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Exploring e-bikes as a mode of sustainable transport: A temporal qualitative study of the perspectives of a sample of novice riders in a Canadian city

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Key Messages

- E-bikes are an under-studied emerging technology with potential to facilitate sustainability agendas in urban transportation (e.g. active, multi-modal, low-carbon mobility).
- Little to no research has been conducted on e-bikes in Canadian urban contexts where sprawl and car dependency are predominant.
- E-bikes may be a viable substitute for cars for shorter commutes, yet weight, winter weather, and battery life remain barriers.

Automobile dependency is widely regarded as unsustainable and non-conducive to the newer Smart Growth planning paradigm. The need for reform in transportation behaviour, policy, and infrastructure is topping urban political agendas globally. E-bikes are one emerging technology with promise for advancing sustainability agendas. E-bikes are revolutionizing transportation in China and parts of Europe, yet little is known about user patterns in North America, particularly Canadian cities where uptake tends to lag. Through longitudinal focus groups and interviews we explore the changing behaviours, experiences, and perceptions of a group of novice e-bike riders over a three-year period in Kitchener-Waterloo, Ontario in order to expand upon the limited knowledge base on urban e-bike usage, impacts, and challenges. Prevailing themes discussed include the types of trips e-bikes are typically used for, implications for physical activity, prospects for enabling a modal shift away from cars and encouraging multi-modal transit, and limitations (e.g., battery restrictions, heavy weight, lack of infrastructure, fear of theft, winter weather, etc.). Further research is needed to better understand how e-bikes influence physical activity, social determinants of health, and safety; how demographic and physical environmental factors influence individual decisions around modal shift; and differences in use patterns between avid and novice cyclists.

Keywords: e-bikes, urban sustainability, transportation, novice riders, Canada

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Examen de l'usage des vélos électriques comme mode de transport durable : une étude qualitative longitudinale basée sur un échantillon de cyclistes débutants dans une ville canadienne

La dépendance à l'automobile est largement considérée comme non durable et contraire au paradigme le plus récent de la planification de la croissance intelligente. Le besoin d'une réforme des comportements, des politiques et des infrastructures de transport domine les programmes de politiques urbaines partout dans le monde. Les vélos électriques sont l'une des nouvelles technologies qui offrent un espoir de promotion des programmes de durabilité. Les vélos électriques révolutionnent le transport en Chine et dans certaines parties de l'Europe, mais on connaît très peu les habitudes des utilisateurs en Amérique du Nord, particulièrement dans les villes canadiennes où l'acceptation tend à accuser un certain retard. Au moyen de groupes de discussion longitudinaux et d'entrevues, nous examinons les changements de comportements, les expériences et les perceptions d'un groupe de cyclistes débutants sur une période de trois ans à Kitchener-Waterloo, en Ontario, afin d'accroître les connaissances sur l'utilisation, les impacts et les défis du vélo électrique urbain. Les thèmes dominants qui sont abordés comprennent les types de déplacements pour lesquels les vélos électriques sont habituellement utilisés, les implications pour l'activité physique, les chances d'entraîner un report modal au détriment de la voiture et d'encourager le transport en commun multimodal ainsi que les limites (p. ex., restrictions des piles, poids élevé, manque d'infrastructure, crainte du vol, climat hivernal, etc.). Des recherches plus poussées sont requises afin de mieux comprendre la façon dont les vélos électriques influencent l'activité physique, les déterminants sociaux de la santé et la sécurité ainsi que la façon dont les facteurs de la démographie et de l'environnement physique influencent les décisions individuelles concernant le report modal et les différences d'usage entre les cyclistes débutants et les mordus du vélo.

Mots clés : vélos électriques, durabilité urbaine, transport, cyclistes débutants, Canada

Introduction

In the past two decades, urban sustainability has moved to the top of policy and research agendas in North American cities. This is, in part, a reaction to the widespread adoption of suburban sprawl as a development strategy since the latter half of the 20^{th} century. Sprawl has been widely criticized for perpetuating automobile dependency and associated risks, including increased greenhouse gas emissions, habitat fragmentation, energy insecurity, injuries and fatalities, social exclusion, reduced economic productivity and well-being due to congestion, and increased chronic diseases related to air pollution and sedentary lifestyles (Boschmann and Kwan 2008; Jin et al. 2012; Bakker et al. 2014; Buekers et al. 2014).

Recent trends in land use and urban design favour intensification and active transportation, in line with Smart Growth principles (Behan et al. 2008). Such large-scale changes in urban form both catalyze and enable shifts in transportation strategies (Behan et al. 2008) that move away from car dependency towards systems that better respond to a range of environmental, social, and public health needs (Nilsson et al. 2012). For example, Ontario's latest Growth Plan for the Greater Golden Horseshoe has encouraged investment in transportation systems that are not only environmentally sustainable, but capable of facilitating multimodal access to recreational and utilitarian amenities (Government of Ontario 2017).

There have been movements towards low-carbon alternatives to the automobile (e.g., public transportation, electric vehicles), as well as more active modes of transportation (e.g., walking and cycling) (Boschmann and Kwan 2008; Nilsson et al. 2012; Langford et al. 2013; Bakker et al. 2014; Buekers et al. 2014). One emerging technology with potential to support these aims is the electric bike or "e-bike." In Ontario, e-bikes are broadly defined as motorized bicycles that can look like conventional bicycles, scooters, or smaller motorcycles (Ministry of Transportation Ontario 2015); depending on the model, varying degrees of human muscle are still required to propel these bikes, in addition to their battery-powered assistance (see Figure 1).

Globally, e-bikes of all types are rapidly rising in popularity, with sales in China alone amounting to more than 10 million annually (Jin et al. 2012). The

Figure 1
Sample of range of e-bike models and designs.
SOURCE: Image courtesy of Amego Electric Vehicles, Toronto. Reproduced with permission.

Netherlands and Germany account for half of all e-bike sales in the European Union at approximately 350,000 annually, which is at least double the sales in the United States (US), despite the smaller populations in both countries (Rose 2011). In the Canadian context, there is little information available on the number of e-bikes sold or used (Flavelle 2014). Despite significant distinctions in performance characteristics and associated risks and benefits, regulatory bodies, sales figures, and research studies typically do not delineate between e-bikes models.

The vast majority of existing e-bike research has focused on China, where several regulatory tools have been employed to encourage their adoption to reduce pollution and congestion (Weinert, Ma, and Cherry 2007; Weinert et al. 2008; Cherry et al. 2009; An et al. 2013). Throughout many parts of Europe, the strong cycling culture and progressive infrastructure are more conducive to supporting cycling in various forms as a primary mode of travel (Colville-Andersen 2014; Flavelle 2014). This contrasts with North American contexts where cycling culture and infrastructure is limited (albeit growing), constraining the number of car trips being replaced by e-bikes or bikes more generally (Heinstein and Moller 2016). Virtually no research has been conducted within the Canadian urban context to assess whether e-bike technology will have the same appeal, uptake, or potential for triggering more sustainable transportation behaviours and planning designs.

Canada is an important case for considering the potential of e-bike technology, given that approximately 81% of Canadian adults rely on cars to commute to work compared to 12% taking transit and 7% using active modes (Statistics Canada 2016). Canada faces unique challenges, including smaller populations and consumer markets, adverse winter weather, and urban built forms that privilege car dependency. Despite these challenges, Canadian planning institutions have recently developed Healthy Communities Practice Guidelines that encourage planners to draft policies that reduce automobile dependency (Canadian Institute of Planners 2014; Ontario Professional Planners Institute 2016). There is a need to strengthen our understanding of e-bike user experiences within North American urban contexts, especially given that e-bike riders are vying for space within exceptionally crowded, car-centric transportation geographies (MacArthur et al. 2014).

This paper contributes to the growing global knowledge base on urban e-bike usage by focusing on early patterns emerging in the under-explored Canadian context. Specifically, we present qualitative data from a preliminary, exploratory study of a small sample of new e-bike riders in urban Kitchener-Waterloo, Ontario. Our findings provide in-depth insight into the perceptions and experiences of these riders, and how these may have changed over time, to help inform future research agendas focused on the potential for emerging e-bike technology to advance urban sustainability within Canada and beyond.

Current state of knowledge on e-bikes

E-bikes are a relatively novel transportation technology. Accordingly, they are the focus of a small, albeit growing, body of literature. These studies vary by location, focus, and methodology, yet generally suggest that e-bikes may help catalyze the adoption of cleaner, more physically active modes of transportation (see Table 1).

E-bike uptake

Existing literature acknowledges that e-bikes are a viable transportation option for a variety of users, who may be motivated by the ability to reduce their carbon footprint, travel greater distances using less energy, bear heavier loads (e.g., a trailer for children or groceries), or increase travel convenience and flexibility relative to public transit (e.g., more direct routes, and elimination of wait times) (Cherry and Cervero 2007; Weinert, Ma, and Cherry 2007; Gojanovic et al. 2011; Rose 2011; Dill and Rose 2012; Langford et al. 2013; Popovich et al. 2014; MacArthur et al. 2014; Haustein and Moller 2016; Jones et al. 2016). E-bikes offer particular benefits to groups that may be experiencing mobility-related marginalization, including aging populations and those with physical disabilities (Gojanovic et al. 2011; Rose 2011; Dill and Rose 2012; MacArthur et al. 2014). E-bikes may also be beneficial to those with limited income due to their cost relative to private automobiles (Weinert, Ma, and Cherry 2007). Conversely, the high upfront costs of purchasing an e-bike, compared to a traditional bike or transit, have been cited as barriers to uptake (Popovich et al. 2014; Fishman and Cherry 2016; Jones et al. 2016). These concerns could be exacerbated in contexts with a shortened riding season due to inclement weather (Langford et al. 2013).

Research has acknowledged that this technology is taken up by both avid cyclists and those new to cycling (Dill and Rose 2012). A primary barrier to uptake is disagreement over whether e-bikes should share trails/lanes with conventional bicycles, given their relatively heavier mass and higher speeds (Dill and Rose 2012). Additional concerns include impacts on the energy grid (Dill and Rose 2012). From a social perspective, studies have documented negative perceptions towards e-bike users by motorists, conventional cyclists, and pedestrians. E-bikes have been perceived as "toys" rather than "real" bikes, and their riders as "lazy" (Dill and Rose 2012; Flavelle 2014; Popovich et al. 2014). Others caution that these sentiments overlook the potential health and environmental benefits of e-bikes as commuter vehicles, relative to cars (Popovich et al. 2014).

E-bikes as potential facilitators of a modal shift?

A small number of studies suggest that e-bikes are typically used for utilitarian travel, such as commuting to school or work or running errands (Weinert, Ma, and Cherry 2007; Dill and Rose 2012; An et al. 2013). A study of a university campus bike-share program found that the most common use for e-bikes was travelling between buildings on campus (Langford et al. 2013). Yet study participants who chose e-bikes over conventional bikes were more likely to travel to multiple destinations and made trips that were approximately 13% longer in distance. For trips off-campus, participants noted they would otherwise have used a private automobile or public transit. The willingness to use an e-bike over a car is significant, given that 86% of those participating in the program owned an automobile (Langford et al. 2013). Other studies also indicate e-bike riders are intent on reducing car dependency (Dill and Rose 2012; MacArthur et al. 2014; Fishman and Cherry 2016). However, the extent to which e-bikes are perceived as a viable substitution for a car remains unclear—including which demographic factors, trip characteristics (e.g., purpose, origin, destination, time of day), and type of built environments (e.g. suburban versus urban) are most likely to support a modal shift. Some riders use their e-bike in conjunction with public transit, but the weight of the battery and the subsequent difficulty lifting e-bikes onto busses or trains can be a deterrent (Dill and Rose 2012).

Health and environmental impacts of e-bike usage

E-bike rider road safety has been examined in several studies in both China and Europe (Wu et al. 2012; Hu et al. 2014; Weber et al. 2014). In 2007 alone, China had 2469 e-bike riders involved in fatal collisions and 16 468 serious injuries (TABCSSM 2008). The greater mass and speed of e-bikes, compared to regular bicycles, can result in severe collisions (Hu et al. 2014). Age is associated with greater injury, with younger populations most

Table 1
Characteristics of existing e-bike studies.

Source	Method	Sample Size	Location of Study	Modes Examined	Questions Asked						
					Demographics	Travel Patterns	User Perceptions	Policy Issues	Traffic Safety	Alternative Modes	Motivation for E-bike Use or Purchase
Langford et al. 2013	Surveys with existing participant group	22	Knoxville, Tennessee	E-bikes, regular bikes	X	X	X				X
Cherry and Cervero 2007	Targeted intercept surveys	1198	Shanghai and Kunming, China	E-bike, regular bike, and LPG scooter users	X	X	X			X	X
Weinert, Ma, Yang, et al. 2007	Targeted intercept surveys	1211	Shijiazhuang, China	E-bikes (460), regular bikes (751)	X	X	X		X	X	
Dill and Rose 2012	Interviews	28	Portland, Oregon	E-bikes	X	X		X			X
An et al. 2013	Surveys	470	Shanghai, China	E-bikes	X	X				X	
Fishman and Cherry 2016	Literature review	–	China, North America, Europe, Asia, Australia	E-bikes	X	X	X	X	X	X	X
Astegiano et al. 2015	Online survey	100	Ghent, Belgium	E-bikes	X	X	X		X	X	
Popovich et al. 2014	Interviews	27	Greater Sacramento Area, California,	E-bikes	X	X	X				X
MacArthur et al. 2014	Online survey	553	North America, mainly US cities	E-bikes	X	X	X		X		X
Jones et al. 2016	Semi-structured interviews, online exit survey	22	Randstad, (Amsterdam and Utrecht), Groningen, (Netherlands), and Oxford (United Kingdom)	E-bikes	X	X	X				X
Haustein and Møller 2016	Online survey	427	Denmark	E-bikes	X	X	X			X	X

at risk in China (Wu et al. 2012), while middle-aged riders (40–65 years old) are more at risk in Switzerland (Weber et al. 2014). Intersections are perceived as the most dangerous point of e-bike trips, particularly when vehicles are turning (Weinert, Ma, and Cherry 2007; Hu et al. 2014).

Physical activity levels among e-bike users have also been explored. Pedal-assist riders have been found to be less active than conventional cyclists, but more active than car commuters (Gojanovic et al. 2011; Langford et al. 2013). Moreover, e-bikes may increase total amounts of daily physical activity (Theurel et al. 2012; Popovich et al. 2014). E-bikes appear to appeal to individuals experiencing health-related mobility restrictions (MacArthur et al. 2014; Jones et al. 2016). Future research is needed to explore changes in physical activity levels before and after e-bike uptake, and amongst riders of both pedelec and scooter models (Gojanovic et al. 2011).

Few studies have explicitly focused on the environmental impacts of e-bikes (Weinert, Ma, Yang, et al. 2007). The most comprehensive study concluded e-bikes had a more positive environmental impact when displacing cars or motorcycles, compared to public transit or conventional bicycles (Cherry et al. 2009). Some aspects of e-bike usage are environmentally positive (e.g., decreased nitrogen oxide emissions) while others (e.g., electricity generation, battery disposal) are negative (Cherry et al. 2009). There is a paucity of research examining the overall ecological footprint of e-bikes throughout their lifecycle.

While the evidence base on e-bike usage, and related health and environmental impacts, is growing, this is one of a small number of in-depth qualitative studies on e-bike riders and it is the first to examine experiences and perceptions over time. This study is also the first to explore the experiences of a small sample of e-bike riders in a Canadian city.

Methodology

This longitudinal qualitative study examined the experiences and perceptions of e-bikes among a sample of riders in a mid-sized city in Ontario, Canada. Kitchener-Waterloo makes for a unique case-study given its progressive planning and development of sustainable modes of transportation. These include the proactive construction of a light rail transit line and an active transportation Master Plan that acknowledges the inclusion of more concrete polices for the use and regulation of e-bikes (Region of Waterloo 2014). Despite their progressive stance, the city lacks cycling infrastructure and biking culture when compared to other mid-sized cities around the globe such as those in the Netherlands, Denmark, and Germany.

Our participants were recruited from a larger sample of e-bike riders involved in a multi-year study investigating the energy impacts of e-bikes and vehicles in the Canadian context. This larger study, known as The Webike Study, provided e-bikes to 25 faculty, staff members, and students at the University of Waterloo while tracking battery use, riding behaviour, and travel patterns via GPS over a three-year period (2014–2017). Participants for Webike were recruited via a larger survey on societal perceptions towards e-bikes and were selected to reflect a diversity of primary commuting modes (car, transit, biking, walking). At the completion of the larger study, participants were given the e-bikes in appreciation of their time, effort, and willingness to have their travel behaviour tracked for three years. Participants rode a Whistler model manufactured by eProdigy that resembles a conventional bicycle and has five levels of pedal-assist power up to 40km/h (see Figure 2). The current study was a voluntary phase of the larger study and involved focus groups and individual interviews with a sample of Webike participants at two points during the larger study. The first round of data collection was held six months into the study, involving 11 participants who took part in one of two focus groups (n=9) or, if unavailable, an individual interview (n=2).

Participants were asked to share their early perceptions and experiences riding the e-bike. A second round of more in-depth interviews (n=10) were conducted two years later as participants were nearing the end of the larger study, in order to provide information-rich narratives (Patton 2014) and provide an opportunity to discuss changes in perceptions, experiences, and behaviours over time. We acknowledge that this is indeed a small sample size and thus not suitable for making generalizations—however, this was neither the aim of our study nor is it in alignment with the epistemological rationale for conducting qualitative research (Elliott 1999). Instead, we used the rich data from our participants to explore the early perceptions and experiences of novice e-bike riders and hope this

Figure 2
The "eProdigy Whistler" e-bike used by study participants. It resembles a human-powered conventional bicycle but comes equipped with a battery that enables electric-assisted propulsion.
SOURCE: http://blizzard.cs.uwaterloo.ca/iss4e/webike-project/. Reproduced with permission.

can inform a future research agenda involving a representative sample.

All focus groups and interviews took place on campus and participants received a $10 campus food service card for participating in each round of data collection. All sessions were audio-recorded and transcribed for analysis. Data were coded and thematically analyzed using both deductive (guided by the literature) and inductive (emerging from the data) approaches (Patton 2014). To ensure rigour, two members of the research team developed, tested, and refined the coding scheme, reviewed all transcripts, and conducted the analysis (Patton 2014).

Findings

Changes in e-bike use over time

All participants in this study were new to riding e-bikes, having ridden them for approximately six months during the time of the first interview and two and a half years for the follow-up. The majority of participants identified as experienced cyclists (n=8 in Round 1; n=7 in Round 2), while others had not ridden a bicycle for decades. Members of our sample varied in their reasons for taking part in an e-bike trial. Some felt strongly about the environmental benefits of reduced car use, others wanted a more physically active commute to work, and some were excited to try a new technology.

Participants largely used their e-bikes for utilitarian (e.g., commuting, running errands) rather than recreational purposes, with those self-identifying as avid cyclists being particularly vocal about preferring a regular bicycle for recreation because they were lighter, easier to control, and increased physical activity. The few riders that were returning to cycling were more likely to use the e-bike for recreational purposes in addition to commuting, particularly during the first round of data collection. For example, one participant used it to pull his daughters around the block in a trailer, another used the e-bike to explore trails behind her house, while another shared the e-bike with her spouse who had a physical disability to enable leisurely bike rides. By the second round of data collection, all participants indicated the e-bikes were predominantly used for utilitarian purposes as opposed to leisure activity. However, several participants shared that the two could not be untangled easily because riding an e-bike (for utilitarian purposes) was a more enjoyable transportation option than a vehicle. For instance, several participants used the e-bike for family commutes to daycare, the farmer's market, or social gatherings and found that there was increased pleasure to the commute:

> Fun. Well, you get to go a little faster uphill . . . I go out with my husband now on our e-bikes so it is not just a means of transportation but it's also an activity. While you're getting to the places you have to go, it's nice . . . (Avid cyclist, Round 2)

> Just recently we got a new bike trailer so I was able to bike the kids up to daycare as well. In any given week we use it between 3–5 times because it just got to the

> point where the kids wanted the bike trailer over the car ride because they thought it was more fun. (Returning cyclist, Round 2)

Participants were asked about perceived benefits and limitations of e-bikes during both rounds of data collection. In total, 15 benefits and 19 limitations were described, with most of the benefits relating to the rider personally and most of the limitations relating to the bike itself or the surrounding environment (see Table 2). Of note, in the initial round of data collection the most frequently discussed limitation was battery life, specifically the fear of losing power. This was especially concerning when travelling new routes, hilly terrains, unpredictable distances, or after the bike had been sitting idle for long periods of time. In the second interview "range anxiety" was less of a concern to participants as they became familiar with the limits of the bike, had solidified travel routes, or in three cases, had experienced a power outage or popped tire and were successfully able to get the bike home without the pedal assist.

After three years of riding, there was a shift in perspectives for both the benefits and limitations of e-bikes (see Table 3). In particular, over time, participants increasingly felt that e-bikes were beneficial for replacing car trips and made commuting more enjoyable overall.

One consistent and significant finding across the two rounds of data collection was the importance of infrastructure as a factor limiting e-bike usage. While all participants stated that designated cycling lanes were an important determinant of using an e-bike, the significance of other types of infrastructure varied between avid and the few returning cyclists. For instance, returning cyclists were more likely to report riding on sidewalks and had a preference for riding on trails over roads. In contrast, avid cyclists were reluctant to ride on cycling trails, given the increased speed of the e-bike over a traditional bike, and felt more comfortable riding on the roads. Returning cyclists stated that they would limit their access to high-traffic streets (even with cycling lanes) because they felt unsafe, whereas the more avid cyclists in our sample more often reported an increase in the overall space and infrastructure they were willing to cycle in, relative to when they were using a traditional bike. Some participants were initially cautious about using their e-bikes on recreational trails because they were unsure if they were allowed to be there or if pedestrians or other cyclists would be receptive to their presence. One participant stated that they had looked into whether there were specific municipal bylaws that may dictate where they were allowed to ride their e-bike, but stated they were not able to find any.

Sparking a modal shift?

Over time, nearly all participants self-reported an increase in the total number of utilitarian trips taken on the e-bike, which had a threefold explanation: 1) increased level of comfort with the technology and battery range; 2) the motor allowing them to travel further than a regular bike or by foot while using similar levels of exertion; and 3) the e-bike being generally viewed as faster than walking, cycling, and public transit—especially amidst major road and light rail transit construction. E-bikes were used to commute between home and work, on average between 6–10km. Of the participants in Round 2 that are now using their e-bike for commuting to work (n=9), all but one indicated that they previously would have driven a car.

E-bikes were particularly advantageous for replacing cars for short trips. Multiple participants emphasized that when factoring in the time to look for and pay for parking, the total commute time between an e-bike and car is comparable.

> It's my exclusive transportation choice now. I sold my car over the winter for unrelated reasons actually but I chose not to replace it because I figured I could get away with just having an e-bike ... In the winter I'll probably take the bus a lot more. (Avid cyclist, Round 1)

> It's kind of a nice way to start the day instead of hopping in the car, looking for parking, paying for parking and whatnot. I'm actually considering selling my car too. We will see if that ends up happening ... (Returning cyclist, Round 1)

In contrast, most participants could not see replacing their car entirely with an e-bike due to Canadian winter weather, safety concerns when travelling with children, or other constraints related to time or having to carry a heavy load.

Participants were also asked about their experiences using e-bikes in tandem with other modes of transportation (e.g., bus, trains), and many

Table 2
Perceived benefits and limitations of using an e-bike by source (Rounds 1 and 2).

Benefits	**Limitations**
Factors influencing riders	
- Use as commuter vehicle (replacing car sometimes) - No need to shower at work (due to minimal exertion) - Less overall effort (compared to regular bikes) - Commute time more enjoyable - More confidence cycling on the road (less conflict with cars) - Increased physical activity and being outdoors - Can cycle comfortably in old age	- Theft concerns (bike is distinctive, looks expensive) - Less exercise or recreational value when compared to pedal cycling - Awkward and heavy to carry battery in public
Factors impacted by bicycle/technology	
- Ease of maintaining speed and going with flow of traffic / less conflict with cars in comparison to regular bikes - Increased mobility and range than normal bike - Ability to pedal without power	- Hard to peddle when battery dead / not using peddle assist due to weight - Short battery life - Delay in bike starting when fully stopped - Fearful of doing repairs on the bike due to the motor assist - Too much assistance (does not let you adjust assistance well) - Difficult to run errands (in comparison to car) - Forgetting to charge and having low/no battery - Heavy to lift
Factors impacted by environment/infrastructure	
- Ease of parking - More convenient than public transit - Lowering carbon footprint	- Weather concerns limit riding for some users (winter) - No longer feel comfortable cycling on sidewalks - Lack of cycling infrastructure - Hard to integrate with public transit (cannot lift onto bike rack) - Fear of using bike on roads without cycling lanes
Social factors	
- Positive comments from the public on appearance of the bike - Encouraged friends/relatives to try e-biking	- Negative comments from the public (stigma of e-bikes being “cheating”) - Fear of using bike on trails due to pedestrian/cyclist conflict

expressed the weight of the bike made this prohibitive: “I am a rather slight person … I am not strong enough to do it. So that would be a major barrier, that the e-bike is heavy” (Avid cyclist, Round 1).

Security concerns, specifically theft, were consistently cited. Participants felt the e-bike was more susceptible to theft or vandalism because it looked expensive due to the battery size, sensory box (being used for the study), or being recognizable as an e-bike. Some stated that theft concerns would sometimes constrain where they were willing to take the bike, including reservations about the safety of public bike racks at transportation hubs.

> If I am taking the bike somewhere I always think where I am going to leave it? If I was to take a bus to Toronto and park the bike in downtown Kitchener for the whole day I probably would be reluctant to use the e-bike for that purpose. I would rather pay 10 dollars for parking my car safely knowing that the car, once I come back, will be there … (Avid Cyclist, Round 1)

As e-bike technology continues to advance (e.g., more discrete batteries, smaller motors), and infrastructure in Kitchener-Waterloo further develops to support more secure cycling storage, these concerns may be alleviated.

Table 3
Most frequently cited benefits and limitations over time.

	Round 1	Round 2
Benefits	1. Use as commuter vehicle (replacing car sometimes) 2. Ease going up hills 3. No need to shower at work (due to minimal exertion) 4. Time savings 5. Less overall effort (compared to regular bikes)	1. Use as commuter vehicle (replacing car sometimes) 2. Made commute time more enjoyable 3. No need to shower at work (due to minimal exertion) 4. Motivated a healthier lifestyle 5. Less conflict with cars (more confident when cycling)
Limitations	1. Hard to peddle when battery dead / not using the peddle assist due to weight 2. Short battery life 3. Theft concerns (bike is distinctive, looks expensive) 4. Awkward and heavy to carry battery in public 5. Hard to integrate with public transit (cannot lift onto bike rack)	1. Hard to peddle when battery dead / not using the peddle assist due to weight 2. Less exercise when e-biking compared to pedal cycling 3. Difficult to remember to charge the battery / plan for longer trips 4. Loss of recreational value / less connection to e-bike than to previous pedal cycle 5. Fearful of doing repairs on the bike due to the motor assist

E-bike use was weather dependent, with individuals being less likely to ride in the rain, snow, or extreme cold. However, avid cyclists were more likely to ride their e-bike in all weather conditions with one elaborating that commuting through snow and slush by e-bike was faster and easier than a regular bike.

All participants stated that once the study was over, they would continue to ride the e-bike they had been given as compensation for their participation in the study. Eight of ten participants in Round 2 stated that they plan to purchase a new e-bike for themselves or a family member in the future.

Health, safety, and environment

Participants' perceptions of the health and environmental benefits of e-bikes were dependent on the mode of transportation being replaced. For instance, e-bikes were perceived as having greater impact on air quality and physical activity when replacing a sedentary form of commuting such as a car or bus, rather than a regular bike. Some shared the positive feelings or sense of stewardship they experienced as a result of choosing an e-bike over transportation modes powered by fossil fuels: "I've always wanted to do this you know greener transportation thing but it never really seemed convenient before and I think that it showed me that it was more convenient and enjoyable than I thought it would be" (Returning cyclist, Round 2). Yet for many that self-identified as already being avid cyclists, they felt e-bikes had little impact on physical health: "When I think of it as a bike, it doesn't meet some of my exercise, enjoyment aspects. When I think of it as a vehicle replacement, it's wonderful!" (Avid cyclist, Round 2).

In the first round, the majority of participants stressed that increasing their daily exercise was not the primary motivator for using their e-bikes, as they believed that e-bike riding alone was not sufficient daily physical activity. However, in the second round the few who identified as returning cyclists felt that commuting using the e-bike was healthier than commuting by car. A few study participants suggested that e-bikes would be particularly beneficial for increasing physical activity for individuals with health conditions or limited mobility (e.g., those related to aging), and some had shared their bikes with their family members for that purpose.

With respect to personal safety, the vast majority of participants felt safest on an e-bike when dedicated bike lanes were available. Avid cyclists more commonly expressed an increase in confidence when riding on the roads because they are able to move at higher speeds and blend with the flow of traffic. During the first round of data collection, none of the participants had experienced negative interactions with pedestrians or other cyclists. However, in the second round one participant reported falling off the bike after quickly braking, resulting in a broken foot which she attributed to the speed and weight of the bike.

Another participant was in a collision after a car driver misjudged the speed of his bike and turned the corner in front of him, resulting in minor injuries to the rider. This individual attributed the accident to the driver's unawareness of the existence and speed of e-bikes and reported being a much more cautious rider after that incident.

Discussion

The findings from this exploratory, longitudinal study add new insights into the early adoption experiences of e-bike users. They shed light on how experiences evolve over time, and within the understudied Canadian urban context where sprawl and automobile dependency predominate. Nevertheless, we acknowledge the limitations of our small sample. Participants in the broader Webike study, including those who took part in the optional qualitative components, were self-selected. Those who are most uncomfortable cycling were less likely to take part in the broader Webike study. Similarly, it is possible that those with a more positive outlook on their e-bike riding experience were more likely to opt into the qualitative study. Consequently, our findings may reflect the perspectives of populations who are more likely to consider adopting e-bikes as an alternative mode of transportation, particularly when presented with an opportunity to "trial" the technology at little-to-no cost. Kitchener-Waterloo is just one sprawling mid-sized city; there remains a need to examine e-bike usage, impacts, and management requirements across different city contexts, densities, and systems of infrastructure.

Given the limited penetration of e-bikes into North American transportation systems, traditional quantitative research methods can be a challenge because of limited sample size. Qualitative research techniques have proven to yield important insights into factors motivating early adoption and catalyzing modal shift (Dill and Rose 2012). Despite the limitations of our sample, this study contributes rich, in-depth data on changing perceptions and experiences of e-bike riders over time, which are useful for identifying hypotheses in need of further validation and new avenues for investigation (Patton 2014).

Our findings suggest that in future studies it will be worth further interrogating whether avid cyclists have different e-riding patterns and needs than novice cyclists. Our sample suggests avid riders are more likely to rely on e-bikes for commuting and utilitarian purposes, and refrain from using them for pleasure. This corroborates past research indicating the usefulness of e-bikes for short errands (Weinert, Ma, and Cherry 2007; Dill and Rose 2012; An et al. 2013). In this study, returning cyclists more frequently mentioned the importance of bike infrastructure or trails to get around, while avid cyclists were more confident to travel in areas without cycling-specific infrastructure. To date, there has been no comparative analysis of how travel behaviour and infrastructure use differs among avid versus novice cyclists who adopt e-bikes, including the relative health and safety implications.

E-bikes are known to displace other modes of transportation (Cherry and Cervero 2007; Dill and Rose 2012; Langford et al. 2013), but it is hard to quantify how much they actually do and which mode they replace. Furthermore, it appears car ownership remains high among e-bike users in North America (Dill and Rose 2012; Langford et al. 2013). In this study, all participants used their e-bike to commute to work, replacing the use of cars and for those who were already avid cyclists, traditional bicycles. Although several participants had used their conventional bikes in conjunction with public transit, all participants felt the e-bike was too heavy to lift onto a bus bike rack, which corroborates the findings in other studies (Dill and Rose 2012). This performance limitation may have important implications with regards to e-bikes helping to support the uptake of integrated, multimodal transportation for travelling further distances—a key tenet of smart and sustainable transportation planning (Behan et al. 2008). Further examining which models are most effective in displacing automobiles or solving "last mile" challenges in public transit remain important future directions for research, policy, and marketing.

Existing research indicates that e-bike use declines in winter months (Langford et al. 2013). In Canada, weather could be a barrier to adoption especially for those who have never commuted by bicycle before. Participants who were avid cyclists suggested that e-bikes may help encourage all-season riding as they make it easier to navigate through snow due to their weight, grip, and power. Further research is needed into winter e-bike riding in Canada as it is unclear whether e-bikes, and more specifically their batteries, effectively handle extreme cold temperatures (Jones et al. 2016). In addition, lack of infrastructure in the winter due to snowplows pushing snow into bike lanes may be an additional barrier to those who prefer the safety of having bike lanes available. Note that in Kitchener-Waterloo, roads are often plowed before sidewalks, and conditions are slippery which can make sharing roads in restricted spaces especially risky. Given the success of cycling in other winter cities, such as Copenhagen (Colville-Andersen 2014), there are models for how to encourage widespread adoption, though various contextual differences need to be acknowledged.

Managing the influx of e-bikes in urban centres is challenging, given they are faster and heavier than regular bikes and smaller and quieter than cars. This raises uncertainties about how and where they should be used and regulated (Edge and Goodfield 2017). In other North American studies, concerns about conflicts between e-bike users and conventional bike riders have been raised, along with uncertainties over how this should be managed through planning or regulatory policy (Dill and Rose 2012; Edge and Goodfield 2017). Study participants initially reported no conflicts with other bike users, although some did express that they were extra-cautious when in close proximity to pedestrians. Some participants speculated that, since the e-bikes they were riding resemble regular bikes, they probably get less scrutiny than they would if riding a scooter model. In the subsequent round of data collection after participants had been riding for a longer period of time, there was a slight increase in reports of risky encounters. Participants in our sample expressed concerns related to sharing infrastructure with motorists, not surprising given the strong car culture in Canada and the lack of biking infrastructure. Participants identified intersections as particularly risky, which is consistent with other studies (Weinert, Ma, and Cherry 2007; Hu et al. 2014; Popovich et al. 2014). To date, there is very little injury or accident data that distinguishes e-bikes specifically, which hinders the evolution of policy and planning in response to the influx of these new technologies (Edge and Goodfield 2017).

Our findings align with past studies indicating perceived health benefits derived from using e-bikes depend upon what mode of transportation the e-bike is replacing. In two US studies (Dill and Rose 2012; Langford et al. 2013), avid cyclists felt that their physical activity declined when riding an e-bike. However, Fishman and Cherry (2016) found that, even among users who used the highest e-bike assist settings, the minimum recommended physical activity level was reached, suggesting they are of use to anyone with a desire to be less sedentary. So far, there has been no detailed comparative research about the health impacts associated with e-bikes, or the differences between pedal-assist and scooter type models (Rose 2011; Dill and Rose 2012).

There was significant discussion by participants, including avid and returning cyclists, that e-bikes made commuting more pleasurable. Given recent findings that correlate commuting experiences with stress and anxiety (Roberts et al. 2011; Wener and Evans, 2011), the role that e-bikes may play in reducing commuting stress is an important avenue to explore.

E-bikes were perceived by participants as better for the environment compared to cars, yet much remains uncertain. Areas in need of further investigation from an environmental perspective include an in-depth lifecycle analysis; identification of which transportation modes e-bikes are replacing; examination of the sources of energy used to charge e-bikes; and exploration into whether they actually reduce congestion, idling, and associated air pollution (Weinert, Ma, and Cherry 2007; Rose 2011).

Conclusion

Improving the sustainability and smart mobility of urban transportation systems continues to be an unfolding priority across North America. The potential role of e-bikes in supporting these agendas is important to further investigate. Here we have linked qualitative data from a sample of e-bike riders in Canada, who were studied over the course of three years, with the small, albeit growing, body of relevant literature to explore e-bikes' capacity to improve healthy and sustainable mobility in urban environments.

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