Travel Behaviour and Society 13 (2018) 165–173

Contents lists available at ScienceDirect

Travel Behaviour and Society

journal homepage: www.elsevier.com/locate/tbs

Bicycle ridership and intention in a northern, low-cycling city

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ARTICLE INFO

Keywords:
Bicycle
Utility cycling
Active travel
Intention
Winter city

ABSTRACT

Cycling as a mode of transportation (i.e. utility cycling) has been given heavy attention and investment in North America over the last decade. It is perceived as an environmentally friendly way to travel, leading to benefits for health and traffic alleviation. This study examines the determinants of utility cycling behaviour and intent, and more broadly, active transportation (i.e. cycling and walking) behaviour in Edmonton, Canada – the northernmost North American city with a metropolitan population over one million. With harsh winter weather and low cycling rates, the city presents a unique case study for cycling behavior. In this research, we analyzed 646 responses to a bike ridership survey conducted in 2014 by the City of Edmonton. Borrowing concepts from behaviour theory, public health and transportation engineering we seek to quantify the effects of infrastructure density, traffic attitude, perceived control over time and distance, and traffic stress tolerance perception on cycling for utility purposes, the intention to cycle more frequently, and the use of an active mode of transportation, specifically for a northern and low-cycling city. Three empirical models were developed to describe cycling behaviour using binary logistic regression. Most variables were significant and in line with other study findings in the current literature. Results point at the importance of perceived safety in deciding or intending to cycle, as well as perceived time and distance of travel. Broad policy implications and suggestions for future research are discussed.

1. Introduction

Cycling, particularly for commuting and transport purposes, has been an object of increasing interest in North America over the last two decades. The degree and intensity of uptake and investment has been varied; cities like Montreal, Vancouver, and Portland have all witnessed sharp increases since 1990, but they are the exception and not the rule (Pucher et al., 2011). Nonetheless, city planners, health officials, and academics alike largely agree that greater levels of cycling can contribute to mitigating ever-increasing congestion in urban environments, reduce transportation-related greenhouse gas emissions and pollution, and offer a remedy to inactivity-related health problems (Guttenplan et al., 2003; Oja et al., 2011; Lindsay et al., 2011). Researchers from diverse disciplines have taken interest in the subject; a central focus has been to identify the correlates and determinants of non-recreational (i.e. utility) cycling and, more broadly, of active transportation.

The objective of this work is to gain insight into cycling behavior, the intent to cycle more often, and the use of active modes of transportation specifically in Edmonton, Alberta, Canada. As a northern city with long winters and heavy snowfall, this locale constitutes an interesting case study of cycling behaviour. Indeed, many North American studies on cycling activity focus on cities such Portland, Seattle, Washington, D.C., Vancouver, etc. – cities with milder climates and urban infrastructures that are more conducive to year-round cycling. Yet, research shows that sub-zero temperatures, wind, precipitation, and poor winter maintenance are associated with lower levels of cycling in winter months (Miranda-Moreno et al., 2013; Flynn et al., 2012; Helbich et al., 2014). Given the northern context, the drivers of the use of active modes and of intent to cycle or to walk could conceivably differ from other, warmer cities. Therefore, we seek to quantify the effects of infrastructure density, traffic attitude, perceived control over time and distance, and traffic stress tolerance perception on cycling for utility purposes, the intention to cycle more frequently, and the use of an active mode of transportation, specifically for a northern and low-cycling city. Incorporating a typology of traffic stress proposed by Mekuria et al. (2012), we test this typology empirically

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https://doi.org/10.1016/j.tbs.2018.08.005
Received 4 April 2018; Received in revised form 20 August 2018; Accepted 22 August 2018
Available online 27 August 2018
2214-367X/

and propose modifications based on findings from this study.

This work makes use of a publicly-available secondary dataset from the City of Edmonton, drawn from a regular survey panel called the Edmonton Insight Community. Research regarding correlates and determinants of cycling, the intention to cycle, and the use of an active mode of transportation will be reviewed in turn. This is followed by a discussion of safety perception and concludes with a review of distinctions between intent and behavior.

2. Literature review

Research regarding cycling for transportation is inherently multidisciplinary. The themes below are reviewed with respect to the literature from social sciences, public health, and transportation engineering.

2.1. Intention to cycle

The Theory of Planned Behaviour (TPB) is one of the most highly applied frameworks to assess the intention to cycle (see Eriksson and Forward, 2011; Kaplan et al., 2015; Milković and Štambuk, 2015; Lois et al., 2015). The theory was developed by Ajzen (1991); briefly, it is based on the premise that intentions are a good predictor of actual behaviour. Intentions are theorized to stem from three elements: attitude towards the behaviour, subjective norms (i.e. the "perceived social pressure to perform or not perform the behaviour" (Ajzen, 1987)), and perceived behavioural control, although some researchers of mode choice also suggest the use of descriptive norms (see Eriksson and Forward, 2011). In their study of car and transit commuters, Lois et al. (2015) found that a positive attitude and the presence of subjective norms regarding cycling explained increased intention to cycle. Their study also included a measurement of habit where a positive influence on cycling intention was also observed.

Without measuring intent itself, other researchers have studied factors influencing the progression of stages prior to actual behaviour change; that is, adopting cycling for utilitarian purposes. For example, Gatersleben and Appleton (2007) utilized the framework of the transactional model of behaviour change (also known as the Transtheoretical model, TTM) developed by Prochaska and DiClemente (1984) and related the five progression stages to more or less positive attitudes and perceptions regarding cycling.

We expect our modeling results to indicate that higher perceived behavioral control and a more positive attitude towards cycling will be associated with a greater intent to cycle.

2.2. Active mode use

Public health researchers have extensively studied active transportation use (mainly walking and cycling) and its correlates. Much of this research follows Saelens et al. (2003), where features critical in urban transportation design –such as population density, network connectivity, and land use mix – were correlated to activity levels resulting from the choice of active transportation. In particular, Panter and Jones' review (2010) is helpful in identifying a list of active travel correlates. The environmental correlates are very similar to those related to cycling only and will be discussed in the next section. The review also identifies cognitive theoretical models that have been used in active transportation research. In addition to TPB, which has a rich history in the assessment of cycling and walking behaviors (Dill et al., 2014), the Theory of Interpersonal Behaviour (TIB), the Norm Activation Model and the Theory of Trying have all been applied (Panter and Jones, 2010). Burbidge and Goulias (2013) also created a conceptual behavioural analysis framework to analyse active travel behaviour. Like many other studies, TPB is included in their model, although the framework distinguishes itself through the inclusion of elements of Decision Field Theory (Busemeyer and Townsend, 1993).

Rather than a behavior, the use of active travel modes can also be studied from the point of view of mode choice theory. Recent mode choice models used in travel demand forecasting are increasingly integrating behavioral aspects, as is the case of the Generalized Random Utility Model (Walker and Ben-Akiva, 2002). Theoretical mode choice frameworks aimed specifically at active travel also exist. One such example is the Theory of Routine Mode Choice Decisions, which integrates variables of awareness and availability, basic safety and security, convenience and cost, enjoyment, and habit (Schneider, 2013).

2.3. Cycling for transportation

Heinen et al. (2010) offer an excellent overview of concepts that have been associated with the use of cycling as a travel mode in transportation research, identifying five categories. The *built environment* includes aspects describing urban form (such as network connectivity), infrastructure, and facilities (bicycle parking, etc.). There is evidence that the presence of dedicated infrastructure induces higher levels of cycling (Dill and Carr, 2014; Burk, 2017). Bicycle infrastructure density is a metric that has also been used to assess bikeability (Winters et al., 2013). The *natural environment* refers to external factors such as hilliness and weather. As in all behavioural research, *socio-economic factors* are also considered. For example, it has been found that men tend to cycle more in countries with low cycling rates, although the relationships between age, income, and cycling are unclear. The *utility* category includes cost, travel time, effort, and safety. The latter often plays a central role in the choice to cycle as both objective and subjective safety assessments are associated with lower levels of cycling (Dill and Voros, 2007; Winters et al., 2011). In fact, an increasingly popular method of cyclist classification is by cyclists' traffic stress tolerance. This concept will be explored in detail in Section 2.4. Finally, the *psychological factors* reviewed bring up the behavioural models presented earlier (TPB, TIB, as well as habit). For example, de Bruijn et al. (2009) found that habit is strongly linked to actual behaviour and acts as a mediator in the intention–behaviour relationship, as measured by the constructs of TPB. The mode choice models discussed in the previous section are also applicable to cycling.

2.4. Traffic stress tolerance and safety perception

Traffic stress tolerance is a means of categorizing cyclists into four groups based primarily on how comfortable they are mingling with motorized vehicles while cycling. The typology was developed by City of Portland bicycle coordinator Roger Geller (c. 2007) and gradually gained widespread adoption. The four cyclist categories are: "Strong and fearless" – the stereotypical male performance road cyclist or bike courier; "Enthused and confident" – avid cyclists who do not mind mixing with moderate traffic, but avoid high-risk situations or high vehicular speeds; "Interested but concerned" – the vast majority of cyclists or potential cyclists, who fear motorized vehicle traffic and feel most comfortable on segregated facilities; and "No way no how" – the portion of the population for whom travelling by bicycle is not an option. It should be noted that this typology, although adopted by many researchers and practitioners, is not based on empirical evidence, but rather from Roger Geller's experience as a planner; it has been critiqued for this reason (Damant-Sirois and El-Geneidy, 2015). However, the typology was tested on a sample of adult Portland residents by Dill and McNeil (2013), who found it to be accurate for classifying the adult population into the four categories.

Mekuria et al. (2012) also created a framework to evaluate different types of road infrastructure based on this typology. They assign specific design and operations criteria to four levels of traffic stress which are briefly described here. LTS4 designates facilities that are only adequate for the "Strong and fearless" – generally important roads with vehicle speeds over 55 km/h, without bicycle lanes. LTS 3 corresponds to conditions the "Enthused and confident" would tolerate, with bicycle lanes provided for higher speeds or no bicycle lanes at lower speeds. LTS 2 is designed for the "Interested but concerned" group, most representative of the mainstream population. The standards used for this level are similar to Dutch standards, which are internationally recognized as most satisfactory to the greatest variety of riders with different abilities and confidence. Finally, LTS 1 is aimed at children who have been taught how to safely cross simple intersections. This level was added by Mekuria et al. (2012) and is not directly based on Geller's typology. This framework informed our development of a level of traffic stress tolerance scale, as shown in Tables 1–3 (presented and discussed in detail later in Section 4.) Traffic stress tolerance can be considered a measure of perceived behavioral control as it relates to one's perception of control over their personal safety. It is expected that a higher traffic stress tolerance will be linked with a greater propensity to cycle.

2.5. From intent to behavior

As stated in Section 2.2, the Theory of Planned Behaviour postulates that intention is a predictor of actual behavior. For this reason, some studies of travel behavior use the three pillars of intention (attitude, perceived behavioral control, and subjective norms) directly as explanatory variables of the behavior, without measuring intent (Dill et al., 2014). Others measure intent only (Eriksson and Forward, 2011; Kaplan et al., 2015; Milković and Štambuk, 2015), both intent and behavior as two separate outcomes (de Bruijn et al., 2005), or intent as a predictor of behavior (de Bruijn et al., 2009; de Bruijn et al., 2005; Eves et al., 2007).

It must be noted that a discrepancy is often observed between intention to perform a certain behavior and the actual performance of that behavior; this is called the intention-behavior gap (Sheeran, 2002). As an example, in a meta-analysis of physical activity intention and behavior, Rhodes and de Bruijn (2013) found that the overall gap between intention and actual performance of physical activity was 46%. Some elements which may explain this gap are increased temporal distance between the measurement of intention and that of the behavior, a lack of self-regulation or actual control over a behavior, previous habits, etc. (Ajzen, 2011). The separate measurement of intent and behaviour is therefore warranted in the application of the TPB framework.

Despite its limitations, TPB is the main theoretical anchor for this work. Our decision to use this theory is based on its frequent use in active transportation literature and on data availability, as we discuss in Section 4.1. The variables and corresponding framework are shown in Table 1; three of the five explanatory variables are considered indicators of perceived behavioral control and one, of attitude. However, none of the response items could be used to measure the third element of TPB, subjective norms. In about half the studies they reviewed and in their own application of TPB, Dill et al. (2014) found social norms not to be significant drivers in active travel behavior, which indicates that the lack of a subjective norm variable in our work may not have a significant impact on results. Our work also includes a measure of infrastructure density, an environmental variable added to complement the TPB constructs, as other researchers have done (Dill et al., 2014). Finally, mode choice frameworks which are suited to the analysis of bicycle and active transport use were excluded due to a lack of suitable data. Models such as the Theory of Routine Mode Choice Decisions (Schneider, 2013) or the Theory of Travel Decision-Making (Singleton, 2013) require data on a travel choice made as well as measures of enjoyment or pleasure, awareness and availability, norms, etc. which impact that specific choice and could not be derived from the data.

3. Study setting

Located north of the 53rd parallel, average daily temperatures in Edmonton are below zero typically for five months of the year, while snowfall is normally recorded from October to May (Government of Canada, 2018). During the shortest days of the year, only 7.5 h separate sunrise and sunset, with morning and afternoon peak commuting hours occurring mostly in the dark (National Research Council Canada, 2018). Positioned in the Canadian Prairies, the city has a mostly flat topography. A notable exception is the river valley. Edmonton was built around the Saskatchewan River and the body of water separates the city in half. Many bicycle and walking trails are located in the valley or on top of the river banks.

With a population of 1.3 million (Statistics Canada, 2017a), Edmonton is also known for being a low-density, car-oriented city. The 2017 motor vehicle collisions report (City of Edmonton, 2017) noted 143 reported bicycle-motor vehicle collisions which resulted in 120 cyclists injured and one fatality. These numbers are fairly consistent with the previous two years. Cyclist crash rates can't be reported as there is little data available regarding cycling volumes in Edmonton.

The city's urban form is characterized by many distinctive suburban planned neighbourhoods designed by Noel Dant in the 1950s. These designs attracted praise from the American Society of Planning Officials at the time, but are now recognized as offering poor connectivity (Edmonton Heritage Council, 2017). Good connectivity is an important feature in facilitating higher levels of cycling (Schoner and Levinson, 2014).

Despite a harsh climate and an urban form designed for cars, the municipal government has recently pushed for more attractive cycling environments. An infrastructure project in 2017 built a network of 7.8 km of protected bike lanes through Edmonton's central business district. The project included numerous upgrades and the construction of several kilometers of other protected bike lanes along important corridors in the Southside and West Central areas (see City of Edmonton (2018) for bicycle network maps).

Even with these recent efforts by city leaders to encourage more cycling in the city, census data on the journey to work shows decreasing levels of cycling in Edmonton: from 1.36% in 2006 to 1.20% in 2016. Moreover, the working population increased by about 20% between 2006 and 2016 while those reporting cycling as their main mode of transportation increased by only 5.2% in the same period (Statistics Canada, 2017b, 2009). With further (and politically contentious) cycling infrastructure investments planned and underway, the examination of determinants of cycling and active transportation behavior and intent specific to a northern, low-cycling intensity city is imperative. In a recent study, Shirgaokar and Gillespie (2016) qualitatively explored Edmonton winter cyclists' adaptation mechanisms and perceptions regarding safety and maintenance. Hunt and Abraham (2006) conducted a stated preference survey to investigate the effects of facility type and time spent on each facility type as well as level of experience, level of comfort, and shower or parking availability at destination on hypothetical cycling trips. Aside from these studies, we are not aware of any other quantitative academic research regarding active traveling and intent specific to this city or a similar northern city characterized by a lack of cycling culture.

Little data is available regarding the rates of utility cycling in Edmonton. The Census provides interesting data regarding cycling volumes; however, it targets the main mode of transportation for journeys to work, considering only the employed labour force thus obscuring cycling behaviour for other (utility) purposes (i.e. grocery store trips, school, etc.). Thus, to examine cycling activity in the city, we turned to a publicly available municipal dataset as described in the following section.

4. Methods

Following the review of the dataset used for the study, the variables included in the three binary logistic regressions to investigate bicycle use, cycling intent, and use of an active mode of transportation will be described.

Table 1
Variables and response items included in the study.

Variable	Response item
Outcome variables	
Utility cycling	"What is your primary mode of transportation?" "What is your secondary mode of transportation?" *Possible answers*: driver, passenger, public transit, bicycle, walk, other
Intention to cycle more often	"I would like to travel by bike more than I do now"[a]
Active travel mode	"What is your primary mode of transportation?" "What is your secondary mode of transportation?" *Possible answers*: driver, passenger, public transit, bicycle, walk, other
Explanatory variables	
Density of cycling facilities[b]	Forward Sortation Area (profiling question), first three characters of postal code
Traffic attitude[c]	"There is so much traffic along streets near my home that it would make it difficult or unpleasant to ride a bike"[a]
Traffic stress tolerance perception[d]	Nine biking comfort items, where respondents rate different facility descriptions from *very comfortable* to *very uncomfortable*
Perceived time[d]	"I don't have time to bike places instead of driving"[a]
Perceived distance[d]	"Many of the places I need to get to regularly are within biking distance of my home"[a]

[a] Four-point scale from *strongly disagree* to *strongly agree*.
[b] Theoretical framework: Transportation (built environment).
[c] Theoretical framework: TBP (attitude).
[d] Theoretical framework: TBP (perceived behavioural control).

4.1. Data

This study utilizes the Bike Ridership survey, a publicly-available dataset produced by the City of Edmonton (City of Edmonton, 2014b). The city maintains a panel of citizens called the Edmonton Insight Community; members are called upon to answer surveys on a range of topics relevant to city administration. The survey was made available August 19–25, 2014, before the latest additions of protected bike lanes, which took place in 2017. A total of 646 survey responses were received from panel members (with completion rate of 63%) in addition to 170 responses obtained from other Edmonton citizens who completed the survey through an anonymous link. These 170 responses are excluded from the present study as important member profile information, including primary and secondary modes of transportation and demographic information are not available for these anonymous respondents. Response items used in the analysis are shown in Table 1. We also controlled for gender, age, employment status, education level, income, and whether the respondent lived with children.

Research questions and explanatory variables considered in this study were designed around the constraints of available data (as the survey was not created, administered, or managed by the authors). Many of the questions used by the City of Edmonton appear to have been inspired or directly adopted from Dill and McNeil (2013).

The panel is not representative of the Edmonton population as a whole. Compared against the 2014 municipal census (City of Edmonton, 2014a), the panel is heavily skewed towards full-time workers (70% versus 57% in the population, excluding school children below 15 years of age), and lacks high school and post-secondary students (2% versus 10% in the population, with the same exclusions). It was not possible to compare other variables, but the panel is also likely to be biased on other traits such as household income and geographic representation. Finally, many of the variables rely on the profiling questions that Insight Community participants answer when they sign up to the community. It is unknown how often the profiling questions are updated, but inconsistencies were noted between stated primary and secondary mode of transportation in the profiling questions (96 reported cycling either as primary or secondary mode) and the number of people who reported cycling for transportation as part of the survey (i.e. commuting to work or school, or for errands and visiting friends – 202 responses). The first value was retained for the analyses, as the primary and secondary mode statements should reflect habitual travel more accurately—the survey question where respondents reported their cycling purpose did not include frequency.

Table 2
Level of traffic stress perception with variable and scale elements based on Mekuria et al. (2012).

Statements included in each LTS level
LTS1 (Cronbach's α = 0.793)
1. A path or trail separated from the street?
2. A quiet residential street?
3. A quiet residential street with bike route signs and shared-use lane or sharrow markings?
4. 4. Residential street with bike route signs and shared-use lane or sharrow markings, and things like traffic diverters that slow down and discourage car traffic?
LTS2
5. A neighborhood commercial shopping street with one lane in each direction, traffic speeds of 40–50 km/hour, on-street car parking and a reserved bike lane?
LTS3 (Cronbach's α = 0.668)
6. Neighborhood commercial shopping street with one lane in each direction, traffic speeds of 40 to 50 km/hr, on-street car parking and no reserved bike lane?
7. Major street with two lanes in each direction, on-street parking, traffic speeds of 50 to 60 km/hour, and a reserved bike lane?
8. Major street with two lanes in each direction, on-street parking, traffic speeds of 50 to 60 km/hour, and a bike lane separated from parked cars by a median?
LTS4
9. A major street with two lanes in each direction, on-street parking, traffic speeds of 50 to 60 km/hour, and no reserved bike lane?

Table 3
Level of traffic stress perception scale elements based on factor analysis.

Statements included in each LTS level
Group 1 (Cronbach's α = 0.793)
1. A path or trail separated from the street?
2. A quiet residential street?
3. A quiet residential street with bike route signs and shared-use lane or sharrow markings?
4. Residential street with bike route signs and shared-use lane or sharrow markings, and things like traffic diverters that slow down and discourage car traffic?
Group 2 (Cronbach's α = 0.840)
5. A neighborhood commercial shopping street with one lane in each direction, traffic speeds of 40 to 50 km/hour, on-street car parking and a reserved bike lane?
6. Major street with two lanes in each direction, on-street parking, traffic speeds of 50 to 60 km/hour, and a reserved bike lane?
7. Major street with two lanes in each direction, on-street parking, traffic speeds of 50 to 60 km/hour, and a bike lane separated from parked cars by a median?
Group 3 (Cronbach's α = 0.748)
8. Neighborhood commercial shopping street with one lane in each direction, traffic speeds of 40 to 50 km/hr, on-street car parking and no reserved bike lane?
9. A major street with two lanes in each direction, on-street parking, traffic speeds of 50 to 60 km/hour, and no reserved bike lane?

In addition to the survey dataset, a graphical representation of the Edmonton cycling network is used to compute the density of facilities in each Forward Sortation Area (FSA), the geographic area determined by the first three characters of the postal code. Network shapefiles were provided, and approved for use in this research, by the City of Edmonton. The FSA representation was obtained from Statistics Canada (2017c).

4.2. Variable construction

Several outcome and explanatory variables required scale construction or computation to become useful for this study, and these processes are described below.

4.2.1. Utility cycling

Respondents who indicate that "Bicycle" was either their primary or secondary mode of transportation are considered utility cyclists and all others are non-utility cyclists (whether they cycle at all or not). Originally, our intent was to distinguish various levels of cycling intensity among utility cyclists. However, the low number in the sample (N = 96) meant that exploratory models were unable to accurately distinguish between different levels of cycling intensity. This binary variable is therefore utilized as a best replacement.

4.2.2. Intention to cycle more often

Intent is measured with a single statement from the survey. The agreement scale used in the questionnaire contains only four items, which is insufficient to liken it to a continuous variable. Therefore, the variable was recoded to a binary outcome with *Strongly agree* coded as 1 and all other responses as 0. Those who strongly agree that they would like to cycle more often than they currently do were isolated from those who somewhat agree to account for acquiescence bias or social desirability bias, which could be more prominent in the survey results as there is no neutral category.

4.2.3. Active travel mode

This variable is once again constructed from primary and secondary modes of transportation stated in the profiling part of the survey. Walking and cycling are considered the only two active travel modes for this survey. A frequency analysis indicated that only 75 respondents walk or bike as a primary mode of transportation, whereas 216 use those as secondary modes (note that only nine respondents use active transportation for both). The correlation between primary and secondary modes is quite low (−0.21), indicating the primary mode of transportation is a poor predictor of the secondary mode. The active travel mode was represented as a binary variable, separating those who use an active mode of transportation either as primary or secondary means of travel from those who only use private vehicles or transit.

4.2.4. Density of cycling facilities

As noted above, the density is calculated using digital map representations of the Edmonton cycling network and of the Forward Sortation Areas (FSAs). Facility lengths (km) and FSA areas (km^2) were calculated using the ArcMap software from ArcGIS. Density was obtained by dividing the total facility lengths within an FSA by the area of the FSA (km/km^2). Density values were then joined to the survey dataset based on the FSA.

4.2.5. Traffic stress tolerance perception

As indicated in Table 1, the traffic stress scale was created based on nine statements describing different facilities that respondents evaluated as more or less comfortable. The statements used by the City of Edmonton appear to be quite similar to those used by Dill and McNeil (2013). Respondents were asked to rank each of the statements on a four-point scale from "very uncomfortable" to "very comfortable".

Each statement was first analyzed according to the framework developed by Mekuria et al. (2012) and assigned to an LTS category. The result of this classification as well as the Cronbach's Alpha (where appropriate) are shown in Table 2.

Cronbach's Alpha (which provides a measure of the reliability of a scale by verifying the internal consistency of the elements it is composed of) was considered somewhat low for LTS 3 and prompted further investigation, including a factor analysis. Eigenvalue less than 1 for the fourth factor ($\lambda = 0.758$) indicates that the data naturally formed three groups rather than four. The four statements included in LTS1 remain the same; however, the other levels are rearranged according to the presence or absence of a bike lane in the statement, as shown in Table 3. This classification is more in line with Dill and McNeil (2013), who separated two groups based on their comfort level on facilities with or without bike lanes.

Table 4
Descriptive statistics for explanatory variables.

Variable	N	Mean	SD	Minimum	Maximum
Utility cycling[a]	646	0.15	0.36	0	1
Intention to cycle more often[a]	646	0.36	0.48	0	1
Active travel mode[a]	646	0.44	0.50	0	1
Density of cycling facilities[a]	638	1.88	1.33	0.00	5.91
Traffic attitude[a]	646	2.82	1.02	1	4
Traffic stress tolerance perception[a]	646	7.59	1.82	3	12
Perceived time[a]	646	2.30	1.07	1	4
Perceived distance[a]	646	2.78	1.11	1	4
Gender (male)	629	0.48	0.50	0	1
Children (yes)	642	0.24	0.43	0	1
Household Income[c]	570	6.85	2.07	1	9
Age[b]	646	7.69	2.83	2	15
Employment variables					
Full-time worker	646	0.71	0.45	0	1
Part-time worker	646	0.07	0.26	0	1
Homemaker	646	0.02	0.15	0	1
Student	646	0.02	0.16	0	1
Unemployed[d]	646	0.14	0.35	0	1
Education level[e]	646	3.78	1.01	1	5

[a] Refer to Tables 1 and 3 and text for scales.
[b] 1. Under $20,000; 2. $20,000 to $29,999; 3. $30,000 to $39,999; 4. $40,000 to $49,999; 5. $50,000 to $59,999; 6. $60,000 to $79,999; 7. $80,000 to $99,999; 8. $100,000 to $149,0009. $150,000 and over.
[c] 1. Under 15; 2. 15–17; 3. 18–24; then in 5-year increments until 79; 15. 80 and over.
[d] Unemployed includes those who are unemployed, retired, or permanently unable to work.
[e] 1. Elementary/grade school; 2. High School; 3. College/technical school; 4. University undergraduate degree; 5. Post-graduate degree or professional school.

Ratings for statements in the same category were averaged and each level was subsequently added to yield values ranging from 4 to 16 for the first scale (Table 2) and 3 to 12 for the second (Table 3). The lowest values represent respondents who are very uncomfortable cycling in any setting, and the highest values represent very confident respondents that would fit into the "Strong and fearless" category. Models were tested using the four-level classification as well as the three-level classification. These preliminary tests showed little difference in model outcomes; thus, only the three-level model, which more closely follows the underlying structure of responses, is shown in the findings.

All other variables included in the analysis were not modified in any significant manner and are therefore not discussed further. Table 4 lists descriptive statistics for the variables used in the models developed. It indicates that 15% of the respondents can be considered utility cyclists whereas 44% use an active primary or secondary mode of transportation. More than a third of respondents would strongly like to cycle more often. On average, respondents have a traffic stress tolerance score of 7.59 out of 12 and cycling facility density is 1.88 km/km^2 by FSA.

4.3. Analysis

All statistical analyses were performed using IBM's SPSS software. We used binary logistic regressions to quantify the effects of cycling infrastructure density, traffic attitude, perceived behavioural control over time and distance, and traffic stress tolerance perception on cycling for utility purposes, the intention to cycle more frequently, and the use of an active mode of transportation. Although intent is considered a predictor of actual behavior (Section 2.5), the lack of a temporal gap between the measurement of intent and the measurement of behavior in the dataset limits our ability to include the intention to cycle more often as an explanatory variable of cycling and active travel behavior. Therefore, intent is exclusively considered an outcome variable.

Note that incomplete responses, generally linked to missing answers

Table 5
Correlation matrix between outcome variables and variables of interest.

Correlates	Utility cycling	Intention to cycle more often	Active travel mode
Utility cycling	1		
Intention to cycle more often	0.24**	1	
Active travel mode	0.48**	0.19**	1
Density of cycling facilities	0.04	0.06	0.27**
Traffic attitude	−0.06	0.22**	0.01
Traffic stress tolerance perception	0.28**	0.25**	0.20**
Perceived time	−0.25**	−0.31**	−0.32**
Perceived distance	0.25**	0.36**	0.33**
Gender (male)	0.16**	−0.02	0.09*
Children (yes)	0.01	−0.01	−0.10**
Household Income	0.06	−0.03	−0.02
Age	−0.05	−0.29**	−0.04
Full-time worker	0.04	0.04	0.02
Part-time worker	0.05	0.04	0.01
Homemaker	−0.06	−0.01	−0.03
Student	−0.01	0.19**	−0.02
Unemployed	−0.05	−0.18**	−0.00
Education level	0.14**	0.10**	0.11**

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

to the profiling questions such as gender and income, were automatically removed from the binary logistic analysis by SPSS, yielding a final sample of 550 respondents. This exposes the results to non-response bias. However, given the lack of evidence to support the representativeness of the panel, further analysis regarding the implications of the removal of these cases was not undertaken.

5. Findings

Traffic stress tolerance perception, perceived behavioural control over time and over distance, as well as education level are all significantly associated with the three outcomes studied (Table 5). Higher traffic stress tolerance and agreement that many destinations are within cycling distance is positively associated with utility cycling, the intention to cycle more often, and the use of an active mode of transportation (whether cycling or walking). As respondents agree to the statement that they do not have time to cycle instead of driving to their destination, utility cycling, active mode use and intent to cycle more often all reduce, indicating a negative correlation.

Surprisingly, a higher density of cycling facilities is significantly associated solely with the use of an active mode of transportation, and not with utility cycling behavior or the intent to cycle. Similarly, the attitude towards traffic (i.e. thinking there is too much traffic in the streets around one's house) is only significantly correlated to the intention to cycle more often. Also noteworthy is the finding that most of the demographic control variables, with the exceptions of gender and education level, are not significantly correlated with the travel outcomes studied.

The statement regarding traffic attitude has an unexpected positive association with the intention to cycle more frequently. The result indicates that as respondents agree more with the proposition that the streets around their house have too much traffic to allow pleasant cycling, they also have a stronger intention to increase their cycling frequency (Pearson correlation = 0.22). This unexpected finding is investigated further following the regression analysis as the relationship might change when controlling for other variables.

The results for the three binary logistic regressions regarding cycling for utility purposes, the intention to cycle more often, and the use of an active mode of transportation are shown in Table 6. The explanatory variables of interest are mostly significant in explaining the three outcomes although the control variables are generally insignificant, similar to the binary correlation results of Table 5. All three perceived behavioral control variables (level of traffic stress perception, perceived behavioural control over time, and perceived behavioural control over distance) are significant for each of the outcomes. Both LTS rating and perceived behavioural control over distance have odds ratios above 1, indicating that a unit increase on these scales equates to higher odds of being a utility cyclist, intending to cycle more often, or using an active travel mode. A single unit increase on the scale of level of traffic stress perception means a person is 58% more likely to be a utility bicycle user whereas the same unit increase indicates a 16% higher likelihood of using an active mode of transportation (Table 6). The difference in likelihood is consistent with the two behaviours: only cyclists' behavior, and not that of pedestrians, should be affected by their perceived level of traffic stress tolerance.

Table 6
Effects of independent variables on utility cycling, intention to cycle more often and the use of an active mode of transportation (N = 550).

Variables	Utility cycling		Intention to cycle more often		Active travel mode	
	β	Odds ratio	β	Odds ratio	β	Odds ratio
Variables of interest						
Density of cycling facilities	−0.09	0.91	−0.06	0.95	0.32	1.37***
Traffic attitude	−0.16	0.85	0.64	1.90***	−0.03	0.98
Traffic stress tolerance perception	0.44	1.58***	0.33	1.38***	0.15	1.16*
Perceived time	−0.55	0.58**	−0.38	0.69**	−0.41	0.67***
Perceived distance	0.57	1.77**	0.36	1.43**	0.36	1.43***
Control variables						
Gender (male)	0.87	2.38**	0.12	1.13	0.39	1.48
Children	−0.26	0.77	−0.08	0.92	−0.34	0.71
Household Income	0.13	1.14	0.02	1.02	−0.01	0.99
Age	0.00	1.00	−0.15	0.86**	0.03	1.039
Part-time worker[a]	1.05	2.86*	0.36	1.44	0.28	1.03
Homemaker[a]	−18.12	0.00	0.91	2.47*	−0.03	0.97
Student[a]	−0.56	0.57	2.62	13.66	−1.02	0.36
Unemployed[a]	0.43	1.53	−0.36	0.70	0.40	1.49
Education level	0.28	1.33	0.22	1.24	0.20	1.22
Constant	−7.96	0.00	−5.00	0.01	−3.00	0.05
Goodness of fit statistic					0.40	
Nagelkerke R^2	0.334		0.353		0.261	

[a] Relative to full-time worker.
* Significant at the 0.05 level (2-tailed).
** Significant at the 0.01 level (2-tailed).
*** Significant at the 0.001 level (2-tailed).

Perceived behavioural control over time, which is stated in negative terms ("I don't have time to cycle instead of driving"), is associated with odds of cycling for transportation, intending to cycle more frequently, or using an active travel mode below 1. Therefore, a unit increase in lack of perceived behavioural control over time results in lower odds of performing those behaviours or intending to cycle.

Similar to the binary correlation results, cycling facilities density is only significant in predicting the use of an active transportation mode. This is surprising as transportation literature generally agrees that cycling is supply-driven; in other words, if facilities are provided, more people are likely to cycle (Dill and Carr, 2014; Burk, 2017). Consequently, we expect that cycling facility density would be an important predictor of utility cycling or the intention to cycle more often. This discrepancy raises questions regarding the adequacy of the density metric, which will be addressed further in the discussion.

Traffic attitude is significant only in predicting the intention to increase cycling frequency. The unexpected outcome initially observed in the bivariate correlations (traffic attitude and intention to cycle: 0.22) is also observed in the logistic regression. The odds of intending to cycle more often are 90% higher with every unit increase in a respondent feeling there is too much traffic on the streets near their house to cycle without difficulty. The introduction of a third variable, safety dependent intent, mediates this relationship. Safety dependent intent is derived from the statement "I would ride a bike more often if I felt safer riding on the road," recoded as a binary variable (agree and disagree). Traffic attitude is significant in explaining safety dependent intent ($\beta = 0.931$, $p < 0.001$), which in turn is significant in explaining the intent to cycle more often ($\beta = 2.378$, $p < 0.001$). When this intervening variable is introduced, the initial relationship between traffic attitude and intent becomes insignificant ($\beta = 0.156$). In other words, the significant positive relationship observed between feeling there is too much traffic to cycle and the intention to cycle more frequently is entirely explained by the fact that those respondents who perceive there is too much traffic generally agree that, if it was safer to cycle on the road, they would ride more often.

Amongst control variables, being a part-time worker and being male are the only significant variables explaining utility cycling. Indeed, odds are 2.86 times higher for part-time workers to be utility cyclists compared to full-time workers. The flexibility afforded by available time is one possible explanation supported by Cass and Faulconbridge's work (2016). Furthermore, men are 2.38 times more likely to be utility cyclists compared to women, which is consistent with trends generally observed in low-cycling countries (Pucher et al., 2011). Note that gender is not significant in explaining the intent to cycle more often. The only other significant control variables for the intention to cycle more often are age and being a homemaker. As the age group increases by one unit, odds regarding the intention to cycle more often are 14% lower, whereas homemakers are 2.47 times more likely to intend to cycle more often compared to full-time workers.

6. Discussion

Overall, the results are in line with other observations reported in the literature. All variables of interest, with the exception of traffic attitude, had expected signs and reasonable magnitudes. Perceived behavioural control plays an important role in intention to cycle as well as the performance of behaviours such as utility cycling and active travel. The significance of perceived distance is important to inform city planning and land use: urban sprawl and single-use neighborhoods are not conducive to higher levels of cycling or active travel. The importance of perceived behavioural control over time, in addition to distance, points to policy solutions that create "enabling timespace matrices" (Cass and Faulconbridge, 2016), where shorter distances and more relaxed schedules (flexible working hours, teleworking, etc.) allow the practice of utility cycling and active transportation. These findings also align with mode choice theories such as the Theory of Routine Mode Choice Decisions, which take into account increased convenience of each mode, including time and distance, as determinants of travel mode choice (Schneider, 2013).

As noted by several others (Dill and McNeil, 2013, 2016; Damant-Sirois et al., 2014), the usual four-group typology of cyclists does not predict cycling frequency well or indeed distinguish cyclists from non-cyclists. This work shows that a higher perceived traffic stress tolerance, as defined here using a comfort level scale, does increase the odds of being a utility cyclist and the intention to cycle more often. The low number of responses from current utility cyclists did not allow us to evaluate its influence on cycling frequency.

The importance of safety in cycling behavior and intent is supported by the influence of an intervening variable, safety conditional intent, in explaining why a negative attitude to traffic is associated with a higher intent to cycle more often. This mediation confirms there is a latent demand for cycling; more people would like to cycle, but feel that conditions are not safe enough. This supports recent efforts by the City of Edmonton to provide protected, snow-cleared bike lanes along well-travelled corridors in the city core.

The significance of perceived behavioural control over distance was demonstrated, but the density of facilities, an objective spatial measure, was only significant for the active mode use. It is possible that the facility density variable was acting as a proxy for density of destinations, density of population, as well as the density of facilities, both for cycling and walking. This is supported by the fact that the CBD and Strathcona (a central city neighborhood) exhibited highest facilities density. Moreover, the survey only provided respondents' Forward Sortation Area, a large spatial unit; the granularity was likely insufficient to capture infrastructure access. In a future survey, the full postal code should be recorded, as well as other spatial attributes which allow the measure of accessibility, such as the distance or location of regular destinations like work, shops, or day care.

Finally, although the level of traffic stress taxonomy yielded significant results, the factor analysis (showing three categories rather than four) raises questions regarding the suitability of Mekuria et al.'s (2012) translation of Geller's classification into facility specifications. Alternately, the flow of the Bike Ridership survey may be at fault since the statements were written descriptions (i.e. not supported by video and photos) and were placed directly after questions regarding the use of bicycle lanes. Participants might have been focusing on bike lane aspects of the description as it was more salient in their memory. This alternate explanation supports the need for new research with the specific objective to validate or adjust the classification.

7. Conclusion

In this research, we aimed to explore determinants of cycling behaviour and intent as well as the use of an active mode of transportation in Edmonton, a northern low-cycling city. The research was conducted using an open dataset (the Bike Ridership survey) from the city of Edmonton. Through scale and variable construction, it was possible to test the importance of five main variables on utility cycling behavior, the intent to cycle more frequently, and the use of an active mode of transportation.

This study contains important limitations due to the use of publicly available, non-academic data. Although creative scale construction permitted the study of five important determinants, these were constrained by the available data. The shortfall of the density of facilities variable, for example, indicates alternate accessibility indicators should be constructed for future work.

Nonetheless, this study is an excellent first step to inform further, more focused research on cycling in Edmonton and a good initial exploration of cycling determinants in a northern winter city. Specifically, this research showed that most of the variables explored have similar impacts in Edmonton on bicycle use, the intent to cycle and the use of an active mode of transportation as have been observed in other cities studied. Indeed, the analyses show that perceived behavioural control over time and distance as well as perceived tolerance to traffic stress are significant in determining these outcomes, which was to be expected based on previous research. Attitude towards traffic, (i.e. feeling there is too much traffic for pleasant cycling around one's residence) was positively correlated with the intent to increase cycling frequency. This effect was found to be fully mediated by the agreement to the statement that respondents would cycle more if they felt safer on the road, confirming the importance of safety as observed in other studies. The potential differentiation of the city due to its colder climate and lack of cycling culture may lie in variables which could not be assessed for this study, such as weather and hilliness. It may also lie not in the nature of the factors driving those outcomes, but rather in the proportion of the population that perceives their environment as reasonably adequate for cycling. Environmental values are also a key driver of behavior such as cycling, which could not be accounted for in this study and should be included in future research. Further, although safety was found to play a significant role in cycling intent, this study did not explicitly consider which reasons might induce the feeling of poor safety on the road. In addition to heavy motorized traffic, other possible safety concerns which should be considered in future research include poor winter maintenance, darkness, and lack of driver awareness of cyclists.

Finally, two broad policy implications arise from this work. The importance of time and distance indicate planning should continue to focus on more compact urban form, coupled with initiatives or policies to allow more flexibility with time constraints. The significance of tolerance to traffic stress and the prominence of safety in intending to cycle more often confirm the importance of providing safe and dedicated space for cyclists on the road. Moreover, as intent to cycle is gender neutral, providing facilities to accommodate the latent demand might help reduce the gender gap observed in utility cycling behaviour.

Declarations of interest

None.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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