. I have used standard referencing practices to acknowledge ideas, research techniques, or other materials that belong to others.

DEDICATION

To Aunt Theresa, in loving memory.

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LIST OF ABBREVIATIONS

MVPA	Moderate-to-Vigorous Physical Activity
PO	Power Output
PPO	Peak Power Output
CO	Cardiac Output
Ca	Arterial Oxygen Content
Cv	Venous Oxygen Content
HR	Heart Rate
RPE	Rating of Perceived Exertion
RPM	Revolutions Per Minute

CHAPTER 1. INTRODUCTION

1.1 INTRODUCTION

Regular physical activity has long been associated with a number of positive health effects across all ages. More specifically, in older adults, regular physical activity can reduce the risk of developing major chronic diseases, cognitive impairments, muscular weakness, and premature death (McPhee et al., 2016; Warburton, Nicol & Bredin, 2006). In spite of these health benefits, only 15% of Canadians aged 60-79 years are currently achieving minimum recommendations for weekly physical activity (Macridis et al., 2020).

As of 2019, 9.5 million Canadians are aged 60 years and older (Statistics Canada, 2019). This demographic is more commonly known as baby boomers. Due to the large baby boomer generation, the number of adults aged 65 years and older is expected to continue to grow in the coming years (Statistics Canada, 2019). Current population predictions suggest that the estimated percentage of Canadians over the age of 65 will be as high as 23 percent by 2030. This growing demographic is also experiencing increasingly high levels of inactivity (Macridis et al., 2020). This will likely result in increased hospitalizations and prevalence of chronic disease among older adults (World Health Organization, 2015).

Increasing physical activity levels through traditional means such a gym membership or exercise classes has been ineffective given current activity levels (Warburton et al., 2010). In fact, despite 68% of older adults indicating a strong intention to be physically active, 85% of older adults continue to fail to meet weekly physical activity recommendations (Macridis et al., 2020). Therefore, novel solutions for increasing the physical activity of Canadians are needed. In recent years, Health Canada has recommended active transportation, such as cycling, to help Canadians achieve the recommended amount of weekly physical activity (Statistics Canada, 2019). By using modes of active transportation, Canadians can more easily integrate an increase of physical activity into their day. However, one of the commonly reported barriers to using cycling as a viable form of active transportation is the increased exertion caused by the added weight of carrying items such as groceries or items of daily living (Fishman & Cherry, 2016).

Pedal assist e-bikes (pedelecs) have been generally proposed as a tool to increase active transportation in older adults as pedelecs have been shown to reduce physical exertion while still providing a moderate intensity of exercise in younger adults (Bourne et al., 2018; Gojanovic et al., 2011; Lakatta, 2002). However, it remains unclear if the assistance provided by a pedelec can remove the barrier of added weight. Thus, the focus of this thesis is to determine whether the intensity of riding a pedelec with added weight differs from unweighted riding and whether this constitutes moderate physical activity in older adults.

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CHAPTER 2: LITERATURE REVIEW

LITERATURE REVIEW

The following literature review will provide an overview of the aging population as well as the context of physical activity in this age group before reviewing contemporary evidence on pedelec use and exercise physiology in older adults. The goal of this review is to provide a comprehensive context to aid the reader in understanding the need to address the following research questions:

1. What intensity of physical activity are older adults engaging in when they self-select pedelec assistance during a 6.25km ride?
2. Does adding 20kg to a pedelec change the level of e-assist used or the intensity of physical activity in older adult users while riding the same 6.25km route?

2.1 AGING DEMOGRAPHICS

The world's population is facing a massive shift in demographics. As average global fertility rates continue to decline and age expectancy continues to increase, older adults make up an increasingly larger proportion of the world's population (WHO, 2011). Globally, adults aged 65 years and older already represent the fastest growing demographic. Importantly, Canada, along with several western nations, is experiencing some of the largest proportional shifts in demographics (United Nations, 2015). In Canada, historically, children have always outnumbered those aged 65 years or older. However, in 2016, Canadian older adults began to outnumber children. Moreover, the proportion of older adults is expected to continue to grow in the coming decades (Statistics Canada, 2020).

This growth in the older adult population is significant due to the many age-associated physiological changes, and how those changes impact the health of older adults. These age-associated physiologic changes can result in increased risk of conditions such as frailty and cognitive impairment (Lewsey et al., 2020). This can lead to increased hospitalization rates in older adults (Chang et al., 2018).

Although, many changes are unavoidable, the rate at which they occur is highly dependent on certain lifestyle choices. Regular physical activity is considered perhaps one of the most impactful lifestyle choices on the rate of age-related physiologic decline (Hughes et al., 2001).

Summary: In the coming decades, the global proportion of older adults is expected to continue to grow dramatically. As the number of older adults continues to grow, so too does the need to address some of the concerning trends related to their health and levels of physical activity.

2.2 ACTIVITY LEVELS OF OLDER ADULTS

The Canadian 24-hour Movement Guidelines recommend that each week older adults accumulate a minimum of 150 minutes of ***moderate-to-vigorous physical activity (MVPA)*** in addition to strength training at least twice per week and several hours of light physical activity to achieve exercise associated health benefits (Ross et al., 2020). These new guidelines are the latest in a series of updates from Canadian Society for Exercise Physiology who introduced the first evidence-informed physical activity guides for older adults in 1999 (Health Canada & CSEP, 1999). The original 1999 guide was based on a growing body of evidence which found increased leisure activity and exercise frequency were associated with positive health outcomes

(Shephard & Bouchard, 1996). In the 1999 guide, older adults defined then as 55+, were encouraged to accumulate 30-60 minutes of moderate physical activity in 10-minute segments, 4-7 day per weeks. Moderate intensity exercises were not specifically defined, however, exercises that make the person feel warm and breathe deeply were encouraged. The guide also recommended that older adults select a variety of physical and daily activities from three groups; strength and balance, endurance, and flexibility. The provided examples of suitable activities included walking, cleaning shelves in the kitchen, and lifting soup cans, among others.

In 2011, CSEP released new guidelines based on updated evidence and a growing body of research on health and physical activity (Paterson et al., 2007; Tremblay et al., 2011). Significant changes were included in the 2011 guidelines, which for the older adult population, included a shift to 65+ from the original 55+ age classification. Further changes included, a simplification of the previous exercise guidelines. The 2011 guidelines focus on 150 minutes of weekly MVPA in a minimum of 10-minute sessions as well as strength training twice per week (Tremblay et al., 2011).

In 2020, CSEP released the first 24-hour movement guidelines for older adults. These guidelines included a shift to focus on the movement behaviors of older adults throughout the whole day and encourage replacing sedentary time with more movement. These guidelines were informed by new evidence which suggests that increased combined movement over 24hours, including light physical activity, have positive health effects (McGregor et al., 2018). The 24h movement guidelines also remove the 10-minute minimum for bouts of MVPA, with emerging evidence suggesting that bouts of MVPA in any duration are associated with positive health outcomes (Jakicic et al., 2018).

Moderate intensity physical activity can be defined as physical activity which causes an increase in heart rate and harder breathing whereas vigorous physical activity causes a more substantial increase in heart rate and breathing in which persons are unlikely to complete full sentences without catching their breath. For MVPA, a heart rate equivalent to 40-90% of an individual's heart rate reserve is needed. For example, in a 60-year-old male with a resting heart rate of 65 beats per minute (bpm) a heart rate range during physical activity from 103-150bpm would represent MVPA. Importantly, these recommendations are supported by strong scientific evidence. A scientific report by the US Physical Activity Guidelines Advisory Committee (2018) examined the evidence supporting these recommendations. A total of 195 reports were reviewed and significant evidence to support the inverse dose-response relationship suggested by the guidelines between physical activity and all-cause mortality. Further, this evidence has recently been supported by the World Health Organization's updated 2020 guidelines (Bull et al., 2020).

The majority of Canadian adults are well aware of the importance of regular physical activity and the associated positive health outcomes (Macridis et al., 2020). However, in spite of the overwhelming evidence and public knowledge, the majority of Canadian adults fail to meet the minimum recommended 150 minutes of MVPA each week based on device measured data (Statistics Canada, 2019). According to the 2019 ParticipACTION report card, just 16% of Canadians aged 18 to 79 are meeting the minimum weekly MVPA, down from 18% in 2015 (Statistics Canada, 2015). Furthermore, 19% of adults aged 50-64 years old and only 15% of 60-79 years old are achieving at least 150 minutes of weekly MVPA (Macridis et al., 2020).

In spite of this, there is a desire to become more physically active. In a study by the Canadian Fitness and Lifestyle Research Institute (CFLRL) (2015) phone interviews were conducted as part of a national physical activity monitoring program. The interviews collected responses from participants across Canada and consisted of various questions relating to the factors which influenced their physical activity and their intentions to become more active. They found that 68% of adults 65 years and older reported having strong intentions of becoming physically active in the next 6 months despite being currently inactive. These findings suggest that further research is needed to better understand any barriers that older adults face when considering increasing their amount of physical activity.

Physical activity can be achieved through many different means. Traditional activities such as gym memberships and organized workout classes can offer great health and social benefits. However, other forms of physical activity such as recreation (leisure activities) and transportation (walking/cycling) can also offer similar benefits (Mueller et al., 2015; Prince et al., 2019; Groessl et al., 2019).

Summary: Regular physical activity is associated with the reduced risk of chronic disease and all-cause mortality. Although older adults are aware of the benefits of physical activity, physical activity levels remain suboptimal in all domains of physical activity, including transportation.

2.2.1 ACTIVE TRANSPORTATION

To increase physical activity, Health Canada recommends Canadians consider using modes of active transportation such as cycling as an alternative to cars or buses (Health Canada, 2014). Previous research has found that integrating physical activity into the daily schedule by using active transportation is an effective means of increasing physical activity levels (Shephard, 2012; Mueller et al., 2015). When physical activity is integrated into the day via active transportation, the need for structured programs and dedicated time for physical activity is reduced. This may allow for older adults to increase their physical activity without the need to find time in their day to be physically active, thereby addressing time related barriers to increasing physical activity.

Every day, over 15million Canadians commute to work, 80% of which use a private vehicle to commute. In metropolitan areas, which account for 82% of Canada's population, this is increased further to 90% of commuters. Currently over 90% daily trips in personal vehicles include the driver alone. In older adults, nearly 80% reported driving as their main form of transportation (Turcotte, 2012). Notably, nearly 50% percent of these trips are under 5km and 75% of trips are under 10km (Statistics Canada, 2019). At present, less than 2% percent of daily trips under 5km in Canada are done by bicycle, however, in Denmark, Netherlands and Germany respectively 24%, 37% and 11% of trips under 5km are done by bicycle. Importantly, cycling remains a popular transportation choice among the older adults in these countries where cycling represents 24% percent of total trips taken by older adults in the Netherlands and 12% percent in both Denmark and Germany (Pucher and Buehler, 2008).

Recent research has suggested that in many Canadian cities, older adults are not choosing to cycle and are instead opting to use personal vehicles. A study by Winters et al. (2015) found that even in a highly bikeable neighborhood in Vancouver which boasts one of the best cycling networks in Canada, only 3% of trips by older adults were taken using a bike. In Toronto, 90% of cycling trips are taken by those who are under the age of 60, and in Montreal this numbers is 80% (Statistics Canada, 2011). These findings suggest that in countries where cycling is a popular transportation choice, a large portion of older adults integrate cycling into their day. However, in countries such as Canada where cycling is relatively unpopular, likely due to lack of infrastructure and other environmental barriers, older adults are far less likely to use cycling as a form of transportation (Winters et al., 2015; Shephard, 2008).

Increasing the use of cycling for transportation among the general population is a complex task and requires the collaboration of municipal, regional, and provincial stakeholders. In the older adult population, this task requires additional considerations as older adults can be faced with further barriers to cycling for transportation. The most commonly reported barriers faced by older adults are distance, effort, topography, safety, travel time, and added weight (Heinen, van Wee and Maat, 2010; Manaugh, Boisjoly, & El-Geneidy, 2017). Socio-economic and demographic factors have also been found to influence the choice of cycling as a mode of transportation (Kaczynski, Bopp, & Wittman, 2010). Further, in a study by Klicnik and Dogra (2019), the perspectives on active transportation in a mid-sized age-friendly city were assessed using focus group interviews. Community dwelling older adults (n=52) reported functional fitness, health and urban design among others as constraints to their use of active transportation. This finding suggests that even in a city considered age-friendly, older adults are faced with considerable barriers to using forms of active transportation. Furthermore, they may not view standard forms of active transportation such as walking and cycling as a viable alternative to cars without addressing barriers.

Summary: Active transportation modes such as cycling increase daily physical activity levels. Cycling remains a popular choice of transportation in several European countries, particularly in the older adult population. However, cycling remains relatively unpopular in Canada due to barriers such as distance, physical fitness, and functionality of infrastructure.

2.3 AGE RELATED PHYSIOLOGIAL CHANGES

Aging is associated with wide ranging degenerative changes to the body's physiological processes. These changes are marked by decreased function across all organ systems, which can lead to impaired function in otherwise healthy older adults. Importantly, age-related physiological changes lead to functional changes that affect exercise capacity and exercise responses.

In the ***cardiovascular system***, aging is associated with gradual degenerative structural and functional changes. More specifically, the structural degeneration includes increased arterial stiffness, increased left ventricular wall thickness, and increased left atrial size (Strait & Lakatta, 2012; ACSM, 2009). Increased arterial stiffness is of particular importance as it increases the systemic vascular resistance, thus reducing the coronary filling pressure and increasing the left ventricular oxygen requirement. Increased left ventricular wall thickness is closely linked to the reduction of early diastolic filling, which results in a reduction in the left ventricular end diastolic volume. End-diastolic volume is the volume of blood immediately prior to systolic contraction, thus it has a direct effect on the stroke volume of each heart beat (Dai et al., 2015). This causes increased left ventricular pressure to maintain cardiac output, and thus impacts exercise capacity.

The related functional changes to the cardiovascular system include the general degeneration of the conduction system and decline in endothelial function among others (Izzo et al., 2018). Combined, the age-associated structural and functional changes to the cardiovascular system leads to decreased aerobic capacity and cardiac regulation (Lakatta, 2002). As a result, aging leads to a reduction in maximal oxygen consumption (VO_2max) and maximal heart rate (HRmax). This leads to a decrease in exercise tolerance and blunted cardiac response to exercise when compared to a younger adult population. These age-related degenerative changes in the cardiovascular system can cause compounding issues, leading to the decreased mobility of older adults (Welmer et al., 2013). As the exercise tolerance of older adults decreases, it becomes increasingly difficult to prevent further physiological decline and maintain physical activity levels (Brawley et al., 2003; Lin et al., 2016). When physical activity is reduced, cardiovascular fitness deteriorates leading to further reductions in exercise tolerance. As this cycle continues, cardiovascular fitness can deteriorate to the point where mobility is reduced.

In the ***musculoskeletal system***, aging in otherwise healthy adults is marked by physiologic changes including the reduction in the amount type I and type II muscle fibers, along with a reduction in muscle cell size (Williams et al., 2002; Wilkinson et al., 2018). This reduction can be measured by the reduction in the cross-sectional area of skeletal muscles, which is known as atrophy. This atrophy of the cross-sectional area of skeletal muscle reduces the force-generating capacity of a given muscle resulting in reduced overall strength (Frontera et al., 2000). Age-related atrophy can be seen in the marked reduction of ***power output (PO)*** in muscle strength testing measured during jump tests and PO on cycle ergometers (Runge et al., 2004; Macaluso and De Vito, 2004; Peiffer et al., 2006).

2.4 EXERCISE RESPONSES

VO_2max, which is a measure of the cardiovascular system's ability to uptake and utilize oxygen during exercise, is greatly compromised by age related physiological changes. The greater the volume of oxygen utilized, the greater the ability to tolerate higher intensities of exercise. VO_2max is determined by the volume of oxygen delivered to the muscles minus the volume of oxygen returned (Lundby, 2016), and can be described using the *Fick equation* below, where heart rate (HR) and stroke volume (SV) represent cardiac output, and arterial oxygen content (*aO_2*) and venous oxygen content (*v*O_2) represent the arterial-venous oxygen difference.

$$VO_2max = (HR \times SV) \times (a\text{-}v)O_2diff$$

The age-related physiologic changes previously mentioned result in a decreased cardiac output as a result of a decreased maximal heart rate and stroke volume (Izzo et al., 2018). The age-related decrease in cardiac output results in a decrease in VO_2 max as age increases; importantly, a reduction of 10% per decade may occur regardless of activity levels (Hawkins & Wiswell, 2003)

In older adults, exercise tolerance is reduced as a result of several factors. The primary factor is an increase in ventilatory mechanical constraints such as those outlined above. However, sex differences also exist in exercise responses, such that males typically experience greater exercise capacity when compared to their female counterparts. This can be explained by the comparatively smaller stroke volume of females (DeLorey & Babb, 1999). This difference in stroke volume allows males to tolerate greater workloads at a lower heart rate as result of greater cardiovascular capacity. In females, increases in heart rate and greater peripheral extraction of oxygen can compensate for reduced stroke volume up to a certain point. However, when increases in heart rate can no longer compensate for reduced stroke volume, the physiologic response to increased workload is blunted (Wheatley et al., 2014). This blunted response results in decreased exercise capacity compared to males, even when adjusted for height and weight.

As mentioned in *Section 2.2*, regular MVPA is associated with several health benefits. Given that aging is associated with altered physiological responses to exercise (see *Section 2.4*), what constitutes MVPA must be clearly defined. Across all activities, a heart rate of 64% to 93% of a person's maximal heart rate is defined as moderate-to-vigorous intensity physical activity

(Roy, 2015). In cycling, the intensity of physical activity can be accurately defined using both heart rate and power output. The following table summarizes previous studies in which heart rate and power output were used to quantify moderate intensity physical activity in older adult males and females.

Table 2. *Summary of Physiological Parameters during Maximal Exercise Tests and Moderate Intensity Exercise on Cycle Ergometer in Older Adults. (MOD - Moderate Intensity; RPE – Rating of Perceived Exertion)*

Study	Population/Age group	Physiological Parameters	Conclusions	Other Relevant Information
Peiffer, J. J., Abbiss, C. R., Chapman, D., Laursen, P. B., & Parker, D. L. (2008)	Male masters-level cyclists (n=32) Age ranges: 35-44y (n=14) (39±3) 45-54y (n=10) (49±3) 55+ (n=8) (65±4)	VO_{2max}, Peak Power Output (PPO), HR_{max}, First Ventilatory Threshold (VT_1), Second Ventilatory Threshold (VT_2)	-Significant declines in VO_{2max}, PPO, and HR_{max} with increased age. -Significantly lower relative VO_{2max} and PPO in 55+ group compared to 35-44y and 45-54y groups. -10% per decade reduction in aerobic capacity. - 55+ group values: relative VO_{2max} 45.89 ± 4.61, PPO 324 ± 51, PPO($W·kg^{-1}$) 4.25 ± 0.41, and HR_{max} 160 ± 14.	-Graded exercise test on cycle ergometer. -Start at 70W increasing by $35W·min^{-1}$ until no longer able to maintain 60rpm. -Normal preferred cadence.
Brown, S. J., Ryan, H. J., & Brown, J. A. (2007)	Endurance trained cyclists (n=56) (20 female, 36 male) Age range: 17-64yr Male (42.1 ± 10.7) Female (37.7 ± 11.9)	VO_{2max}, PPO, HR_{max}, Power Output (PO) at La^-_{4mmol}	-Age-associated decline in males ($0.65ml·kg^{-1}·min^{-1}·year^{-1}$) and females ($0.39ml·kg^{-1}·min^{-1}·year^{-1}$). -Negative correlation between age and HR_{max} in males, but not in females. -Negative correlation between age and PPO in males, but not in females.	-Continuous incremental test until volitional exhaustion. Starting PO was set to PO achieved at 4.5mmol of Lactate in previous testing. -PO increased by $20W·min^{-1}$. -Normal preferred cadence.
Andersson, E. A., Lundahl, G., Wecke, L., Lindblom, I., & Nilsson, J. (2011)	Habitually active ($2·week^{-1}$) and apparently health younger and older adults. Older adults (n=23) (64-79years) Younger adults (n=21) (20-32years)	VO_{2max}, PPO, HR_{max}, RPE (Borg Scale)	-Older female relative VO_{2max} 22.9 ± 2.0 $ml·kg^{-1}·min^{-1}$ (19.5–26.5). -Older male relative VO_{2max} 26.884.6 $ml·kg^{-1}·min^{-1}$ (18.8–32.7). -Older female and male PPO were 112 ± 20W and 181 ± 36 respectively. -HR_{max} was 155 ± 9 and 165 ± 11 for older females and males respectively.	-Step wise test beginning at 74W for older adults with resistance increased by $25W·min^{-1}$.

González-Bartholin, R., Mackay, K., Valladares, D., Zbinden-Foncea, H., Nosaka, K., & Peñailillo, L. (2019)	Healthy physically active older adults (n=10) (2 women and 8 men) Mean Age: 60.4 ± 6.8 (51-73)	VO_{2peak}, PPO, HR_{max}, RPE (Borg Scale)	- VO_{2peak} 25.8 ± 6.5 ml·kg^{-1}·min^{-1} - PPO 197.3 ± 66.1W.	-Incremental maximal exercise test on cycle ergometer beginning at 50W and 20W·min^{-1} until volitional exhaustion or unable to maintain 60rpm.
Linares, A. M., Goncin, N., Stuckey, M., Burgomaster, K. A., & Dogra, S. (2020)	Healthy older adults (n=30) (15 women, 15 men) Mean Age: men 70.2±6.0 Women 69.0 ± 6.6	VO_{2max}, PPO, HR_{max}, RPE (Borg Scale)	-HR_{avg} during moderate intensity continuous exercise (MOD) while cycling 125.1 ± 14.5 (women) and 123.3 ± 19.5 (men). -PO during MOD cycling 73.1 ± 15.5 (women) and 109.5 ± 26.4 (men).	-PO for MOD cycling was set to 50% of PPO as measured from incremental maximal exercise test.
Klonizakis, M., Moss, J., Gilbert, S., Broom, D., Foster, J., & Tew, G. A. (2014)	Post-menopausal women (n=22) Mean Age: 64 ± 4years	VO_{2peak}, HR_{max}, RPE (Borg Scale)	-Mean PO for MOD 82 ± 13W. -HR after 5mins of MOD cycling 128 ± 10bpm (79 ± 6% of HR_{max}). -HR after 40mins of MOD cycling 143 ± 9bpm (88 ± 5% of HR_{max}) . -VO_{2peak} 25.0 ±7.4 ml·kg^{-1}·min^{-1}. -HR_{peak} 158 ± 6 bpm.	-PO for MOD cycling was set to 65% of PPO from incremental maximal exercise test on cycle ergometer. -Resistance on cycle ergometer increased by 15W·min^{-1} from 0W until volitional exhaustion.
O'Brien, M. W., Johns, J. A., Robinson, S. A., Bungay, A., Mekary, S., & Kimmerly, D. S. (2020)	Healthy older adults (n=12) (8 female, 4 male) Mean Age: 68 ± 6 years	VO_{2max}, HR_{max}, PPO	- VO_{2max} 23 ± 4 ml·kg^{-1}·min^{-1}. -PPO 150 ± 36W. -HR_{peak} 156 ± 7 bpm.	-PO for MOD cycling was set to 60% PPO from incremental maximal exercise test on cycle ergometer. -Resistance on cycle ergometer increased by 15W·min^{-1} from 1W·kg^{-1} until volitional exhaustion.
Strasser, B., Keinrad, M., Haber, P., & Schobersberger, W. (2009)	Healthy older adults (n=13) Mean Age: 76±5 years	VO_{2max}, HR_{max}, W_{max}/kg	- VO_{2max} 18.59±5.30 ml·kg^{-1}·min^{-1}. - W_{max}/kg 1.06±0.29. - HR_{peak} 131.5 ± 20.5 bpm.	-PO for MOD cycling was set to 60% PPO from incremental maximal exercise test on cycle ergometer. -Resistance on cycle ergometer increased by 10W·min^{-1} from 20W until volitional exhaustion.

Lovell, D. I., Cuneo, R., & Gass, G. C. (2010)	Healthy moderately active older adult men. (n=12)	VO_{2max}, HR_{max}, PPO	- VO_{2max} 22.6 ± 0.7 $ml \cdot kg^{-1} \cdot min^{-1}$. -PPO 144 ± 5W. -$HR_{peak}$ 150 ± 4 bpm.	PO for MOD was set to 50-70% VO_{2max}. -Resistance on cycle ergometer increased by $5W \cdot 20sec^{-1}$ from 15W until volitional exhaustion.

Summary: In older adults, moderate intensity physical activity can be defined as 50-65% of peak power output. The average heart rate for moderate intensity physical activity in older adults would be between 100-132bpm.

2.5 E-BIKES

Among the various modes of active transportation, cycling offers users more range and faster trips when compared to all other modes of active transportation. In recent years, a sub-classification of electric bicycles, known as pedal assist e-bikes (pedelecs) have become increasingly popular and have emerged as another potential mode of active transportation. Research by Langford et al (2017) and Bernsten et al (2017) has found that pedelecs offer a means of integrating physical activity into the day by allowing for longer and more frequent trips when compared to walking or conventional bicycles. Further, pedelecs offer controllable electric assistance which reduces physical exertion required while still allowing for riders to achieve moderate intensity physical activity (Castro et al., 2019; Peterman et al., 2016; Sundfør et al., 2020). This suggests that pedelecs can be considered a form of active transportation while providing increased range and allowing for more frequent trips when compared to conventional cycling or walking.

2.5.1 DEFINING E-BIKES

In the literature, the term ‘e-bike’ is commonly used to describe all types and classes of electric bicycles designs. As seen in Figure 1, pedelecs exist as a sub-classification of e-bike. A systematic review by Fishman and Cherry (2016) explains that modern e-bikes are often given the classification of e-bike simply because they are bicycles with a form of electric powered assistance. This kind of broad classification is commonly used by governments for regulatory purposes given e-bikes are a relatively new technology and there exist several types and styles of e-bikes. Thus, crafting different regulations for every variation of e-bike can be a complex task. However, further categorization of e-bikes is necessary in research exploring their use as a form of active transportation

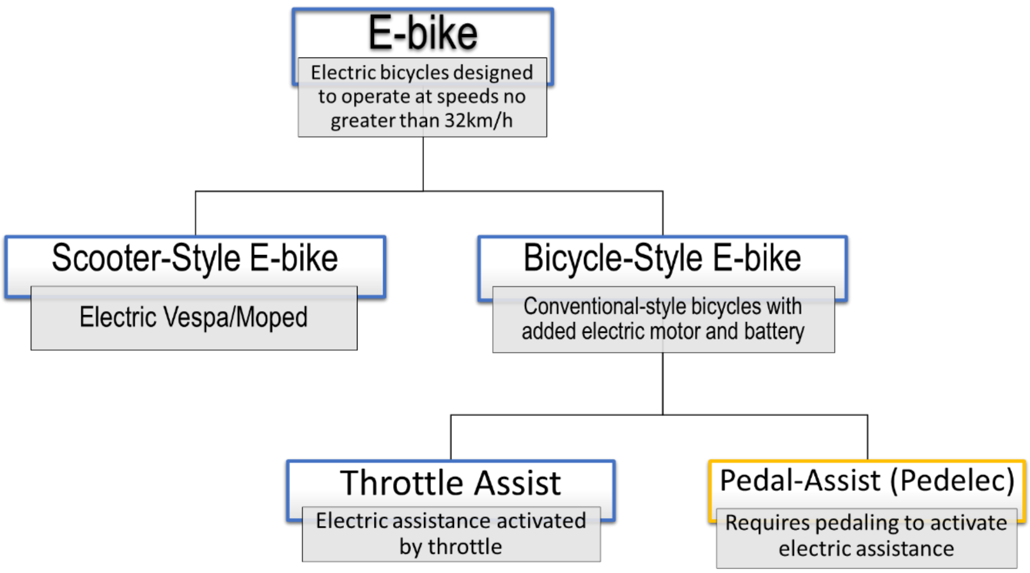

Figure 1. *Flowchart of E-bike Classifications*

Fishman and Cherry (2016) classify e-bikes into two main categories, bicycle-style e-bikes and scooter-style e-bikes. This distinction centers around the differences in the design characteristics of the two styles of e-bikes. As the name suggests, scooter-style e-bikes are very similar in style and operation to gas powered scooters or mopeds. They are often classified as e-bikes since they include a form of pedals. However, the pedals included on scooter-style e-bikes often serve little to no function beyond satisfying regulatory specifications to be considered an e-bike. Moreover, in spite of regulatory requirements, pedals are often removed by the user after purchase. The classification of scooter-style e-bikes as e-bikes is important to some users and manufacturers as it often carries reduced licensing and insurance requirements compared to gas powered scooters. Given that scooter-style e-bikes utilize a throttle system to engage electrical power and require no meaningful form of physical exertion, they are therefore not a form of active transportation.

Conversely, bicycle-style e-bikes, also known as electrically-assisted bicycles do include fully functional pedals and design characteristics of a conventional bicycle. Amongst bicycle-style e-bikes there exist two further sub categories, pedelecs and throttle assist e-bikes. The distinction between the two types of bicycle-style e-bikes lies in the mechanism by which the assistance is activated. Pedelecs generally provide electric pedal assistance using an integrated electric motor which can only be activated once a torque sensor detects that the rider is actively pedaling and applying force through the pedals (Fishman & Cherry, 2016). In pedelecs, the amount of assistance provided by the motor is determined by two factors. The first factor is the amount of force the rider applies to the pedals. The amount of assistance provided by the motor is directly proportional to the torque produced by the rider. Therefore, increased rider effort results in increased electric assistance delivered from the motor. The second factor is the assistance mode selected by the rider. Assistance modes provided by pedelecs are most commonly available in low, medium, and high settings (Fishman & Cherry, 2016). Each assistance mode is set with a specific assistance percentage and maximum torque delivery. For example, a typical low setting may return 40% of the rider's power as electrical assistance whereas a high setting may amplify the rider's power by 250%. Therefore, increased rider effort and higher assistance modes result in increased electric motor power output, up to a certain point. In Canada, e-bikes are regulated by the Canadian Transportation Act, which states that e-bikes can only provide electric assistance up to a speed of 32km/h, at which point the rider can continue at higher speeds unassisted (Transport Canada, 2001).

Throttle assist e-bikes conversely do not contain a torque sensor and instead the electric assistance from the motor is controlled from a throttle independent of the rider's force production and pedaling (Fishman & Cherry, 2016). In other words, a throttle-assist e-bike functions similarly to a scooter-style e-bike while providing the added option to use the pedals. Therefore, they cannot be included as a mode of active transportation.

Importantly, all of these classifications of e-bikes are often used synonymously in much of the existing literature. Therefore, when considering the application of e-bikes within the context of active transportation and physical activity, ***pedelecs*** are the only classification of e-bike which can be considered.

Summary: The term e-bike is applied to a wide range of e-bike styles. Pedelecs are the sub-classification of e-bikes known as bicycle-style e-bikes. Pedelecs require physical exertion to activate any electric assistance. Conversely, scooter style e-bikes operate with a throttle despite featuring pedals, and require no physical exertion before delivering electric assistance. As pedelecs are the only type of e-bike that ensures physical exertion from the rider, they are the only type of e-bike that can be included in this review.

2.5.2 PEDELECS AND OLDER ADULTS

E-bikes, particularly pedelecs, have become increasingly popular globally among older adults due in part to the advantages offered by the added assistance (Fishman & Cherry, 2016). The following chart details the current state of the literature relating specifically to older adults and pedelecs.

Table 3. *Current Literature on E-bikes and Older Adults.*

Study	Population/Age group	Methods	Findings
Johnson, M. and G. Rose (2015)	Australian e-bike owners aged 65+ (n=69)	Online survey to determine e-bike usage, motivations for purchase and safety issues.	Participants reported frequent usage (88% weekly, 34% daily),
Haustein, S., & Møller, M. (2016)	Danish e-bike users (n=427) aged 18-70+	Online survey to determine changes in cycling patterns and car replacement after gaining e-bike access.	>50% of new e-bike owners replaced a car with their e-bike. E-bikes equalized age differences in cycling frequency between younger and older participants. Cycling enthusiasm was largest predictor of increase in cycling frequency.
Van Cauwenberg, J., De Bourdeaudhuij, I., Clarys, P., De Geus, B., & Deforche, B. (2018)	Belgian community-dwelling adults aged 65+ (n=1146)	Questionnaire completed online or in-person to compare the sociodemographics, health characteristics, and access to motorized transport between e-bike owners and non-e-bike owners.	Sex, increased BMI and car ownership were found to be related the odds of participants being an e-bike user. E-bike users were found to ride further and more frequently for transport and recreation when compared to non-e-bike owners
Van Cauwenberg, J., De Bourdeaudhuij, I., Clarys, P., de Geus, B., & Deforche, B. (2019)	Belgian e-bike owners aged 65+ (n=357)	Online and interview survey to determine e-bike owner use and perceptions	Participants reported advantages such as being able to ride further distances and replace 50% of their car trips. Reported disadvantages included e-bike weight and battery issues.
Leger SJ, Dean JL, Edge S, Casello JM. (2019)	Canadian e-bike owners aged 60+(n=37) and Community Stakeholders (n=17)	Interviews with stake holder and focus groups with older adults with a range of cycling experience to determine facilitators, barriers and perceptions of e-bikes.	Findings suggest that stakeholders and older adults perceive e-bikes as offering increased convenience, reduced reliance on vehicle and fun. Perceived barriers included cycling infrastructure, regulation and stigmatization.

Leyland, L.-A., Spencer,B., Beale, N., Jones, T., & van Reekum, C. M. (2019)	British non-cyclists aged 50-83 (n=100)	8-week outdoor cycling intervention. Participants divided into non-cycling control, conventional cycling and e-bike cycling groups. Cognitive function and well-being assessed pre and post.	E-bike group improved executive function, processing speed and mental health score when compared to the non-cycling controls. Similar improvements were seen in the conventional cycling group.

As outlined above, current research has predominantly focused on the experiences and usage of pedelecs by older adults who own pedelecs. Leyland et al., (2019) is the only study to date in which the effect of pedelecs on older adults was not measured using self-reported data. While their work on pedelecs and the cognitive function of older adults contributes greatly to the current research, there remains a lack of understanding on the physiological effect of pedelec riding in healthy older adults. As outlined in *Section 2.3*, age related physiological changes result in an altered response to exercise in the older adult population. As pedelec use continues to grow, particularly amongst older adults, so too does the need to better understand the role pedelecs may play in facilitating the continued physical well-being of older adults.

In younger adults, the physiological responses to pedelec use have been studied, and are summarized in the following table. It is clear that pedelecs elicit at least moderate intensity physical activity and, in some cases, consistent pedelec use can result in improvements to cardiovascular fitness.

Table 4. *Summary of Literature on Physiological Responses to Pedelec Use in Younger Adults. (METs - Metabolic Equivalents, PA – Physical Activity)*

Study	Population / Age group	Physiological Parameters	Conclusions	Other Relevant Information
B. Gojanovic, J. Welker, K. Iglesias, C. Daucourt and G. Gremion (2011)	18 adult participants (12 women, 6 men). Mean Age: 35.7 ± 9.7 Sedentary:<150min MVPA·wk	-Heart rate and VO_2 measured directly. -Reported as $\%HR_{max}$, $\%VO_{2\ max}$, Metabolic Equivalents (METs) and Rating of Perceived Exertion (RPE) (Borg Scale).	-Pedelec with 'medium' and 'high' assistance levels achieved at least moderate to vigorous intensity PA (55% and 66% of $VO_{2\ max}$). -47% of pedelec 'high' and 88% of pedelec 'medium' rides achieved vigorous intensity PA (>6.0METs). -Pedelec riding was significantly faster.	-Pedelec 250W and 25km/h max -Course was primarily uphill and integrated with regular traffic. -Participants had no previous e-biking experience. -30min recovery between rides. -Cycled at commuting intensity.
Berntsen, S., Malnes, L., Langåker, A., & Bere, E. (2017)	8 adult participants (2 women, 6 men) Median Age: 39 (range 23-54) Caucasian, non-smokers, with no know disease, and no medication use.	-Heart rate and VO_2 measured directly. -Reported as $\%VO_{2\ max}$, METs and RPE (Borg Scale)	-95% of time spent cycling using pedelec was considered MVPA. -51% of VO_{2max} for hilly and flat route average on pedelec. Compared to combined 58% of VO_{2max} on conventional bike. -Pedelec was faster (19.9min) compared to conventional bike (25.1min) resulting in 26% less time spend in MVPA.	- Pedelec 250W and 25km/h max -Assistance mode was no specified. -Two courses were used; 8.1km mostly flat route and a 7.1km with more hills).
Sperlich, B., Zinner, C., Hébert-Losier, K., Born, D.-P., & Holmberg, H.-C. (2012)	Sedentary adult women (n=8) Mean Age: 38 ± 15 (22-61) <2.5h MPA ·wk No experience cycling or e-biking	-PO, electrical activity produced by quadriceps (EMG), $VO_{2,}$ heart rate and blood lactate measured directly. -RPE (Borg Scale) Reported as percent difference between trials.	-Pedelec riding with assistance constitutes at least MPA. -Pedelec riding with assistance required 29% less power output, over 9.5km, than riding with assistance turned on. -29% lower heart rate and 33% less oxygen uptake required when assistance was turned on. -Lower RPE and greater enjoyment with assistance turned on.	-Acceleration to 25km/h test with a 9.5km outdoor circuit with varying incline. -Cycled with and without assistance on pedelec. -Pedelec provided no assistance above 25km/h. -Cycled at self-selected leisure place.

Höchsmann, C., Meister, S., Gehrig, D., Gordon, E., Li, Y., Nussbaumer, M., Rossmeissl, A., Schäfer, J., Hanssen, H., & Schmidt-Trucksäss, A. (2018).	Overweight adults (n=32) (BMI 25-35kg/m^2) (4 women, 28 men) Median Age: 37 <150min/week of MVPA	-VO_{2peak}, HR_{max} and blood pressure at 100W, BMI, resting heart rate and blood pressure measured pre and post intervention.	-Trend toward improvements in VO_{2peak}. No difference in VO_{2peak} compared to conventional cycling group after 4 weeks. -Decreases in blood pressure at 100W. -Trend toward higher elevation gain and faster cycling in the e-bike group. -Median heart rate was 74.9% and 73.3% of HR_{max} for the e-bike group and conventional bike group respectively.	-Compared cardiorespiratory fitness improvements of e-bike use to conventional bike use after 4-week intervention. -Pedelec limited to 250W and 25km/h assisted top speed. -Self-selected speed to commute to work at least 3 days per week. -Three assist modes available (low, standard, and high).
Alessio, H. M., Reiman, T., Kemper, B., von Carlowitz, W., Bailer, A. J., & Timmerman, K. L. (2021)	Healthy adults free of acute injury of clinically significant disease (n=30) (14 women, 16 men). Mean Age: 26.2±12.7	VO_{2max}, heart rate, RPE (Borg Scale) All measures reported as a percentage of max.	-Pedelec required lower cardiovascular, metabolic and perceived effort under E1 and E2 assistance levels when compared to conventional cycling. -Workload while riding under E1 and E2 conditions still met intensity level to constitute physical activity.	-Pedelec limited to 350W and 20mph assisted top speed. -Pedelec riding at E1 assistance level (125-174W) and E2 assistance level (200-250W) was compared to riding a conventional bike over a 3-mile outdoor test track.
Stenner, H. T., Boyen, J., Hein, M., Protte, G., Kück, M., Finkel, A., Hanke, A. A., & Tegtbur, U. (2020).	Healthy blue-collar and white-collar worker from 4 different workplaces. (n=101) (47 female, 54 male) Mean Age: 43±11	VO_{2max}, HR_{max}, METs, RPE (Borg Scale). Only heart rate and RPE were measured during rides and were reported as %HR_{max}	-Pedelec ride time and frequency were significantly higher than conventional bike. -No differences in average trip time. -Mean HR was 8% lower over 2 weeks of pedelec use, but was still considered MVPA. -Total time spent in MVPA was higher during pedelec use. -Reduced exertion requirements for pedelec may have encouraged participants to use pedelec for more trip types (i.e. Groceries).	-Compared 2 weeks of pedelec riding to 2 weeks of conventional bike riding using cross-over design. -No usage specifications were made. -Pedelec limited to 25km/h.

Peterman, J. E., Morris, K. L., Kram, R., & Byrnes, W. C. (2016)	Sedentary commuters with job that did not require significant PA (n=20) (14 female, 6 male) Mean Age: 41.5±11.5 (22-55years)	VO_{2max}, HR, fasting OGTT (Oral Glucose, Tolerance Test) and blood lipid profile (cholesterol levels), DXA scan (body composition), mean arterial pressure, RPE (Borg Scale) METs estimated from HR data.	-Significant improvements in VO_{2max}, power out and OGTT. -Participants self-selected a moderate intensity of PA (72.1 ± 5.4% of HR_{max}) while riding pedelec. -No significant differences in distance cycled from week 1 to week 4. -Over half of participants exceeded the minimum riding requirements by at least 50%. -Non-cycling PA remained the same despite increased pedelec use.	- 4 week intervention of pedelec use at least 3 days·week for 40min·day. -Pedelec 250W max, limited to 32km/h. -Self-selected pace and usage.
Langford, B. C., Cherry, C. R., Bassett, D. R., Fitzhugh, E. C., & Dhakal, N. (2017)	Healthy adult E-bikeshare users in a university setting (n=17) (6 female, 11 male) Age: Primarily young adults [2 (31-40) 2 (50+)]	VO_{2max}, HR_{max}, Power Output, METs, RPE (Borg Scale).HR was used to estimate VO_2 and Energy Expenditure (EE) during outdoor rides.	- Pedelec riding constitutes at least moderate intensity PA and can elicit vigorous intensity PA on uphill terrain.-EE while riding the pedelec remained on relatively stable over downhill, flat and uphill sections. -Lower power output and EE required to maintain faster average speeds.	- 4.43 outdoor route of varying terrain. Comparing pedelec to conventional bike and walking. -Participants instructed to use only highest assistance level. - Pedelec 250W max. -VO_2 and EE were normalized by weight for analysis.
de Geus, B., Kempenaers, F., Lataire, P., & Meeusen, R. (2013)	Healthy non-cyclists who commuted to work via motorized transport. (n=24) (11 women, 13 men) Mean Age: 45 ± 7 years (men) and 43±6 years (women)	VO_{2max}, HR_{max}, Blood lactate, Peak power output. No physiological measures during intervention.	- Significant increases in peak power output in men and women. -Power output at blood high blood lactate concentration (4 mmol·1^{-1}) was significantly increased for men and women. -No changes in VO_{2max} after 6-week intervention.	- 4-week control period with 6-week intervention period. -Required to cycle at least 3 times per week to and from workplace. -Participants instructed to switch assistance on or off at will.

2.6 RATIONALE AND PURPOSES

Given the increasing popularity of pedelecs among older adults, and the corresponding low physical activity levels in this population, more research assessing the physiological response to pedelec use is needed. In particular, research addressing some of the barriers to active transportation in this population may encourage greater uptake. The effect of age-related declines in exercise capacity are not clearly understood as it relates to pedelec use. In particular, it is not clear from the current literature if pedelec use could still be classified as MVPA in older adults based on heart rate or power output, or if certain conditions (e.g. adding load to the bike to simulate groceries) would lead to an increase in e-assistance, and thus render pedelec use as inactivity.

Thus, the purpose of this thesis is to investigate the acute physiological response of older adults to pedelecc cycling. The specific purposes of the research are to determine if:

1. self-selected pedelec riding (pace and assistance levels) along a 6.25km track can be classified as MVPA based on heart rate and power output responses in older adults.
2. adding 20kg of load to the pedelec while riding along a 6.25km track changes the level of e-assist and thus the intensity of the activity completed.

2.6.1 HYPOTHESES

1. It is hypothesized that despite self-selected e-assistance and pace, older adults will be engaging in MVPA, that is a heart rate between 64-93% of heart rate maximum or higher, based on previous research by Langford et al. (2017). It is difficult to hypothesize the exact power output as no research to date has investigated power output related to pedelecs. However, based on previous research presented in Table 1, it is hypothesized

that older adults will be cycling at 50% of the peak output they achieved during a maximal exercise to achieve MVPA (Linares et al., 2020; Lovell et al., 2010).

2. It is hypothesized that older adults will increase the amount of electric assistance they receive from the pedelec when the simulated load of items of daily living are added to the pedelec but there will be negligible difference in the intensity of the cycling. This is based on research that shows that throttle-assist mail delivery e-bikes can compensate for the increased energy demands of added load during simulated mail delivery (Bini et al., 2019).

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CHAPTER 3: MANUSCRIPT

Physiological Responses of Pedal-Assist E-bike use in Older Adults

3.1 ABSTRACT

Background: In recent years, pedal-assist electric bicycles (pedelecs) have become increasingly popular as a form of active transportation for all ages. Pedelec riding has been found to elicit moderate-to-vigorous intensity physical activity (MVPA) in younger adults, however, it is unknown if pedelec riding elicits a similar intensity of physical activity in older adults. *Purpose:* The purpose of this study was to determine if self-selected pedelec riding (assistance level and pace) can be classified as MVPA in older adults, and if loading the pedelec changes the level of e-assist used, and thus the intensity of the activity completed. *Methods:* Participants (n=21, mean age 70.1 ± 5.1) completed a maximal exercise test in a laboratory setting followed by two 6.25km outdoor pedelec rides at a self- selected comfortable pace, once with 20kg of load added to cargo bags and once without, in random order. To determine the intensity of physical activity, each participant's maximal heart rate (HRmax) and power output (POmax) from their maximal exercise test were compared to their respective average HR and PO from the outdoors rides. *Results:* Nearly all participants (19/21) achieved a mean intensity of MVPA, classified as 64-93% of HRmax. Mean intensity from unloaded and loaded rides was 76% HRmax and 75% HRmax, respectively. No differences were observed when comparing HRavg, HRpeak, POavg or POpeak between unloaded and loaded pedelec rides. *Conclusions:* Older adults self-select at least MVPA while riding pedelecs on a closed course. The added load did not change the intensity of pedelec riding. Future research should investigate if older adults achieve a similar intensity of physical activity in a more natural riding environment, and explore any gender differences in intensity selection that may exist.

3.2 INTRODUCTION

Across all ages, and particularly in older adults, regular physical activity can reduce the risk of developing major chronic diseases, cognitive impairments, muscular weakness and premature death (McPhee et al., 2016; Warburton et al., 2010). To achieve these health benefits, current physical activity guidelines recommend a minimum of 150 minutes of weekly moderate-to-vigorous aerobic physical activity (MVPA), defined as 64-93% of maximal heart rate (HRmax) (Riebe et al., 2018; Ross et al., 2020). In spite of this, only 15% of Canadian aged 60-79 years are currently achieving the minimum recommendations for weekly MVPA (Macridis et al., 2020).

To increase physical activity, the World Health Organization has long recommended integrating physical activity throughout the day by using forms of active transportation such as walking and cycling as an alternative to automobiles (World Health Organization, 2007). In spite of these recommendations, cycling remains an unpopular mode of transportation among older adults. This has been attributed to a multitude of barriers, both physical and perceived (Heinen et al., 2010; Klicnik & Dogra, 2019; Manaugh et al., 2017). Among the most notable barriers in urban and sub-urban regions are distance, effort, topography, safety, travel time and added weight (Jones et al., 2016; Van Cauwenberg et al., 2018; Winters et al., 2011).

Pedal-assist electric bicycles, (hereafter referred to as 'pedelecs') have in recent years, become increasingly popular globally as a form of active transportation for all ages, including older adults (Haustein & Møller, 2016; Leger et al., 2019). Pedelecs closely resemble conventional bicycles while offering riders adjustable electrical assistance proportional to the power they apply to the pedals. The resulting decrease in required physical exertion thereby decreases some of the physical barriers to cycling as an active mode of transportation by offering riders the ability to ride further, faster and more frequently while expending less physical effort (Alessio et al., 2021; Edge et al., 2018; Fishman & Cherry, 2016). Evidence from several studies suggests that, although pedelecs require less physical effort than their conventional counterparts, they still elicit at least moderate intensity physical activity in younger adults under controlled conditions (Bourne et al., 2018; Gojanovic et al., 2011; Lakatta, 2002). Furthermore, in a study by Hansen et al. (2018), 15 older adults (13 male, 2 female) with coronary artery disease, aged 64±7 years, achieved MVPA while riding an electrically assisted bicycle over a 10km outdoor track. However, it is important to note that the electrically assisted bicycle used in this study utilized a front hub motor which provided either a predefined low or high level of assistance which was activated independent of the rider's pedal power. This evidence supports the use of pedelecs in younger adults, and electrically assisted bicycles in older adults, as a means of MVPA, however, it is unknown if pedelecs, where assistance is self-selected, would elicit a similar intensity of physical activity in older adults.

Previous studies have measured the intensity of physical activity elicited by pedelecs with the assistance level pre-set, preventing the rider from adjusting the amount of assistance available to them. In a real-world setting, pedelec riders are likely to adjust the amount of assistance they receive while riding to account for external factors such as hills, wind, or the weight of added cargo items such as groceries. Therefore, the purpose of the present study was to determine if pedelec riding can be classified as MVPA in older adults who are able to ***self-select*** the level of assistance and the pace of their ride. A secondary purpose was to determine if added load to the pedelec led to a change in the self-selected level of e-assist used, and thus the intensity of the activity completed. Previous research has consistently found that pedelec riding elicits MVPA, as measured by mean %HRmax, across several adult populations. La Salle et al.

(2017) found active younger adults reached 79.1%HRmax, Gojanovic et al. (2011) found inactive adults reached at least 74.5%HRmax with high-level assistance, and Simons et al. (2009) found active middle-aged adults reached intensities of at least 67.1%HRmax. Therefore, we hypothesized that self-selected pedelec riding would be classified as MVPA (≥64%HRmax) in active older adults. We also hypothesized that once load is added, older adults would increase the amount of assistance, therefore maintaining the intensity of the activity. This is based on previous research on by Bini et al. (2019) who found that during simulated mail delivery on electrically-assisted bikes, postal workers experienced no differences in energy expenditure between three load conditions (unloaded, 16kg added, and 32kg added). Moreover, it was found that postal workers increased the amount of assistance they received to compensate for the added load.

3.3 METHODS

3.3.1 Study Design

A randomized cross over study design was used to compare differences in the physiologic response to riding a pedelec in two conditions completed in random order: loaded and unloaded. The order in which participants completed the trials was randomized via a random number generator.

3.3.2 Participants

Participants were eligible if they were aged 60 years or older, engaged in a minimum of 150 minutes of MVPA per week, were comfortable cycling on an outdoor track for roughly 10km, and had access to a bicycle helmet. Participants were excluded if they had a current or previous injury that would prevent them from cycling, or were assessed as high risk for maximal exercise testing based on the health screening done using the Get Active Questionnaire (CSEP, 2017). An equal number of male and female participants were recruited for this study.

3.3.3 Study Protocols and Measurements

Each participant completed one laboratory session and two separate outdoor pedelec rides. During the laboratory session, resting measures of heart rate and blood pressure, as well as body composition (height, weight, and waist circumference), and maximal exercise measures were assessed.

Session 1: Laboratory testing

Laboratory testing began with measures of resting heart rate (Polar H10, France) and resting blood pressure, as well as anthropometric measures of height, weight, and waist circumference. Participants were then familiarized with the one-way mouth-piece (Hans-Rudolph, Shawnee, KS, USA), nose clip, cycle ergometer (Lode B.V., Groningen, The Netherlands), and the metabolic cart (Parvo Medics 2400, Salt Lake City, UT, USA). A ramped protocol was used for the maximal exercise test which began with a 2 min warm-up at 50W of resistance, increasing by 1W every 3-5sec until volitional exhaustion was reached. Volitional exhaustion was defined as the point at which participants expressed an inability to continue or were unable to maintain a consistent cadence between 70-90rpm. Maximal heart rate (HR_{max}) was measured as the highest recorded heart rate in beats per minute (bpm) using a chest strap heart rate monitor (Polar H10, France). Peak power output (PPO) was recorded as the highest power output (W) during the test.

Sessions 2 & 3: Pedelec rides

This study utilized a 2020 Verve +3 Low-Step (Trek, Waterloo, WI, USA) model 30980 pedelec size medium fitted with a Kiox (Bosch, Germany) head unit, and 32L rear mounted double pannier bags (Basil GO MIK, the Netherlands) which combined, weighed approximately 25kg, including the battery. The Trek Verve +3 utilizes a 500Wh battery to power the mid-mounted 250W Bosch Active Line Plus motor which offers 50Nm of torque and pedal assistance up to speeds of 32km/h. Electric pedal assistance for this model of pedelec is engaged only when the rider applies power through the pedals. The amount of electric pedal assistance provided is dependent on: (1) the rider's pedal power measured using a proprietary torque measurement system (Bosch, Germany), and (2) the assistance mode selected. For this study, participants had 4 assistance modes available, each offered a different support level percentage (OFF: 0, ECO: 40%, TOUR: 100%, SPORT: 180%). This pedelec was equipped with 9 gears with a gear ratio range from 1:1.06 to 1:3.45.

The course used for this study was located at Windfields Farm, near the University of Ontario Institute of Technology campus in Oshawa, Ontario. The course used was a 1.25km loop marked with directional signage on private property which was closed off to traffic. The terrain

Figure 1. *Map of 1.25km outdoor course (Left), Participant on paved section of course (Right).*

of the course was mixed, comprised of approximately 700m of paved concrete, 550m of unpaved gravel road and 6m of elevation change. This loop was completed 5 times for a total of 6.25km.

Each participant completed two 6.25km pedelec rides at least 48h apart; during one session the bike was ***loaded*** with 20kg in rear-mounted pannier bags, while the other session was performed ***unloaded***. Upon arriving to the pedelec ride session, participants were instructed on how to use the pedelec and rode the complete loop twice while accompanied by a researcher to ensure they were familiar with the course and all available assistance modes. Participants wore a chest strap heart rate monitor (Polar H10, France) paired with a Bosch Kiox head unit to allow for continuous collection of heart rate matched to ride data. Participants were instructed to ride at a self-selected comfortable pace and to use the electric assistance modes (Off, Eco, Tour, Sport) that would be representative of a trip to an appointment or to complete errands. During each ride, heart rate, power output, speed, elevation, and cadence were measured continuously. The total ratio of engine power to human power as well as percentage of time spent in each assistance mode over the 6.25km ride was recorded at the end of each ride.

The pedelec rides took place between July 26th, 2021 and August 23rd, 2021. Weather conditions during this period varied with ambient temperatures ranging from 22-35˚C. All procedures were approved by the Research Ethics Board of the University of Ontario Institute of Technology, and all participants provided written informed consent.

3.3.4 Measures

Heart rate and power output data from the Kiox bicycle computer were analyzed using Bosch e-Bike Connect Software. Average heart rate (HRavg) and power output (POavg) were calculated as their respective mean values from each complete pedelec ride (beats per minute and watts). Peak heart rate (HRpeak) was defined as the highest recorded bpm, while peak power output (POpeak) was defined as the highest recorded watts value during each complete ride.

Intensity of the pedelec rides was defined using %HRmax, which was calculated as the HRavg during the pedelec ride divided by the participant's HRmax from the maximal exercise test, multiplied by 100 (see equation below).

$$\%HRmax = \frac{HRavg}{HRmax} \times 100$$

3.3.5 Statistical Analysis:

Descriptive statistics are presented as means (M) and standard deviations (SD). Cohen's d was calculated using Gpower to determine effect sizes between unloaded and loaded pedelec rides. A small effect size was defined as d = 0.2, moderate d= 0.5, large d= 0.8 (Cohen, 2013). Paired samples t-tests were used to determine differences between unloaded and loaded pedelec rides for all outcome measures (HRavg, HRmax, POavg, POmax, and assistance modes). Statistical significance was set to an alpha of $p<0.05$. Statistical analyses were carried out using Microsoft Excel version 1808 (Microsoft, USA).

Sample size calculation:

Previous studies using sample sizes of 3-17 have measured the intensity of physical activity while riding pedelecs in younger adults (Berntsen et al., 2017; Gojanovic et al., 2011; Langford et al., 2017; Meyer et al., 2014; Simons et al., 2009). Therefore, given the descriptive nature of the primary research question, a sample size of 20 (10 males and 10 females) was deemed sufficient.

3.4 RESULTS:

Figure 2. depicts the number of participants assessed for eligibility (n=35), and the number of participants in the final analysis (n=21).

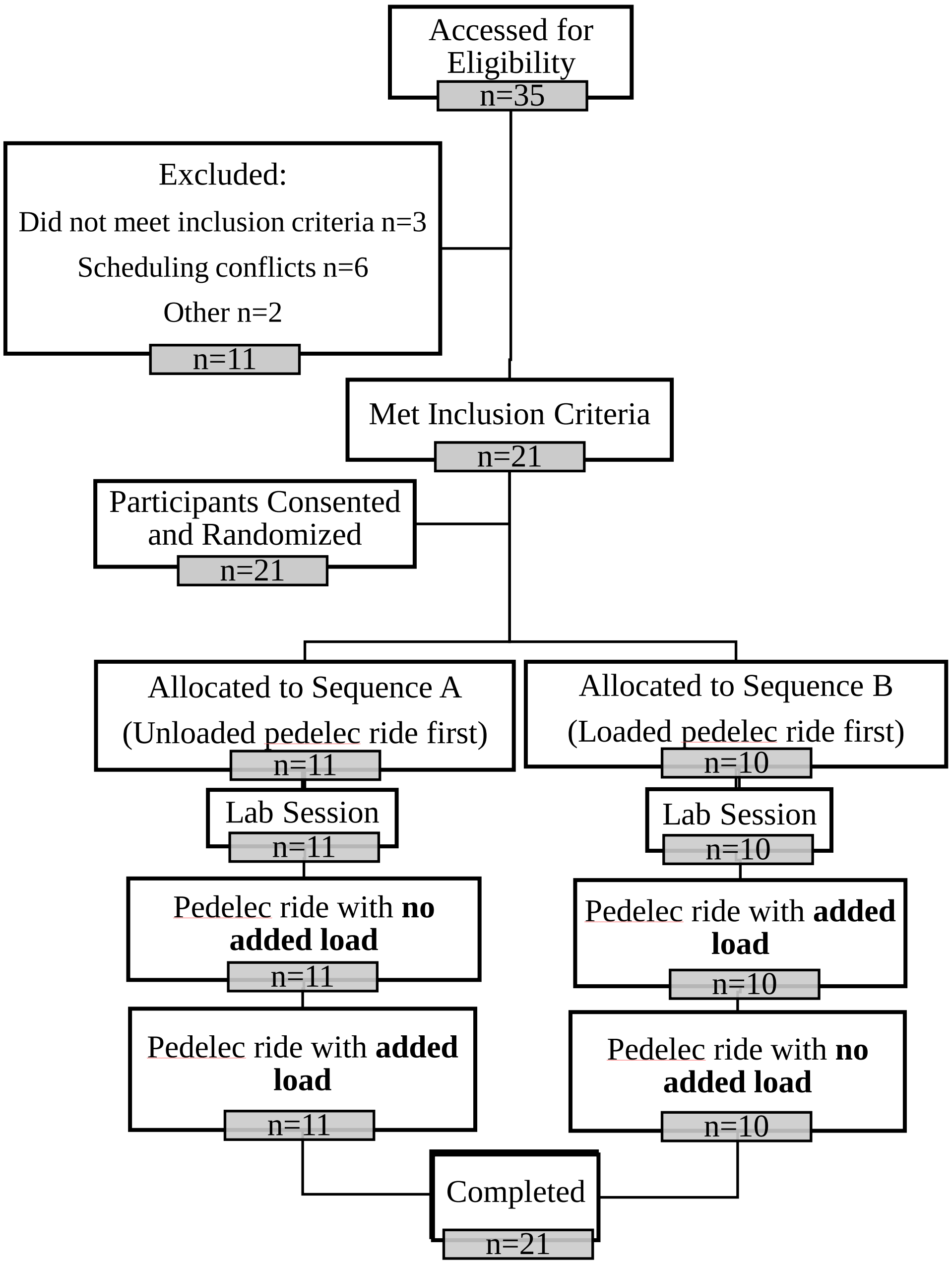

Figure 2. *Study flow chart.*

The average age of the sample was 70.2 years (±5.2) and consisted of a similar proportion of males (n=11) and females (n=10). Additional samples characteristics can be seen in Table 1.

Table 1. Participant Characteristics (Mean ± SD)

	Female (n=10)	**Male** (n=11)	**Total Sample** (n=21)
Age (yrs)	68.9± 6.1	71.3 ± 4.1	70.1 ± 5.1
BMI ($kg·m^2$)	25.8 ± 3.9	27.8 ± 4.6	26.8 ± 4.3
Heart Rate at rest ($beats·min^{-1}$)	64.2 ± 9.0	67.3 ± 7.7	65.8 ± 8.3
SBP at rest (mm Hg)	119.2 ± 9.2	124.7 ± 7.9	122/71 ± 8.8
DBP at rest (mm Hg)	71.1 ± 10.5	72.54 ± 7.4	71 ± 8.8
Waist Circumference (cm)	85.9 ± 11.2	97.0 ± 10.0	91.7 ± 12.0
Physical Activity ($min^{-1} \cdot wk$)	378.0 ± 181.9	378.1 ± 190.3	378.0 ± 181.6
$\mathbf{VO_{2max}}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	31.3 ± 8.3	34.4 ± 5.8	32.9 ± 7.1
$\mathbf{HR_{max}}$ ($beats \cdot min^{-1}$)	158.0 ± 13.9	161.18± 10.4	159.6 ± 12.0
Peak Power Output (W)	159.9 ± 30.9	212.2 ± 31.4	187.3 ± 40.5

HR avg from unloaded (*M =119.6, SD=12.0*) and loaded (*M=120.7, SD=15.6, d=0.07*) rides can be seen in Figure 3. No significant differences in POavg were observed when comparing unloaded (*M=114.8, SD=31.1*) to loaded (*M=110.7, SD=29.2; d=0.13*) rides. Peak heart rate was similar (NS) between unloaded (*M=136.2, SD=13.9*) and loaded (*M=137.8, SD=11.1; d=0.12*) rides. Peak PO, from the loaded ride (*M=248.7, SD=67.2*) was similar (NS) to the unloaded ride (*M=255.5, SD=73.7; d=0.09*).

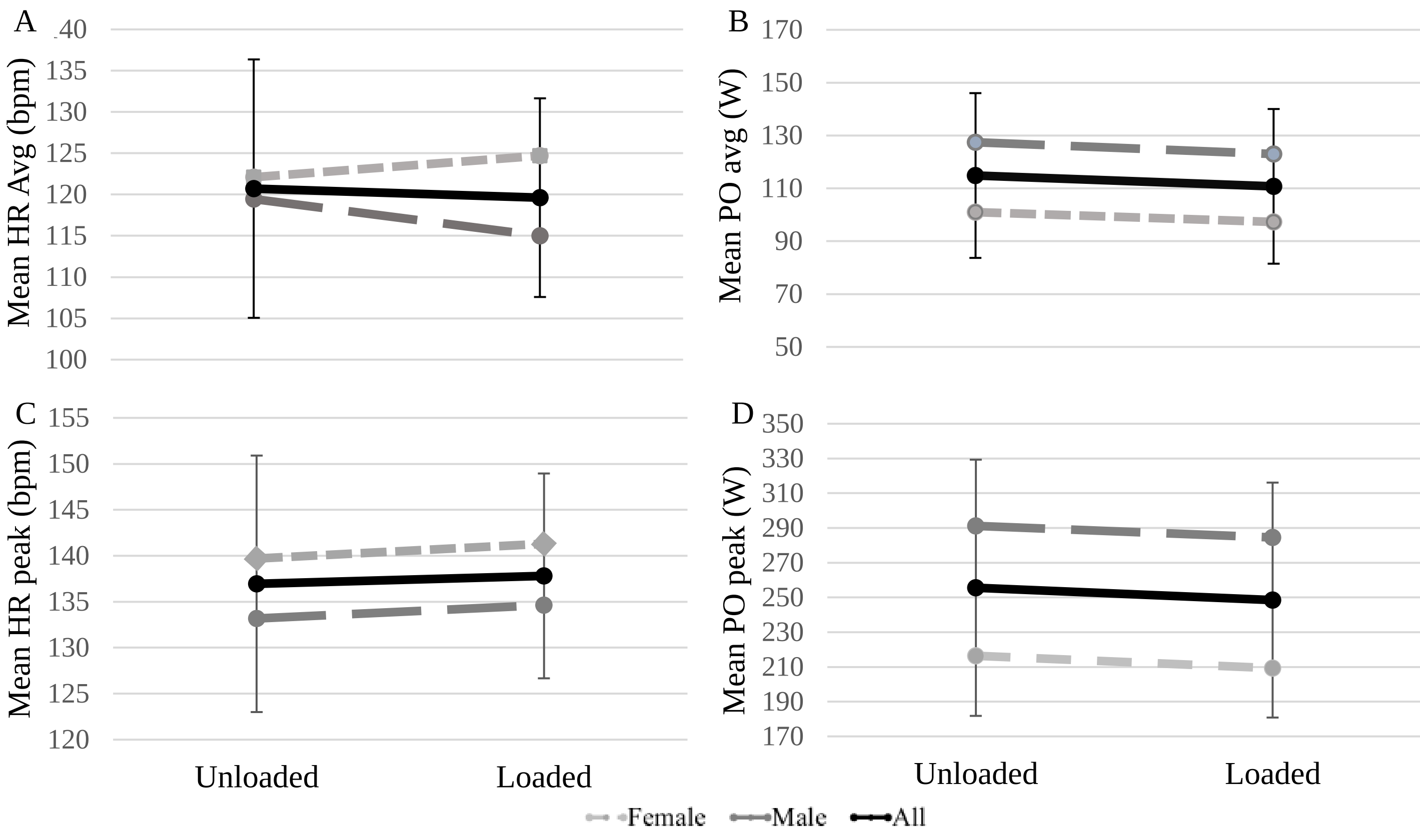

Figure 3. *HRavg (A), POavg (B), HRpeak (C), POpeak (D) during unloaded and loaded 6.25km pedelec rides. Presented as mean and standard deviation.*

All participants had an HRavg of at least light physical activity (50-63% HRmax) during both sessions; 90% of participants (19/21) were in the MVPA range (>64% HR_{max}), while 47.6% and 38.0% of participants were in the vigorous intensity PA (77-95% HRmax) in the unloaded and loaded sessions, respectively (Figure 4).

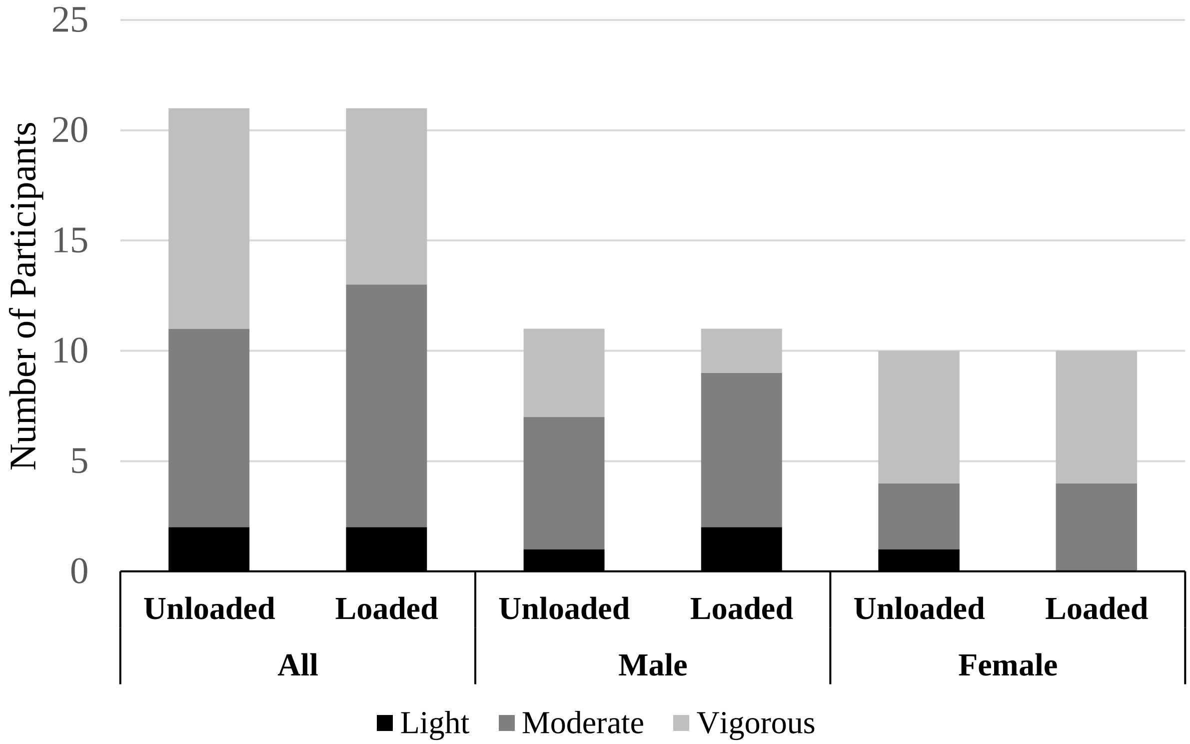

Figure 4. *Number of participants in light, moderate, or vigorous intensity physical activity during unloaded and loaded pedelec rides.*

Table 2 presents the mean %HRmax from the unloaded and loaded rides by sex.

Table 2. Mean % of HRmax Achieved During Pedelec Rides

	All (n=21)	**Male (n=11)**	**Female (n=10)**
Unloaded	75.69 ± 12.00	74.53 ± 11.84	78.00 ± 12.55
Loaded	75.01 ± 10.81	71.74 ± 9.46	79.86 ± 11.00

The average percentage of assistance modes used was similar (NS) across loaded and unloaded trials. A greater percentage of TOUR and SPORT mode use during the loaded trial can be seen in Figure 5, however, this difference was not statistically significant.

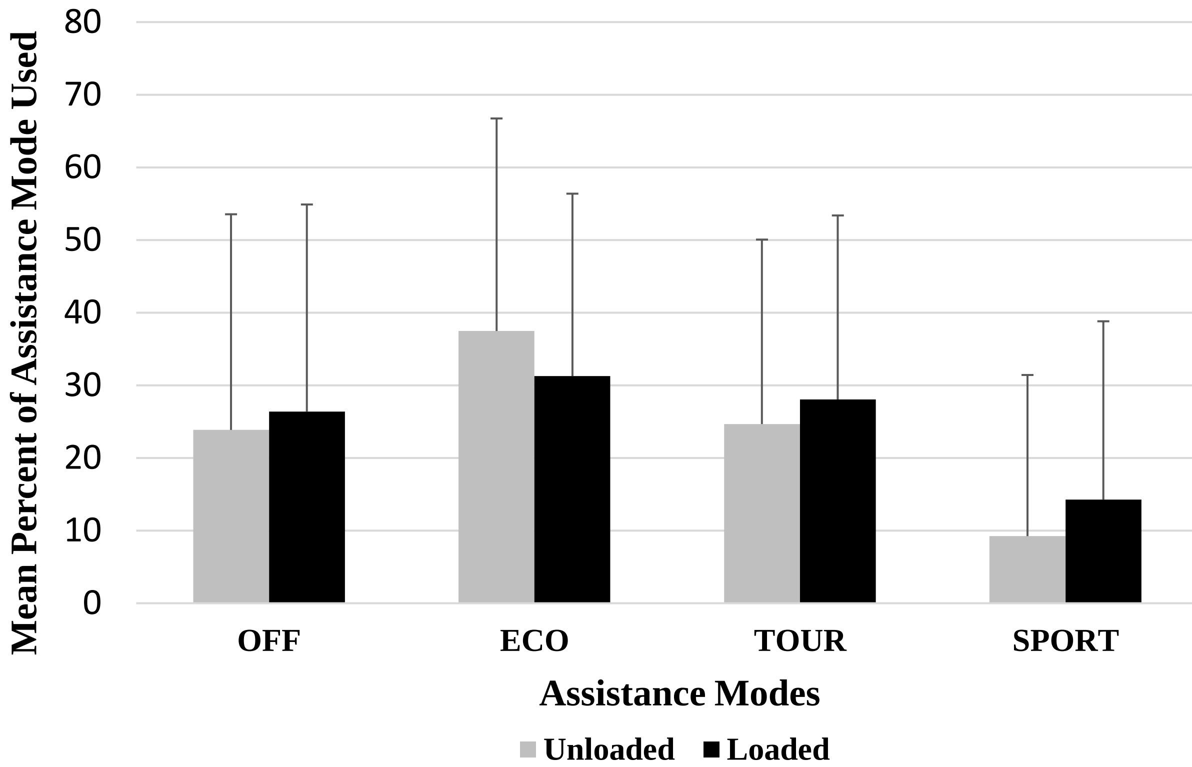

Figure 5. *Mean percent of each assistance mode used during unloaded and loaded pedelecs rides.*

3.5 DISCUSSION

The goal of this work was to determine whether self-selected pedelec riding would be classified as MVPA in older adults, and whether adding load would have an impact on the intensity of pedelec riding. The data confirmed both our hypotheses. First, we found that older adults do self-select an intensity classified as MVPA as determined by their percent of HRmax and percent of POmax. Second, when compared to the unloaded pedelec ride, added load did not result in any significant differences in average heart rate or average power output. To our knowledge, this is the first study to classify pedelec riding in older adults as MVPA, which suggests that regular pedelec riding at a self-selected pace has the potential to assist older adults in meeting physical activity guidelines and achieving health related benefits.

Our finding that self-selected pedelec riding can be considered MVPA is consistent with previous research by La Salle et al. (2017), Cooper et al. (2018), Berntsen et al. (2017), Gojanovic et al. (2011), and Hochsmann et al. (2018) who found pedelecs elicit MVPA in younger adults, adults with type 2 diabetes, active adults, inactive adults, and overweight adults, respectively. Direct comparisons between our study and previous works is difficult given the differences in course topography, pedelecs used, study protocols, and population characteristics. However, the 6.25km flat course used in the present study is comparable to those used by Berntsen et al. (2017) and Simons et al. (2009) which were flat and 8.1km and 4.3km respectively. Berntsen et al. (2017) reported a mean intensity in the MVPA range (52%VO_2max) with the pedelec set to the maximal assistance level (250W up to 25km/h). In active middle-aged adults Simons et al. (2009) reported mean intensities of 67%HRmax and POavg of 94W when riding with low assistance and 69%HRmax and POavg 101W with high assistance. This is comparatively lower than the 75%HRmax and 115W seen in the present study from the unloaded pedelecs rides. Notably, the intensities from the present study are more closely matched to those from longitudinal studies by Peterman et al. (2016) (72.1%HRmax) and Cooper et al. (2018) (74.7%HRmax) where pedelecs were provided as an active transportation intervention and participants were asked to ride at a self-selected commuting pace. This suggests that older adults may self-select an intensity equal-to or greater-than that of their younger counterparts during real-world active transportation use. Future intervention research should aim to confirm this over a longer ride duration and in a more real-world setting.

Similar to Hansen et al. (2018), the present findings suggest that older adults self-select a higher intensity of physical activity when given control over assistance levels compared to previous studies in which intensity was self-selected, but the electrical assistance provided by the pedelec was pre-set (Alessio et al., 2021; Simons et al., 2009). Allowing for the self-selection of both intensity and assistance levels while pedelec riding is important when investigating the physiological responses to pedelecs use in real-world settings. As reported by MacArthur et al. (2018) those who use pedelecs for real-world active transportation travel are likely to transport small cargo such as groceries and frequently experience variable changes to terrain or environmental factors (wind). These real-world factors can greatly impact the intensity of pedelec riding, and therefore prompts riders to adjust the amount of assistance they use to compensate for the increased workload. Further, when comparing between loaded and unloaded pedelec rides, participants were found to use the highest two assistance modes more often during the loaded trial, suggesting that they compensated for the added weight by increasing the assistance modes used. Importantly, this did not compromise the intensity of the activity when compared to the unloaded session. Previous studies which have investigated the intensity of physical activity while pedelec riding have prevented participants from increasing or decreasing assistance modes while riding (La Salle et al., 2017; Langford et al., 2017; Simons et al., 2009). Peterman et al. (2016) measured the physical activity of pedelec riding at a self-selected intensity over 4-weeks of commuting, with free choice of assistance modes, however, data on assistance modes used were not collected. They found that sedentary commuters self-selected a moderate intensity and achieved significant improvements to VO_2max and power output. Similarly, the present study allowed participants to adjust the level of assistance they received at any point. We believe that this is more representative of real-world pedelec use as cyclists are likely to adjust assistance, thereby moderating the intensity of physical activity, depending on environmental conditions (i.e. hills or wind). Thus, we recommend that future research seeking to investigate the physiological aspects of pedelecs riding replicate real-world use by allowing participants to freely select assistance levels.

This is the first study to determine that added load does not significantly impact the intensity of pedelec riding in older adults. The previously mentioned research by Bini et al. (2019) found that during simulated mail delivery on a flat indoor course, postal workers compensated for added load (16-32kg) by increasing the assistance received, thus resulting in no change in intensity. However, the e-bike used was a throttle-assist e-bike, purpose-built for mail delivery and featured a hub-drive throttle-assist system which operates independent of any pedaling. The present study utilizes a pedelec with a mid-drive pedal-assist system which requires active pedaling to be activated. By utilizing a torque sensor, the pedelec is able to provide electric assistance proportional to the pressure applied to the pedals. This suggests that, similar to throttle-assist e-bikes, pedelecs can be used for active transportation applications where carrying added load is required, without increasing exertion.

Although the present study was not powered to examine any sex differences, on average, female participants achieved vigorous intensity physical activity in both unloaded and loaded pedelec rides, that is, 78% and 80% HRmax, respectively. On the contrary, male participants achieved a moderate intensity physical activity in both loaded rides (72%HRmax) and unloaded rides (75%HRmax). This difference between male and female participants could be due to the higher absolute workload of both rides, and may be attributed to physiologic sex-based differences in skeletal muscle and respiratory systems (Ansdell et al., 2020). Previous studies have found females have 33% less lower body skeletal muscle mass and 30% lower body strength once sex-based differences in height and weight are controlled for, thus resulting in lower power output (Janssen et al., 2000; Miller et al., 1993). In the respiratory system, female morphological characteristics such as smaller lung and airway size lead to lower respiratory efficiency and results in greater exercise intensity when compared to similarly aged males (Dominelli et al., 2019; Joyner, 2017).

3.5.1 Limitations

Participants in this study were recruited via social media posts, posters at local bike shops and snowball sampling. This resulted in many experienced cyclists who were already exceeding the minimum physical activity recommendations being included in our sample. This in turn could limit the generalizability of our findings, that is, they may not be applicable to less experienced or more sedentary older adults given our participants were already active and riding conventional bicycles regularly. Moreover, many of the participants in our study were recreational cyclists who did not regularly use cycling for active transportation. This may have resulted in some participants self-selecting a comfortable pace more similar to a faster recreational ride, and not an errand type ride. It must also be recognized that self-selection of pace and assistance may be influenced by gender, however this was not accounted for in the present study. The self-selected pace, and thus intensity, may also not be fully representative of a real-world setting. The course used in this study was closed to traffic and was ridden continuously. In a real-world setting, older adults using pedelecs for active transportation are likely to encounter other road users and traffic lights which are likely to impact their self-selected pace. Moreover, as a result of being separated from traffic in the present study, participants may have felt more comfortable riding at a greater intensity than they would have had they been riding mixed in with other road users. All participants recruited in the present study also owned at least one personal conventional bike used for recreational riding and many owned more than one, suggesting that participants had a higher socio-economic status. Given that the pedelec used in this study retails for approximately $4000 CAD, it is reasonable to assume that purchasing a pedelec may not be realistic for a large segment of the older adult population. The familiarity with the pedelec is another limitation to this study. All but two participants had no previous experience riding pedelecs prior to participating in this study. All participants were familiarized with the controls and functions of the pedelec during their 2.5km familiarization ride, however it is possible that the riding behaviors observed during our study would not be consistent if all participants had prior experience riding a pedelec under real-world conditions or were pedelec owners. Finally, to simulate the added load of groceries or items of daily living, the present study utilized a fixed added load of 20kg which may have created an imbalance in relative workload between participants with a lower peak power out and those with a higher peak power output. This imbalance could therefore be responsible for the differences in intensity seen between female and male participants.

Future research should look to investigate the intensity of physical achieved by this population in a real-world setting by providing older adults with pedelecs for an extended period of time. This would help to determine if the MVPA achieved in this study is replicated outside of a closed course setting and if pedelecs can be a tool for older adults to increase their overall physical activity levels and health in the long-term. Further, given that we found added load can be compensated for with added assistance, future research should investigate if older adults who are provided with a pedelec (with cargo-carrying capabilities) use it for utilitarian trips, thereby increasing their physical activity.

In conclusion, pedelec riding on a closed course at self-selected pace elicited MVPA in active older adults. Load added to the pedelec, mimicking the weight of groceries, did not have an effect on the intensity of physical activity over 6.25km of riding. Therefore, pedelecs may aid older adults in meeting physical activity guidelines while also providing a means of active transportation for more utilitarian applications.

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CHAPTER 4: GENERAL DISCUSSION

4.1 THESIS SUMMARY

The purpose of this thesis was to determine if self-selected pedelec riding along a 6.25km track can be classified as MVPA based on heart rate and power output responses in older adults, and if adding load to the pedelec while riding along a 6.25km track changes the level of e-assist and thus the intensity of the activity completed.

We hypothesized that despite self-selected e-assistance, older adults would engage in MVPA, that is a heart rate of 64% HRmax or higher, and a POavg of 50% PPO or greater. We found that 19/21 participants achieved MVPA with a mean intensity of 75.6±12 %HRmax and 62.6 ±16.0 %PPO. Thus, our results indicate that pedelec riding at a self-selected pace with a self-selected level of assistance can be classified as MVPA in older adults.

We also hypothesized that older adults would increase the amount of electric assistance they receive from the pedelec when the simulated load of items of daily living are added to the pedelec but there would be negligible difference in the intensity of the cycling. We found no statistically significant differences in intensity between unloaded (75.6±12 %HRmax) and loaded (75.0±10.8 %HRmax) rides. Furthermore, no significant differences between unloaded and loaded rides were found in HRavg (Unloaded:119.6 ±12.0 vs. Loaded: 120.7 ± 15.6) or HRpeak (Unloaded: 136.2 ±13.9 vs. Loaded 137.8 ± 11.1). With regard to the power output, POavg was similar (NS) between rides (POavg Unloaded: 114.8 ± 31.1 vs. Loaded 110.7 ± 29.2). Peak PO from the loaded ride (248.7 ± 67.2) was similar (NS) to the unloaded ride (255.5 ± 73.7). Therefore, our findings confirm our hypotheses and suggest that added load has a negligible effect on the intensity of pedelec cycling.

4.2 Self-Selected Pace and Assistance

One of the overarching objectives of our study was to determine if pedelecs, when used as a means of active transportation, elicit an intensity of physical activity great enough to achieve health related benefits in older adults.

Previous studies who have measured the intensity of pedelec riding have allowed for the self-selection of pace, but restricted any changes in assistance modes (La Salle et al., 2017; Langford et al., 2017; Simons et al., 2009). Peterman et al. (2016) measured the physical activity of pedelec riding over 4-weeks of commuting with free choice of assistance modes, however, the assistance modes used were not recorded. This allowed for controlled measures of intensity at a given assistance mode, however pedelec riding restricted to individual assistance modes may not best reflect real-world use. Under real-world use for active transportation, pedelecs riders are able to modulate the intensity of their riding through several means. Similar to conventional bicycles, the intensity of pedelecs riding can be modulated by changing gears and pressure applied through the pedals. However, unlike conventional bicycles, many modern pedelecs offer a range of electrical assistance levels. Each increase in assistance level increases the proportional assistance provided by the electric motor, thus each change in assistance level changes the intensity of pedelec riding. As reported in a review by Fishman and Cherry (2016), under real-world use, pedelec riders reported finding an increase in assistance particularly useful when accelerating from a stop and when riding on uphill gradients. Therefore, to best represent the real-world use of pedelecs for active transportation, a key aspect of our study design was to allow for the ***self-selection*** of both pace and assistance levels. To ensure self-selection of pace was representative of real-world use, participants were instructed to cycle at a consistent pace which would best represent a trip to run errands such as going to the grocery store. Although, representative of real-world use, allowing for changes in assistance levels introduces a new variable which directly impacts intensity. Moreover, the majority of the older adults included in our sample were new pedelec riders who had not ridden a pedelec under real-world conditions. It is therefore possible that, in spite of a 2.5km familiarization ride, a learning effect was present. Meaning, that with more experience, participants may have used the assistance levels differently, and thus changed the intensity of pedelec riding. To control for this, future studies should aim for a more homogenous sample of experienced older adult pedelec riders.

The topography of the course is also likely to have influenced the self-selection of assistance by participants. As previously mentioned, increasing the amount of assistance provided by the pedelec is commonly done to compensate for the increase in physical exertion caused by accelerating from a stop and riding on uphill gradients. Although the course used in this study was relatively flat, it did include uphill gradients, accelerations, and rough terrain all of which may have influenced the participant's selection of assistance modes. This is difficult to confirm given that data on selection of assistance modes could not be matched to specific time points or GPS data. However, anecdotally, participants reported using higher assistance modes on areas of the course which required increased exertion. Therefore, inferences related to assistance mode selection can be made using heat maps of the power output and speed data seen in Figure 6 & 7. Both the power output heat map (Figure 6) and the speed heat map (Figure 7) are taken from the same unloaded ride. The three corners circled in red denote corners where, due to the nature of terrain and angle of the turn, participants had to slow down, then increase power output to accelerate back up to speed. The yellow sections denote areas of the course with an uphill gradient.

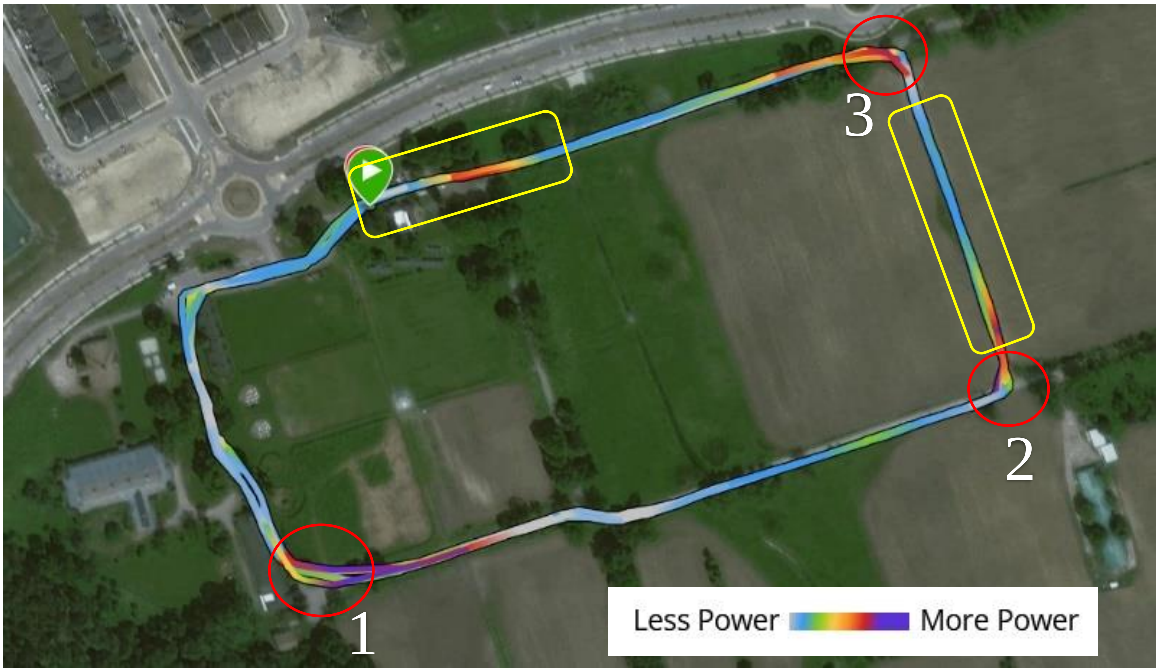

Figure 6. *Heat map of power output during 6.25km pedelec ride.*

When the areas with increased power output are compared to the heat map of speed (Figure 7) it is clear that speed increased following increased power output in corners 1 and 3, suggesting that power output is linked to increase in speed. However, on the sections with an uphill gradient, power output at the start of the incline is increased, but decreases quickly to power output levels seen in flat sections of the course. In spite of this reduction in power output on an uphill gradient, speed remained relatively consistent (circled in white). This suggests that a higher assistance mode was selected thereby reducing the power output required to maintain a consistent speed on an uphill gradient. Therefore, any insights related to the self-selection of both pace and assistance modes must take into consideration influence of the topography and layout of the course used.

Figure 7. *Heat map of speed during 6.25km pedelec ride.*

4.3 Distance and Topography of the Course

The outdoor course designed for this study was a 1.25km loop, completed 5 times for a total distance of 6.25km. The loop was marked with directional signage on private property and was closed off to traffic. The terrain of the course was mixed, comprised of approximately 700m of paved concrete, 550m of unpaved gravel road and 6m of elevation change (see Appendix B1 for course pictures).

The design of the course was informed by several key factors, each with a large influence on the primary outcome measures of this study (HR and PO). Given that, the course was designed to best represent real-world pedelec use. First, the location of the course was on private property which limited the impact of traffic lights, other road users, and cycling infrastructure which are otherwise likely to influence rider behavior and thus self-selected pace (Van Cauwenberg et al., 2019). Moreover, qualitative research by Leger et al. (2019) found that safety concerns due to poor cycling infrastructure resulted in changes in the pedelec riding behavior of Canadian older adults, with some resorting to riding on sidewalks to avoid conflicts with cars. Therefore, during real-world use, self-selected pace is likely dependent in part on the quality of the cycling infrastructure and the concentration of other road users. Therefore, the impact of poor cycling infrastructure and other road users must be considered when interpreting the implications of the findings from the present study relating to self-selected intensity.

Furthermore, by using a course closed off to traffic, participants may have felt less stressed and safer compared to riding on shared public roads, thereby reducing potential stressors which may have influenced heart rate response. Moreover, separation from other road users may have resulted in participants feeling safe enough to ride faster and therefore at a greater intensity than they may have otherwise on shared public roads. A 6.25km course distance was selected given that, in Canada 75% of car trips taken by older adults are under 10km and 50% are 5km or less (Turcotte, 2012). Moreover, the distance selected is in line with previous studies with similar objectives, which have utilized courses ranging it total distance from 3.5 – 10km (Hansen et al., 2018; La Salle et al., 2017; Langford et al., 2017). The topography of the course was largely flat and included 6m of elevation gain each lap for a total of 30m. This topography was selected as it is largely representative of the southern Ontario region. Previous studies by Berntsen et al. (2017) and Langford et al. (2017) have found that in spite of electric assistance, the intensity of pedelec riding increases on courses with more undulating topography. This suggests that the topography of the course used in the present study likely limited the intensity of pedelec riding and a greater intensity may have been seen if greater elevation change was included in the course design.

4.4 Active Sample

Participants recruited for this study were required to participate in a minimum of 150minutes of weekly physical activity and be comfortable riding a bicycle outdoors for roughly 10km. These eligibility criteria were implemented to ensure, a homogeneous sample, that participants would be able to reach the termination criteria for the maximal exercise test, all participants could safely complete both outdoor pedelec rides, and to minimize any learning effect of riding a bicycle. While these objectives were met, the generalizability of our findings is limited to active older adults. On average, the older adults recruited for this study had weekly physical activity levels which were more than double the minimum recommended by current physical activity guidelines. Given that 85% of Canadian older adults are failing to meet the current guideline minimum of 150minutes per week, the results of the present study cannot be generalized to less active Canadian older adults without further research.

Many of our participants were recruited through snowball sampling which resulted in the majority of participants being active members of a local cycling club, thus many participants were highly active and regularly cycled extended distances. Therefore, it is possible that the experience and activity level seen in our sample significantly impacted self-selected intensity. Thus, it would be reasonable to hypothesize that a sample of inactive and less experienced older adult cyclists may self-select a different intensity. Future research should aim to include a larger sample of cyclists with a greater range of experience levels to determine if self-selected pace remains consistent across all experience and activity levels.

4.5 Type of E-Bike

As previously mentioned, the definition the term 'e-bike' varies considerably by country and thus it is often used an umbrella term to describe several classifications of scooter-style-electric bicycles and bicycle-style electric bicycles (Fishman & Cherry, 2016). Importantly, only bicycle-style electric bicycles include pedals which can feasibly be used to propel the bike. Among bicycle-style electric bicycles, there exist several sub-classifications, of which, only e-bikes with pedal-assist (pedelecs) require physical exertion to activate the electric assistance. Therefore, in the context of active transportation and physical activity, only pedelecs were considered when selecting an e-bike for this study. Further criteria for pedelec selection included specific design characteristics. These included, mounting points for cargo carrying accessories (i.e. pannier bags), low-step frame design to reduce risk of falls when mounting and dismounting the pedelec, and a medium size frame to accommodate participants of different heights. The pedelec selected for this study includes a rear cargo rack with a proprietary mounting system for rear-mounted pannier bags, supplied by the manufacturer. Therefore, this system was used when weight was added for the loaded pedelec rides. This method was also used as rear-mounted pannier bags are the most popular method to carry added load on bicycles. However, many other solutions exist which may have improved a rider's comfort. Several participants reported that having all of the added load placed over the rear wheel made the front tire of the pedelec feel very light and unbalanced. This may have affected their self-selected pace, particularly over the unpaved selections of the course. It is therefore possible that the distribution of weight impacted the self-selected intensity of the loaded pedelec rides. Future research should aim to more evenly distribute added load by using additional cargo carrying accessories such as front-mounted pannier bags or a cargo trailer.

4.6 Implications

This study had two main findings from which several implications can be drawn. First, we found that older adults do self-select at least a moderate intensity of physical activity as determined by their percent of HRmax and percent of POmax. Second, when compared to the unloaded pedelec ride, added load does not result in any significant differences in average heart rate or average power output. As previously mentioned, our primary finding suggests that regular pedelec riding at a self-selected pace has the potential to assist older adults in meeting physical activity guidelines and achieving health related benefits. When taken together, our primary and secondary findings have potential implications for the physical and social well-being of older adults, the environment, and transportation infrastructure and policies. On an individual scale, our findings further support existing evidence that the regular use of pedelecs as a means of active transportation can improve cardiorespiratory health (Cooper et al., 2018; Malnes, 2016).

4.7 Broader Implications

Given the scope of the present study, the implications from our findings are most applicable at the level of the individual. However, there exist broader environmental and infrastructure implications when considering the impact of a large-scale shift towards active transportation. When evaluating the environmental impact, the transportation sector is major contributor to total global emissions and ambient air pollution. Current estimates suggest that transportation tailpipe emissions are responsible for 11.4% of emissions and ozone mortality (Anenberg et al., 2019). These tailpipe emissions have direct health impacts, particularly in G20 countries where vehicle tailpipe emissions are responsible for 5.38 deaths per 100,000, resulting in 7.8million years of life lost per year globally (Anenberg et al., 2019). Although pedelecs cannot replace all vehicle trips, McQueen et al. (2020) estimated that CO_2 emissions related to personal transport could be reduced by 12% if pedelecs were used for just 15% of personal miles travelled. Given that 75% of car trips under 10km, our findings further support existing evidence that a broader transportation mode shift towards increasing pedelecs use is feasible and would have a considerable positive environmental impact.

In spite of these environmental benefits, a broader transportation mode shift towards pedelecs is unlikely without significant improvements in active transportation-friendly infrastructure (Leger et al., 2019; Winters et al., 2011). The upfront cost of building or improving existing infrastructure is likely to exceed both historic and current investments, making it difficult for municipal and regional governments to fund. However, when taking into consideration the emission reductions, and health and injury savings, the returns on investment outweigh the cost 11:1 (Chapman et al., 2018). Therefore, policy and funding decisions made by all levels of government relating to investments in active transportation infrastructure should be informed by (1) the return on investment, and (2) the evidence provided by the present study and others which demonstrates the potential of modes of active transportation such as pedelecs to improve health and replace car trips.

4.8 Future Research

Future research should aim to investigate the intensity of physical activity achieved by this population in a real-world setting by providing older adults with pedelecs for an extended period of time. This would help to determine if the MVPA intensity is replicated outside of a closed course setting and if pedelecs can help older adults increase their overall physical activity levels and health. Further, given that we found added load can be compensated for with added assistance, future research is needed to determine if older adults who are provided with a pedelec (with cargo-carrying capabilities) use it for utilitarian trips, thereby increasing their physical activity.

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APPENDIX A

A1. Eligibility Questionnaire

A2. Informed Consent

A3. CSEP Get Active Questionnaire

A4. Cycling History Questionnaire

A5. Data Collection Sheet Session 1

A6. Borg Rating of Perceived Exertion Scale

A7. Map of Outdoor Course

A8. Data Collection Sheet Session 2 & 3

A9. E-bike Experience Questionnaire

APPENDIX A1 – *Eligibility Questionnaire*

Eligibility Questionnaire

1. Age: _____
2. Do you currently have any conditions that could be triggered or worsened by engaging in moderate intensity exercise while outdoors in the summer?

   Yes ☐

   No ☐

   If yes, please explain:

   ____

   ____

3. Are you currently taking any prescription or over the counter medications regularly?

   Yes ☐

   No ☐

   If yes, please list the medications here: ____

4. Do you have any injuries or conditions that would limit your ability to cycle on a stationary bicycle or outside on a pedal assist e-bike? (e.g. knee injury)

   Yes☐

   No ☐

   If yes, please describe the injury here: ____

5. Do you own a bicycle helmet certified by Transport Canada?

   Yes ☐

   No ☐

6. Are you comfortable cycling on a closed course for roughly 10km?

   Yes ☐

   No ☐

If you have any questions concerning the research study, or experience any discomfort related to the study, please contact the researcher, Michael Jenkins, at 613.883.2930 or michael.jenkins@uoit.ca. Alternatively, you may contact the principal investigator, Dr. Shilpa Dogra, at 905.721.8668 ext. 6240 or shilpa.dogra@uoit.ca. Any questions regarding your rights as a participant, complaints or adverse events may be addressed to Research Ethics Board through the Research Ethics Coordinator – researchethics@uoit.ca or 905.721.8668 x. 3693

APPENDIX A2 – *Informed Consent*

ONTARIO TECH UNIVERSITY

Study Title: Physiological and Behavioural Aspects of E-bike use in Older Adults

Name of Principal Investigator: Dr. Shilpa Dogra, PhD, CSEP-CEP (UOIT)

Study Information and Consent Form

Introduction:

You are invited to participate in a research study that is being conducted at Ontario Tech University. Throughout this document you will find the study purpose, procedure, benefits and risks, as well as your right to refuse to participate or withdraw from the study. Please thoroughly read and understand all sections of this document before you agree to participate in this study. This is known as the informed consent process. Should you have any questions concerning any of the information, words, or your rights, please contact the researchers above to gain full understanding before signing this consent form.

Purpose & Explanation of the Study:

The purpose of the proposed study is to twofold: 1) to better understand how changing the weight of an e-bike impacts exertion and enjoyment levels of cycling, and 2) to understand the perceptions of e-bikes in older adults. To do so, you will be asked to attend one laboratory sessions (exercise testing) and two field sessions (e-bike circuit). You will be asked to complete some questionnaires as well, and MAY be asked to conduct a video conference interview to discuss your perception of e-bikes.

Eligibility:

In order to be eligible, you must be over the age of 60 years. You must also have no major cardiometabolic, respiratory, or musculoskeletal conditions that would impact your ability to cycle on a stationary bike or conventional bike. You must own a bicycle helmet certified by Transport Canada and be comfortable cycling on a closed course for roughly 10km. You have already completed an eligibility questionnaire, and we have confirmed these criteria. At the first session, we will also be measuring your resting heart rate and blood pressure. This is to ensure your safety.

Assessment Procedures:

During the laboratory session, you will be asked to complete a maximal exercise test on a stationary bicycle and to complete a questionnaire related to your cycling history. The purpose of the maximal exercise test is to determine your maximal heart rate, peak power output, and cardiorespiratory fitness. Throughout this session your oxygen consumption and heart rate will be constantly monitored. Your height, weight, waist circumference, resting heart rate and blood pressure will be assessed. The two e-bike rides will be conducted outdoors in random order. The two rides will be identical with the exception of the weight of the bike. For both rides an e-bike will be set up with a pedal power meter, a head unit displaying revolutions per minute (RPMs) and a single pannier bag mounted on a rack over the rear wheel. You will be asked to wear a heart rate monitor chest strap and complete 5 laps of a 2km enclosed outdoor track over mixed terrain at a comfortable pace. In one of the two rides, weight will be added to the pannier bag. Immediately following the completion of the session, you will be asked to complete a questionnaire on your enjoyment and perceptions of the ride. Upon completing both rides, you will complete an additional questionnaire.

We will also be randomly drawing names of participants to complete an interview so that we can better understand perceptions related to e-bike use. This interview will be set up at a date and time that is convenient to you, and your participation in this interview is completely voluntary.

Participant Compensation:

You will not be paid for your participation in this study; however, you have much to gain! You will be sent your personal results in the form of an email at the end of the study. These data will provide you with information related to your personal cardiovascular fitness and peak power output on the stationary bike.

Risks and Participant Safety:

Participation in any research study is associated with some risks. The potential risks of this study include, feelings of shortness of breath, quickened heart rate, light headedness, and muscular discomfort during and following exercise, risk of falls and feeling coerced in to participating in the study. You may also experience feelings of soreness due to your physical exertion during the maximal exercise test. To minimize these risks and to ensure your safety throughout this study, the researchers involved with the study have current first responder training, and have degrees in Kinesiology. Additionally, an emergency action plan is posted in the laboratory and will be brought to the field sessions. We will also encourage you to follow all instructions closely, and immediately report any unusual exercise related symptoms**.**

COVID-19: There may be additional risks to participating in this research during the COVID-19 pandemic that are currently unforeseen and, therefore, not listed in this consent form. Our complete COVID-19 related safety precautions are listed in the attached COVID-19 appendix.

If you feel that you are in a vulnerable group with respect to COVID-19 effects (e.g. senior with chronic comorbidities, immunocompromised, living with individuals that may be susceptible to COVID-19), it may be best that you do not participate in the study.

Benefits:

There are numerous benefits to you as a participant in this study. Engaging in the study will provide you with information related to your cardiovascular health and cycling performance metrics. Participating in this study will also allow you the opportunity to ride the new 2020 Trek Verve + low step and try the Bosch Kiox e-bike computer.

Cost of Participating:

There are no costs associated with participation in this study. There will be no reimbursement for any costs incurred for participating in this study (e.g. transportation fees etc.).

Withdrawal:

You have the right to withdraw from the study without any consequence and will be allowed to do so at any point during the study. If you would like to withdraw from the study, please contact the researcher via email at Michael.jenkins@uoit.ca or in person. In addition, any data collected from you can be withdrawn and destroyed. Please notify us if you would like your data to be destroyed. You have the right to withdraw your data at any point during the study or for up to 1 month following completion of the study.

You maintain your right to withdraw from the study, including research data. If you do withdraw, we must still continue to maintain your contact information and will only give it Durham Public Health and the University if required for contact tracing.

Participant Confidentiality:

At each session, a member of the research team will be present to collect data. Following the session, only the PI and members of the research team will have access to your data. Your data will be kept confidential and will be coded (therefore stored anonymously). All hard copies of your data will be stored in a locked cabinet in a laboratory at Ontario Tech University; these will be shredded once data are analyzed. An Ontario Tech University Google drive will be used to store all electronic files. Only the research team will have access to electronic files.

We will be collecting your name and phone number that we must retain in order to follow up with you and/or conduct contact tracing if you may have been exposed to COVID-19 in coming to the research site. In some cases, this may need to be shared with the University or Public Health, and as a result, we cannot guarantee privacy and confidentiality of your participation in the study. Contact information will be kept separate from data collection through the research study to allow for de-identification of the research data. Although your data will be kept confidential and stored anonymously, we cannot guarantee anonymity, as the personal contact information does identify you as a participant.

Participant Concerns and Reporting: If you have any questions concerning the research study or experience any discomfort related to the study, please contact the researcher Dr. Shilpa Dogra at 905.721.8668 ext. 6240 or Shilpa.Dogra@uoit.ca.

This study has been approved by the Ontario Tech University Research Ethics Board REB 15896.

Any questions regarding your rights as a participant, complaints or adverse events may be addressed to Research Ethics Board through the Ethics and Compliance Officer - researchethics@uoit.ca or 905.721.8668 x. 3693.

Consent

I understand the procedures, potential risk and benefits of this study. Any questions regarding this study have been answered to my satisfaction.

I understand my consent to participate, or to not participate in this study is voluntary. I also understand my right to withdraw from any part or all of this study for any reason. I waive no legal rights by participating in this study.

If I have any questions regarding my rights as a research participant, or about any issues relating to this study, I will contact Dr. Shilpa Dogra at 905.721.8668 ext. 6240 or Shilpa.Dogra@uoit.ca.

Please indicate below if you consent to the information collected in the eligibility questionnaire being used in the study.

Yes ☐ No ☐

Please indicate if you consent to your data being used for purposes of secondary analysis

Yes ☐ No ☐

I hereby consent to participate in this study.

____________________________ ______________________ ______/______/________

Participant (Print Name) Signature Date

For a member of the research study: I have ensured the named participant above has thoroughly understood all aspects of this research study, and have answered all questions to their satisfaction.

____________________________ ______________________ ______/______/________

Research Member (Print Name) Signature Date

APPENDIX A3 – *CSEP Get Active Questionnaire*

CSEP | SCPE
THE GOLD STANDARD IN EXERCISE SCIENCE AND PERSONAL TRAINING

Get Active Questionnaire

CANADIAN SOCIETY FOR EXERCISE PHYSIOLOGY –
PHYSICAL ACTIVITY TRAINING FOR HEALTH (CSEP-PATH®)

Physical activity improves your physical and mental health. Even small amounts of physical activity are good, and more is better.

For almost everyone, the benefits of physical activity far outweigh any risks. For some individuals, specific advice from a Qualified Exercise Professional (QEP – has post-secondary education in exercise sciences and an advanced certification in the area – see csep.ca/certifications) or health care provider is advisable. **This questionnaire is intended for all ages – to help move you along the path to becoming more physically active.**

☐ **I am completing this questionnaire for myself.**

☐ **I am completing this questionnaire for my child/dependent as parent/guardian.**

PREPARE TO BECOME MORE ACTIVE

The following questions will help to ensure that you have a safe physical activity experience. Please answer YES or NO to each question before you become more physically active. If you are unsure about any question, answer YES.

YES	NO	
		1 Have you experienced **ANY** of the following (A to F) **within the past six months**?
○	○	**A** A diagnosis of/treatment for heart disease or stroke, or pain/discomfort/pressure in your chest during activities of daily living or during physical activity?
○	○	**B** A diagnosis of/treatment for high blood pressure (BP), or a resting BP of 160/90 mmHg or higher?
○	○	**C** Dizziness or lightheadedness during physical activity?
○	○	**D** Shortness of breath at rest?
○	○	**E** Loss of consciousness/fainting for any reason?
○	○	**F** Concussion?
○	○	**2** Do you currently have pain or swelling in any part of your body (such as from an injury, acute flare-up of arthritis, or back pain) that affects your ability to be physically active?
○	○	**3** Has a health care provider told you that you should avoid or modify certain types of physical activity?
○	○	**4** Do you have any other medical or physical condition (such as diabetes, cancer, osteoporosis, asthma, spinal cord injury) that may affect your ability to be physically active?

NO to all questions: go to Page 2 – ASSESS YOUR CURRENT PHYSICAL ACTIVITY ➤

YES to any question: go to Reference Document – ADVICE ON WHAT TO DO IF YOU HAVE A YES RESPONSE ➤➤

CSEP | SCPE
THE GOLD STANDARD IN EXERCISE SCIENCE AND PERSONAL TRAINING

Get Active Questionnaire

ASSESS YOUR CURRENT PHYSICAL ACTIVITY

Answer the following questions to assess how active you are now. **1** During a typical week, on how many days do you do moderate- to vigorous-intensity aerobic physical activity (such as brisk walking, cycling or jogging)? DAYS/ WEEK

2 On days that you do at least moderate-intensity aerobic physical activity (e.g., brisk walking), for how many minutes do you do this activity? MINUTES/ DAY

For adults, please multiply your average number of days/week by the average number of minutes/day: MINUTES/ WEEK

Canadian Physical Activity Guidelines recommend that adults accumulate at least 150 minutes of moderate- to vigorous-intensity physical activity per week. For children and youth, at least 60 minutes daily is recommended. Strengthening muscles and bones at least two times per week for adults, and three times per week for children and youth, is also recommended (see csep.ca/guidelines).

GENERAL ADVICE FOR BECOMING MORE ACTIVE

Increase your physical activity gradually so that you have a positive experience. Build physical activities that you enjoy into your day (e.g., take a walk with a friend, ride your bike to school or work) and reduce your sedentary behaviour (e.g., prolonged sitting).

If you want to do **vigorous-intensity physical activity** (i.e., physical activity at an intensity that makes it hard to carry on a conversation), and you do not meet minimum physical activity recommendations noted above, consult a Qualified Exercise Professional (QEP) beforehand. This can help ensure that your physical activity is safe and suitable for your circumstances.

Physical activity is also an important part of a healthy pregnancy.

Delay becoming more active if you are not feeling well because of a temporary illness.

DECLARATION

To the best of my knowledge, all of the information I have supplied on this questionnaire is correct. If my health changes, I will complete this questionnaire again.

I answered NO to all questions on Page 1

I answered YES to any question on Page 1

Name (+ Name of Parent/Guardian if applicable) [Please print] | Signature (or Signature of Parent/Guardian if applicable) | Date of Birth

Date | Email (optional) | Telephone (optional)

With planning and support you can enjoy the benefits of becoming more physically active. A QEP can help.

☐ **Check this box if you would like to consult a QEP about becoming more physically active. (This completed questionnaire will help the QEP get to know you and understand your needs.)**

APPENDIX A4 – *Cycling History Questionnaire*

Please fill in the table below using ✓ for YES and leave blank for NO. Please see the definitions of each bike type provided at the end of this questionnaire.

	Type of Bike	**Road**	**Hybrid**	**MTB**	**Low-Step**	**E-bike**	**Other** Please Specify
1.	Do you own this type of bike?						
2.	Do you ride this bike all year round?						
3.	Do you have any cargo attachments on this bike, such as panniers or a basket?						
4.	Do you ever use a trailer attached to this bike?						
5.	Do you use this bike for commuting or for chores?						
6.	Do you ride this bike for recreation/ exercise?						
7.	Do ride this bike with friends or family?						

		Road	**Hybrid**	**MTB**	**Low-Step**	**E-Bike**	**Other Please specify**

8.	In the summer months, how many **days** per week do you ride this bike?						
9.	In the winter months, how many **days** per week do you ride this bike?						
10.	On an average recreational ride, how many **kilometers** do you ride this bike?						
11.	On an average commute ride, how many **kilometers** do you ride this bike?						
12.	On an average errand type ride, how many **kilometers** do you ride this bike? (Errands: groceries, appointments, etc.)						
13.	How many **days** per week do you typically use this bike to run errands or grocery shop?						
14.	How many **days** per week do you typically use this bike for commuting?						
15.	If you are currently considering purchasing a new/used bike, **what style** are you considering?						
16.	Have you ever ridden any of these bike types with rear mounted panniers?						

Please fill in the table below using the units indicated in **bold** in the table

APPENDIX A5 – *Data Collection Sheet Session 1*

Lab Session 1 – Participant Background Questionnaire and Lab Session Data Collection Sheet

Participant ID Code:

Date (dd/mmm/yyyy)	
Participant Arrival Time	________ AM☐PM☐
Participant Has No New Health Conditions Since Completing the Eligibility Questionnaire:	YES ☐ NO ☐

Participant reviewed informed consent: YES ☐

Participant signed informed consent: YES ☐

Participant reminded of right to withdraw: YES ☐

Sex: Male ☐ Female ☐ Other ☐ Prefer not to answer ☐

Baseline Measures

Measure	**Data**	**Notes**
Resting Heart Rate (bpm)		
Resting Blood Pressure (mmHg)	**1st** **2nd**	
Height (cm)		
Weight (kg)		
Waist Circumference (cm)		

<u>Session Measures: Maximal Exercise Test</u>

Time	RPM (70-90)	Watts	HR	RPE
WARM-UP				
1 min		50		
2 min		50		
TESTING PROTOCOL (1W/3sec)				
1 min		60		
2 min		80		
3 min		100		
4 min		120		
5 min		140		
6 min		160		
7 min		180		
8 min		200		
9 min		220		
10min		240		
11min		260		
12 min		280		
13 min		300		
14 min		320		
15 min		340		
16 min		360		
COOL-DOWN				
1 min		50		
2 min		50		
3 min		50		
4 min		50		

APPENDIX A6 – *Borg Rating of Perceived Exertion Scale*

6 – No Exertion at all

7 – Extremely Light

8

9 – Very Light

10

11 – Light

12

13 – Somewhat Hard

14

15 – Hard (heavy)

16

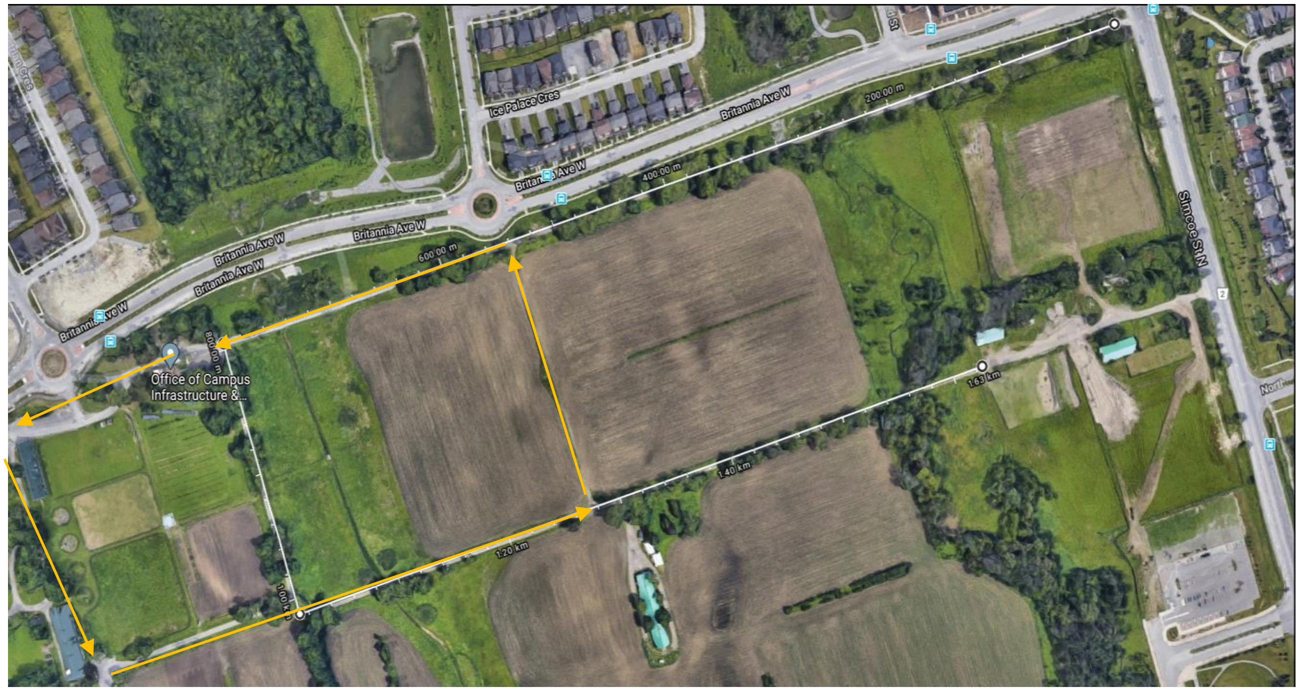
17 – Very Hard

18

19 – Extremely Hard

20 – Maximal Exertion

APPENDIX A7 - *Outdoor Course Map*



Imagery ©2020 Google, Imagery ©2020 First Base Solutions, Maxar Technologies, Map data ©2020

50 m

APPENDIX A8 – *Data Collection Sheet Session 2 & 3*

Field Session Data Collection Sheet – Start line collection sheet

Participant ID Code.		**Date (dd/mmm/yyyy)**	
Participant Arrival Time	_________ AM☐PM☐	**Session to be completed today.**	Weighted ☐ Unweighted☐
Participant has arrived with a helmet approved by Transport Canada	YES ☐ NO ☐	**Participant Has No New Health Conditions Since Completing the Eligibility Questionnaire:**	YES ☐ NO ☐

Participant reminded of right to withdraw: YES ☐

<u>Outdoor Measures</u>

Measure	**Data**	**Notes**
Temperature (Celsius)		
Humidity (%)		
Track Conditions (dry/wet)		
Wind Speed (Km/h)		
Wind Directions (Degrees)		

Session Measures

Time	**RPE**	**Notes**
Start time:		
Split 1:		
Split 2:		
Split 3:		
Split 4:		
Split 5:		
Split 6:		
Split 7:		
Split 8:		
Split 9:		
Split 10:		

APPENDIX A9 – *E-bike Experience Questionnaire*

<u>E-bike Experience Questionnaire</u>

1. How far would you consider riding e-bike for transportation on a regular basis?

0-2km ☐ 2-4km ☐ 4-6km ☐ 6-8km ☐ 8-10km ☐ 10-15km ☐ 15-20km ☐

20km+ ☐

2. How far would you consider riding a conventional bike for transportation on a regular basis?

0-2km ☐ 2-4km ☐ 4-6km ☐ 6-8km ☐ 8-10km ☐ 10-15km ☐ 15-20km ☐

20km+ ☐

3. How far could you see yourself riding an e-bike to complete trips which require you to carry extra weight?

0-2km ☐ 2-4km ☐ 4-6km ☐ 6-8km ☐ 8-10km ☐ 10-15km ☐ 15-20km ☐

20km+ ☐

	Please indicate your response to the following statements with a "X" in the box that best suits your personal impressions.	**Prefer not to answer**	**Strongly Agree**	**Agree**	**Neither agree or disagree**	**Disagree**	**Strongly disagree**
1.	I found the e-bike easy to use.						
2.	I found the e-bike comfortable.						
3.	I found the e-bike easy to handle over the mixed terrain course.						
4.	I felt comfortable while riding the e-bike with added weight.						
5.	I had to work harder when weight was added to the e-bike.						
6.	I felt in control while riding this e-bike.						
7.	I felt safe while riding this e-bike.						
8.	I enjoyed riding this e-bike.						
9.	I prefer riding this e-bike to a conventional bike.						

	Effort	**Prefer not to answer**	**Significantly harder**	**Harder**	**Same**	**Easier**	**Significantly easier**
1.	The ride with the added weight was?						
2.	The ride without the added weight was?						
	Discomfort	**Prefer not answer**	**Significantly greater**	**Greater**	**Same**	**Less**	**Significantly Less**
3.	The discomfort in my legs with added weight was?						
4.	The discomfort in my legs without added weight was?						
5.	The discomfort in my back with added weight was?						
6.	The discomfort in my back without added weight was?						

1. Now that you have ridden a pedal assist e-bike twice, what are your general impressions of the e-bike?

____

____

____

____

2. Did any of your perceptions about e-bikes change after having completed this study.

Please Explain.

____

____

____

____