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Factors affecting mode choice for the home–elementary school journey: Evidence from Halifax, Canada

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Key Messages

- Most children are chauffeured to school, including many of those who live close to their school.
- Distance significantly impacts elementary students' travel mode choices for the home–school journey, especially walk and bus modes.
- Older and smaller elementary schools, especially in densely populated communities, tend to encourage walking for the home–school commute.

This research investigates personal, school, neighbourhood, and weather characteristics that are associated with travel mode choices for children's direct journeys between home and school. Travel diary and socio-demographic data were collected from elementary school students aged 5 to 11 years in Halifax, Nova Scotia, and were joined with characteristics about their respective school, neighbourhood, and weather. Multinomial and mixed logistic regression were used to examine the relationships between these characteristics and choices between car, bus, and walk travel modes. Results indicate that personal, school, neighbourhood, and weather characteristics all impact mode choice decisions, yet distance between home and school is among the most significant. To promote active travel between home and school, our findings suggest that smaller elementary schools should be sited centrally within compact, high-density neighbourhoods that are designed for active travel, thereby minimizing school travel distances and maximizing the practicality of active travel modes.

Keywords: journey to school, school siting, neighbourhood design, mode choice, active transportation

Facteurs influençant le choix du mode de transport entre l'école primaire et la maison : preuves recueillies à Halifax, au Canada

Cette recherche examine les caractéristiques personnelles, scolaires, météorologiques et du quartier qui sont associées au choix du mode de transport pour les déplacements des enfants entre la maison et l'école. Les données sociodémographiques et un journal des déplacements ont été collectés auprès d'élèves du primaire âgés de 5 à 11 ans à Halifax, en Nouvelle-Écosse, et ont été combinés aux caractéristiques de leur école, de leur quartier et de la météo. Nous avons utilisé une régression logistique mixte et multinomiale pour examiner les relations entre ces caractéristiques et les choix entre les modes de déplacement suivants : la

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voiture, l'autobus et la marche. Les résultats indiquent que les caractéristiques personnelles, scolaires, météorologiques et du quartier ont toutes une incidence sur les décisions concernant le choix modal, mais la distance entre la maison et l'école est parmi les plus importantes. Pour promouvoir le déplacement actif entre la maison et l'école, nos conclusions suggèrent que de plus petites écoles primaires devraient être situées dans un emplacement central dans des quartiers compacts et à forte densité qui sont conçus pour des déplacements actifs, minimisant ainsi la distance des déplacements vers l'école et maximisant l'aspect pratique des modes de déplacements actifs.

Mots clés : transport à l'école, localisation de l'école, conception du quartier, choix du mode, transport actif

Introduction

The form and function of our neighbourhoods, as well as the size and location of our schools, have important social, economic, and environmental impacts, plus significant implications for public health policy. For example, among the current generation of schoolchildren, mounting evidence suggests a dramatic decline in rates of active travel (AT) modes, namely walking and cycling, for the journey between home and school (McDonald 2007, 2008; Grow et al. 2008; Babey et al. 2009; Buliung et al. 2009; Wendel and Dannenberg 2009; Botchway et al. 2014; McDonald, Salvesen, et al. 2014). Decreased rates of AT and levels of physical activity may be partially due to automobile-oriented urban design (Forsyth and Southworth 2008), but recent school siting policies and decisions, particularly the locations where new schools are built (Lees et al. 2008; McDonald, Salvesen, et al. 2014; Kim and Lee 2016), have also led to increased distances between students' homes and their schools. The obvious consequence of these school siting policies and decisions is that fewer students live within legislated maximum walking distances (*viz.* minimum distance for bus service), and thus must be driven to and from school by either car or bus. From an AT perspective, it appears that school siting policies and decisions are disconnected from, and uncoordinated with, not only other planning decisions but also current policy directions and academic discourse in community planning (McDonald 2010; Spinney and Millward 2011a).

Regardless of the cause for current low rates of AT for the home–school commute, the problem with an increasing proportion of children being chauffeured is a commensurate decrease in the potential opportunities for children to regularly engage in physical activity (Strong et al. 2005; Deka and Von Hagen 2015). As the journey between home and school is the most common travel activity among Canadian children (Stefan and Hunt 2006), it provides the most prevalent opportunity for children to regularly engage in physical activity (Binns et al. 2009). While we are reminded by Sirard and Slater (2008) that it is not possible to establish causal relationships between being chauffeured to school, decreased levels of physical activity, and increased prevalence of childhood obesity, today's generation of schoolchildren is less physically active and increasingly prone to obesity (Tremblay and Willms 2003; Frank et al. 2004; Janssen et al. 2006; Ewing et al. 2011; Botchway et al. 2014). Yet, there is convincing evidence that suggests children who walk to school are more physically active than others (Frank et al. 2005; Cooper et al. 2010; Voss and Sandercock 2010). Regardless of the relationships with obesity or physical activity, AT provides important opportunities for children to benefit from exposure to nature (Louv 2005), develop responsibility, explore and interact with their neighbourhood, and foster independence (Bean et al. 2008; Fusco et al. 2012; Larsen et al. 2015), while also reducing environmental impacts associated with increased automobile use (Stewart 2011).

Since the pioneering works by Beaumont and Pianca (2002), there have been decades of mounting evidence documenting the many social, economic, and environmental benefits of AT, which has contributed to a growing interest in the journey between home and school among academic researchers, public health officials, and urban planners alike. Consequently, several programs and policies are being developed and major investments are being made to help promote AT in general, and active school travel (AST) in particular. For example, the "Active and Safe Routes to School" program (McDonald, Steiner, et al. 2014; Active and Safe Routes to School 2018) used the school travel plan (STP) to encourage AT through improved public education programs about traffic safety, better engineering of the pedestrian and cycling environment, enforcement of traffic laws, encouragement to participate in AT, and evaluation of STP efforts (the five E's). It is noteworthy that such programs are based on the hypothesis that mode choice decisions for children's journey between home and school are influenced by characteristics of the built environment (e.g., Braza et al. 2004; Frank et al. 2006; Schlossberg et al. 2006; Larsen et al. 2009). However, we are cautioned by McMillan (2007) and by Larsen et al. (2009) of the limitations of the evidence to support such a hypothesis. Moreover, Mitra and Buliung (2015, 4) point out that empirical results "are sometimes at odds with each other, particularly with regard to the influence of the neighbourhood environment." These often-conflicting results are indicative of the complexities of the mode choice decision-making process and the challenge of empirically disentangling the influence of local contextual conditions (including the built environment) on those decisions.

If public health interventions, community planning policies (including school siting), and neighbourhood design practices are to produce a positive change in mode choice decisions, it is first necessary to better understand the locally relevant factors impacting schoolchildren's commuting patterns. The consequences have important social, economic, environmental, and public health implications. If the goal is to promote physical activity, there is a need to provide programing and policies that remove barriers and promote the conditions necessary for children and their parents to choose active modes of transportation (Osborne 2005; McMillan 2007; Cooper et al. 2010; McDonald 2010; Napier et al. 2011). However, the socio-ecological model of health behaviours (Sallis and Owen 1997) posits that multiple layers of intrapersonal, social, and physical environment variables influence an individual's behaviours. The perceived intrapersonal, social, and physical environment barriers vary widely among children and their parents, which makes the multi-layered mode choice decision-making process highly complex (Faulkner et al. 2010); recent review articles have summarized the literature pertaining to active modes of home–school transportation (Davison et al. 2008; Sirard and Slater 2008; Stewart 2011; D'Haese et al. 2015; Wang et al. 2016) and they all appear to indicate that more empirical evidence is needed. In fact, several authors have noted the lack of empirical evidence concerning the correlates of transportation-related physical activity (Merom et al. 2006; Schlossberg et al. 2006; Duncan et al. 2016). Related to work by Easton and Ferrari (2015), who used multi-level modelling of personal, school, and neighbourhood factors in Sheffield, United Kingdom, this research tested a set of a priori hypotheses to provide further empirical evidence regarding the relative impacts of personal, school, neighbourhood, and weather characteristics on mode choice decisions for children's journeys between their home and elementary school in Halifax, Nova Scotia, Canada.

Data description

The data employed in this study are derived from a sample of 1,971 randomly selected households within Halifax Regional Municipality (HRM) that voluntarily participated in the STAR (Space-Time Activity Research) survey between April 2007 and May 2008 with a response rate of 21%. Most AST studies employ recall questionnaires or hands-up classroom tallies, which can be both unverifiable and unreliable. In contrast, the Halifax STAR survey deployed travel diaries to capture information about travel times, purposes, modes, social contacts, and locations that were rigorously validated against the diary data of other household members. The data collection process began with a pre-notification letter being sent to each randomly sampled residential address to inform the household members they had been chosen to participate and should anticipate a telephone call within the next few days. A computer-assisted telephone interview was used to recruit each household and to collect demographic information about all household members. A randomly selected household member over the age of 15 acted as the primary respondent and this individual completed a GPS-assisted time-diary instrument. All other household members over the age of 5 were asked to complete 48-hour travel diaries, with proxy reporting allowed by parents or guardians for respondents under the age of consent.

Self-reported travel diary surveys have been the standard data collection tool used by transportation researchers for the last half century. The travel diary used in the STAR survey captured the dynamic location, travel modes between locations, the activities performed at each location, and the start and end times at each location for a 48-hour reporting period. The completed diaries were returned the day after their reporting period and subsequently converted into digital format. During the data-entry process, each location was geocoded (i.e., assigned latitude and longitude coordinates) using a linked gazetteer. The home and school coordinates, and attributes, were entered into TransCAD® along with a street network file to compute objective street network travel distances in metres, assuming two-way travel on all streets.

This research is concerned with mode choice decisions for elementary school students, who were defined as respondents between the age of 5 (starting Primary) and 11 (starting Grade 6) years and proxy reported "student" as their main activity. Since the school board policy in Halifax is to provide busing services to elementary school (Grades Primary through 6) children who live beyond 2,400 metres of their school, we chose to further limit our analysis to elementary schoolchildren who reside within 2,400 metres (shortest-path road distance) of their school. The result was 195 elementary schoolchildren who engaged in 913 school-related trips (26.5% of all trips) that resemble a proportional distribution over all 10 months of the school year (i.e., September through June).

A cross-tabulation of origins and destinations was used to further limit our analysis to only "direct" trips between home and school (DHS trips), which account for 70.1% of all elementary schoolchildren's school-related trips. We recognize that this eliminates multi-modal trips (2.2%), multi-destination trip chains (4.2%), and intermediate stops at someone else's home (10.1%) on the way either to or from school (e.g., babysitter, siblings' school). The remaining sample, and the prevailing unit of analysis, is 383 DHS trips (221 home-to-school and 162 school-to-home) that were taken by 195 elementary school students. The elementary schoolchildren's travel mode choices were: 147 car trips (as passenger); 67 bus trips (mostly school bus); and 169 walk trips. It is noteworthy that bicycle was reported for only 69 (2.4%) of the elementary schoolchildren's trips, and for only 7 (0.8%) of their school-related trips. Therefore, bicycle trips were excluded from this analysis.

The 383 DHS trips examined herein either originated or terminated at one of 50 different elementary schools throughout the county-sized study area, whose geographic coordinates were collected and validated. Information about each school was retrieved from the Halifax Regional School Board website (www.hrsb.ns.ca) for the public schools, and the *Conseil Scolaire Acadien Provincial* website (www.csap.ednet.ns.ca) for the sole reported French language school. Specifically, we retrieved information about the date of construction for each school building, the size of the building(s) in square metres (not available for the French school), and total student enrollment in 2007. These school characteristics were joined with the travel diary information.

Neighbourhood features refer to the social, economic, and built environments surrounding each of the 50 schools attended by the respondents. We used Statistics Canada's 2006 census data, reported at both the dissemination area and census tract scales, to summarize and the area-level socio-economic neighbourhood for all census tracts substantially within 2,400 metre buffers around each school. Based on preliminary analysis, we chose population density, in persons per square kilometre, at the dissemination area scale, plus two variables at the census tract scale: apartments as percent of private occupied dwellings and weighted mean age of dwellings. We also used ESRI ArcGIS 9.3 software to compute several neighbourhood-level metrics to characterize both the transportation infrastructure and land use patterns within the 2,400-metre buffers around each school. Specifically, we computed (a) street density using a ratio of four-way intersections to all intersections, (b) density of sidewalks (ratio of sidewalk length to road length), and (c) an entropy index to measure the variety of different land uses. The entropy index was computed using six land uses based on work by Frank et al. (2006). Furthermore, due to the well-established impact of travel distance on mode choice decisions, and despite the inherent limitations (e.g., Duncan and Mummery 2007; Buliung et al. 2013; Zhu and Levinson 2015), we also calculated the shortest-path street network distances between each student's home and their school.

We hypothesized that mode choice decisions for DHS trips are impacted generally by the seasons (Fall, Winter, Spring) and specifically by mechanical and/or thermal comfort (i.e., inclement weather). Data from the weather station at Halifax Stanfield International Airport (44° 53.0' N, 63° 31.0' W, with 145.4 metre elevation) were downloaded, formatted, and joined with the travel diary data. More specifically, the weather data include daily temperature (min., max., mean); total precipitation, total rainfall, and total snowfall reported in millimetres; maximum wind speed; and depth of accumulated snow on the ground. The ambient weather data were joined to the travel diary data based on the date information.

Mode choice model

Model formulation

The discrete choice model presented in this section was formulated to quantify the significant factors that help explain the mode choice behaviour of elementary schoolchildren's DHS trips. The model predicts the probability of a student choosing car (C), bus (B), or walk (W) travel modes. Let U_{in} be the utility associated with travelling student n and mode i:

$$U_{in} = V_{in} + \varepsilon_{in}$$

where V_{in} is a linear-in-parameter function that depends on observed factors characterizing student n and mode i, and ε_{in} is an unobserved error term. The mode choice probability P_{in} can be formulated as the popular Multinomial Logit Model (MNL) shown in equation 1 if the error terms ε_{in} are iid (for all i and n) and follow the Gumbel distribution.

$$P_{in} = \frac{\exp(V_{in})}{\sum_m \exp(V_{mn})} \qquad (1)$$

Although the MNL has been employed extensively in mode choice analysis in the past, the application of the Mixed Logit Model (MXL) has become more commonplace in the recent literature (Santos et al. 2013; Noland et al. 2014; Khan et al. 2016). The basic advantage of the MXL is its ability to capture the impacts of unobserved heterogeneity among the modelled decision makers (Train 2009). Also, the MXL remedies the issue of serial correlation that is usually present in travel diaries or panel data (Daniels and Hensher 2000; Hensher et al. 2005). Unlike the MNL model, the MXL model assumes that the impact of a particular covariate in the utility function varies among the modelled decision makers. That is, the parameter β associated with a given covariate is not a fixed-point value, but rather it varies among the heterogeneous and unobserved groups of travelling children. Assuming β follows some known distribution Φ (e.g., normal distribution), the mode choice probability P_{in} can then be formulated as the weighted probability across all possible β's pertaining to Φ, that is:

$$P_{in} = \int_{\beta_n} \frac{\exp(V_{in/\beta_n})}{\sum_m \exp(V_{mn/\beta_n})} P(\beta|\Phi) \mathrm{d}\beta \qquad (2)$$

Model specification

The specification of the utility functions forming the mode choice models, shown in equations 1 or 2, is based on the four groups of variables that represent the personal, school, neighbourhood, and weather characteristics for the 383 DHS trips made by 195 elementary school students who reside within 2,400 metres of their school. The objective was to test a set of a priori hypotheses and to explain mode choice behaviour for elementary students' DHS trips. Table 1 lists the variables used in the formulation of the mode choice models.

Based on preliminary analysis of personal characteristics, we hypothesize that older students (at least 9 years old) are less likely to be chauffeured to school, either by their parents or the bus driver, as a sign of independence. We also postulate that families who earn more than $60,000 are more likely to drive their children to school, as are families who own two or more cars.

These school characteristics were used to test two hypotheses: students attending larger schools and students enrolled in newer schools are less likely to walk. Compared to older schools, which are typically in the older and more dense areas of the study area, newer schools tend to be larger and more prevalent in suburban areas, which tend to be more auto-oriented in general and as such are less conducive to walking (Gurwitt 2004).

Regarding the impact of neighbourhood characteristics, we hypothesized that school catchment areas with high-density neighbourhoods tend to be smaller and more compact, which means that more students live closer to their school, thus encouraging walking. Likewise, schools in areas with older

Table 1
Explanatory variables for mode choice model specification.

Variable name	Description
Participant characteristics	
Child age	Age of student
High income	1 if family earns $60,000 or more a year, 0 otherwise
Old female child	1 if student is female 9 years or older, 0 otherwise
Cars (2+)	1 if family of student owns 2 or more cars, 0 otherwise
Household size	Number of household members
School characteristics	
New school	1 if the school was constructed after 1980, 0 otherwise
Large school	1 if the school building is > 37,322 sq. m, 0 otherwise
Neighbourhood characteristics	
Apartment %	Percentage of apartments in area
Population density	Population density
Distance to school	Distance (in metres) between student's home and school
Intersection density	Ratio of four-way intersections to all intersections
Weather characteristics	
Total rain	Total rainfall in millimetres
Fall semester	1 if month is September through December, 0 otherwise

dwellings are typically smaller and more closely spaced, thus encouraging walking. Schools in areas with a higher percentage of apartments are assumed to have a higher population density and thus are expected to encourage walking—but may also be newer, more suburban, and thus encourage more driving. Finally, based on work by Cervero and Kockelman (1997), Larsen et al. (2009), Curtis et al. (2015), and Neatt et al. (2017), we hypothesized that areas with a high level of entropy (i.e., mixed land uses) may be more conducive to walking. However, this effect may not be an independent one, since high entropy tends to be correlated to neighbourhood vintage, population density, and neighbourhood design. Moreover, the effects are complex and have varying impacts on different groups of people (e.g., age) and different types of walking (commute vs. recreation). Nonetheless, the notion that mixed land uses increases the practicality of walking remains a central tenet of the theory and practice of community planning and neighbourhood design. Finally, the distribution of home-school trips over all 10 months of the school year provided an opportunity to control for daily weather conditions and seasonal climate variations. For example, we hypothesized that meteorological conditions that pose major mechanical or thermal discomfort (e.g., raining or too cold) may also pose a barrier to walking.

Modelling results and discussion

Table 2 presents the results of four MNL mode choice models and one MXL model that were estimated using the NLOGIT 5.0 econometric software. The MNL models were estimated under different utility specifications. While the first four models test the respective impacts that individual, school, neighbourhood, and weather characteristics have on the mode choice for DHS trips, the fifth model combines all factors into one pooled model. The MXL model uses the same specification as the MNL model, but it relaxes the assumption of fixed point parameters to account for unobserved heterogeneity in the modelled sample.

The results suggest well-behaved MNL models as discerned from the signs of the estimated parameters and the achieved adjusted rho-square values. The results from the first four MNL models clearly suggest that the neighbourhood factors have the highest explanatory and predictive power in the model with an adjusted rho-square of 0.26 and 54% predicted correctly. By comparison, socio-economic characteristics rank second in terms of their explanatory and predictive power. School attributes exert the least impact on the explanation of the observed mode choice behaviour.

Model results support most of our hypotheses for participant characteristics. For example, model

Table 2
Parameter estimates of children's home-to-school mode choice models.

		Socio-economic		**School**		**Neighbourhood**		**Weather**		**Pooled MNL Model**		**Pooled MXL Model**	
Variable Name	V_{in}	**Beta**	**t-stat**	**Beta**	**t-stat**	**Beta**	**t-stat**	**Beta**	**t-stat**	**Beta**	**t-stat**	**Beta**	**t-stat**
Constant	C	3.621	5.759	0.927	5.922	0.432	2.386	0.810	5.341	3.255	3.759	4.720	3.723
Child age	C	−0.492	−6.444							−0.558	−5.475	−0.779	−5.027
High income	C	1.652	4.181							2.630	4.970	3.186	4.426
Old female child	B	0.727	2.273							0.951	2.305	1.368	2.733
Constant	W	0.522	0.838	1.441	7.493	3.335	7.722	0.149	0.792	3.611	3.034	4.145	2.257
Cars (2+)	W	−0.977	−3.139							−1.278	−2.421	−1.561	−1.978
Household size	W	0.294	2.181							0.082	0.371	0.035	0.109
New school*	W			−0.446	−1.922					0.399	0.866	0.083	0.127
Large school	W			−0.458	−2.117					0.805	1.557	1.724	2.001
Apartment %*	C					0.02	3.213			0.019	1.981	0.037	1.837
Population density	W					0.001	4.446			0.001	4.357	0.002	3.358
Distance to school	W					−0.003	−9.477			−0.003	−7.070	−0.004	−3.955
Intersection density	W					−2.322	−1.546			−7.195	−2.723	−5.051	−1.275
Total rainfall	C							−0.01	−0.68	0.054	2.330	0.055	1.668
Fall semester	W							1.576	7.085	1.233	2.924	1.684	2.570
Standard deviation (normal distribution)													
Apartment %*	C											0.078	2.584
New school*	W											1.797	1.598
Rho-square		0.125		0.014		0.261		0.068		0.465		0.531	
Adj. rho-square		0.115		0.008		0.255		0.063		0.452		0.517	
% predicted correctly		47%		39%		54%		43%		69%		69%	

*Parameters in the MXL model are random and follow a normal distribution.
Utility $\boldsymbol{V_{in}}$ pertains to the following modes: Car (C), Bus (B), and Walk (W).

results indicate that students (or more correctly their parents) are significantly less likely to choose car for DHS travel as the child gets older. This decision may relate to greater parental ease regarding sensible behaviour and safety, augmented with pressure for independence from the child. The model also indicates that older girls (9 through 11 years) are more likely to ride the bus than younger girls, and an increased share of car trips for families with incomes over $60,000 and those who own two or more cars.

Regarding the school characteristics, the model supports the widely held notion that both newer and larger schools fail to encourage walking. For example, newer schools tend to be larger buildings and, expectedly, have larger student populations, and they also tend to be located on larger lots that are typically located on the outskirts of the community (Lees et al. 2008; Cohen 2010; Ewing et al. 2011; McDonald, Salvesen, et al. 2014; Kim and Lee 2016), which are consequently much less accessible by active travel modes. The process of building large schools on the outskirts of our communities is widely acknowledged as "school sprawl" (McMahon 2000).

Regarding the neighbourhood characteristics, model results support all our hypotheses and indicate the most significant neighbourhood feature ($t = -9.5$ in the MNL model) is the distance between home and school. School siting has direct implications for the distances students are required to travel, which mainly impact walk and bus modes (Jensen 2008; Binns et al. 2009; Ewing et al. 2011; Spinney and Millward 2011a; McDonald, Salvesen, et al. 2014; Deka and Von Hagen 2015). Also significant was population density, and to a lesser extent the percentage of apartment dwellings: both are positively associated with walk mode choices. Interestingly, the entropy variable was positive and significant when introduced on its own in the walk utility, but its significance started diminishing in the presence of additional variables. Furthermore, the parameter switched sign, suggesting it is highly correlated with one or more of the other utilized variables. As such, entropy was excluded from the final specification of the models.

Model results indicate that neither snow on the ground nor wind speed (mechanical comfort) nor mean daily temperature (thermal comfort) exhibited a statistically significant impact on mode choice decisions, other things being equal, and were dropped from the final model specification. Model results also indicate, intuitively and expectedly, total rainfall was positive and significant for the car mode. Moreover, the combined impact of weather, especially comparing the fall (September through December) and winter (January through June) semesters of the school year, exhibits a positive and significant impact on walking during the fall semester. Given the difficulty disentangling the combined impacts of weather variables, the cumulative impacts of weather may be better characterized by an hourly composite index that focusses on inclement weather (Spinney and Millward 2011b) that uses both objective measurements, such as a "weather score" (McGinn et al. 2007), and subjective measurements, such as "perceived weather" (McGinn et al. 2007; Shao 2016).

When the personal, school, neighbourhood, and weather variables are combined in the pooled models, inter-correlations are identified and the separate effects of the variables are isolated. As seen in Table 2, the pooled MNL model reveals the overriding importance of the neighbourhood variables on the choice to walk, and most particularly the negative effect of distance to school and the positive effect of population density. These two variables are also important in the pooled MXL model, but to a lesser degree. Interestingly, intersection density has an inhibiting effect on walking in both models, presumably related to road safety concerns.

In both pooled models, car ridership is strongly related to two key socio-economic variables: negatively to child age, and positively to high household income. In contrast, older female child has a modest positive effect on bus ridership, while ownership of two or more cars has a barely significant positive effect on car ridership. Household size is insignificant in both pooled models. The two school attributes of age and size tend to change in the pooled models and barely figure in the pooled MNL model; age is insignificant while size is barely significant. However, the mixed model suggests the presence of heterogeneity effect in the school age variable. While the mean value of the school age coefficient is not significant (i.e., mean equals zero), the standard deviation is 1.80, which suggests that the propensity to choose walking varies widely among students. The latter could be due to the locational difference of newly developed schools in Halifax, which lends itself to the unobserved heterogeneity in the choice of active transport by students, other things being equal. Interestingly, the large-school variable in the pooled mixed logit model becomes significant and positive. Perhaps this could be due to the nature of larger schools, which are more likely to attract a disproportionate number of students who prefer to walk, other things being equal. In general, school characteristics are not independent from the neighbourhoods in which they are sited. In Halifax, older and smaller schools tend to be located in high-density inner-city areas, thus affording their students shorter walking distances.

The presence of unobserved heterogeneity manifests itself in the percentage of apartments coefficient. The results pertaining to the mean and standard deviation of this parameter in the mixed logit model suggest that the propensity to choose car varies among the population of students. Meaning, not all students and their families have the same tendencies with respect to their choice for car travel. Again, this could be attributed to the location of the apartments where the students and their parents live with respect to where the schools are located. The two pooled models both account for a large proportion of variation in student mode choices, as indicated by their high and similar adjusted rho values (0.452 for MNL and 0.517 for MXL). Both models correctly predict 69% of mode choices.

Concluding remarks

The primary purpose of this research was to investigate the personal, school, neighbourhood, and weather characteristics that impact travel mode choices for elementary schoolchildren's direct trips between their home and school in Halifax, Nova Scotia. The study reported here represents one of the first to comprehensively examine travel mode choices for Halifax schoolchildren by using MNL and MXL to analyze a wide range of personal, school, neighbourhood, and weather characteristics. We recognize there are also psychological, social, environmental, physical, and attitudinal factors, which vary among the different actors, each with their own perspectives and schedules (e.g., Black et al. 2001; Susilo and Liu 2016; Yu and Zhu 2016) that collectively influence mode choice decisions. We also recognize that this research may benefit from separately modelling the journey to school and the journey from school, because the trip to school is often, and in many ways, different from the trip home from school (Buliung et al. 2009; Larsen et al. 2009; Buliung et al. 2013), owing mostly to the scheduling of parents' journeys between home and work (Faulkner et al. 2010; Carver et al. 2013). Based on the relationship between the students, school, neighbourhood, and weather characteristics and the travel mode choices examined herein, we may conclude that other variables are required to more fully explain mode choice decisions.

This study has revealed the key role played by home-to-school distance as a predictor of walk choices, which corroborates findings of most previous studies (e.g., Schlossberg et al. 2006; Cole et al. 2007; McDonald 2007, 2008; Spinney and Millward 2011a; Curtis et al. 2015; Olaru and Curtis 2015). However, we used a fairly coarse spatial resolution for the distance measurement, and we failed to incorporate pedestrian/multi-use pathways even though we recognize the actual route travelled may significantly differ (Dessing et al. 2016). Closer examination of the distances between a respondent's home and their school could offer more nuanced insights into the impact of distance on walk modes. In future work, it might be instructive to empirically construct distance decay models for different neighbourhood types, and thereby predict "walksheds" for the journey to school for different neighbourhood types. Such research may provide valuable information for future discussions on neighbourhood design and school location policy and practice, and on walking distance threshold policies for different age groups.

Neighbourhood population density is another important predictor of choosing to walk. High-density neighbourhoods often contain more children and allow more closely spaced schools, and hence more children living within easy reach of their school. High-density areas tend to be in the inner city, and thus tend to have both older and smaller schools. The smallest elementary schools (in both building size and number of students) have the highest rates of walking, with almost two-thirds of the students choosing to walk. Though the multivariate models suggest that age and size of school have negligible proximate effects, beyond their relationship to the two neighbourhood variables, small schools can be sited closer to each other, and hence act as the root cause in reducing home-to-school distances. The results of this research, therefore, support suggestions made by others (Timperio et al. 2006; Babey et al. 2009; McDonald 2010; McDonald, Salvesen, et al. 2014; Curtis et al. 2015; Olaru and Curtis 2015; Kim and Lee 2016), recommending the siting of smaller community schools either in or adjacent to residential areas that are densely populated with school-aged children.

However, as we discovered in this study, many children who live within close proximity to their school are chauffeured between home and school by car. The MNL and MXL results show that two key predictors of the car mode choice are the child's age and the household income. Again, to some extent these are proximate causes, and the root causes may relate more to issues of perceived child maturity and traffic safety (related to age), or to automobile and parental availability (related to income) (see Carver et al. 2013). Therefore, developing interventions aimed at promoting active transportation must address not only the siting of schools, but also the objective and perceived barriers to walking (and cycling) faced by different groups of schoolchildren (Kim and Heinrich 2016; Wendel and Dannenberg 2009; Yeung et al. 2008). For example, it is necessary to also improve the safety of the pedestrian environment to promote increased use of AT (Merom et al. 2006; Carver et al. 2013; McGowan et al. 2016). Much of the focus appears to be on improved design of the pedestrian environment, but if the focus was on increasing AT rates for the journey between home and school, infrastructure improvements and programs to encourage bicycling should have the greatest potential impact. This is because under the right conditions a reasonable walking distance for elementary schoolchildren may be about 400 metres (one-quarter of a mile) or upwards of 800 metres under the right conditions for older students.

However, a bicyclist can cover about three times the distance of walking in the same amount of time (Jones et al. 2013). Therefore, a reasonable bicycling distance should be 1,200 metres for elementary schoolchildren and upwards of 2,400 metres for the oldest students, under the right conditions. Our data showed that bicycling is clearly an underutilized mode option in our study area, so it is reasonable to suspect infrastructure improvements and programs to encourage bicycling may have significant untapped potential.

Improving school siting and traffic safety requires interdisciplinary reasoning among decision makers, who do not always fully appreciate the implications of neighbourhood design or school siting decisions for transportation planning, public health, nor the social, economic, and environmental costs. This challenge is made more difficult by the requirement that developers, planners, and policy makers understand the needs of children (Cohen 2010; Curtis et al. 2015) and reconcile children's needs with the needs of the broader community (Bishop and Corkery 2017). For example, if the primary purposes of school-siting are to provide a variety of educational programs and sporting opportunities, economies of scale will inevitably require a large-campus design, intended for automobile and school bus traffic, and it will inevitably be spatially separated from many the community members it services. However, if the primary purposes of school-siting are to service neighbourhood children, to promote active transportation as a means of increasing the levels of physical activity among children, and to reduce traffic congestion and its consequent environmental and public health impacts (e.g., traffic safety, air quality), the school should be small, well incorporated into the scale and design of the built environment, and located within a reasonable distance of the neighbourhood children it services. Such a residential design model accords with the "neighbourhood unit" proposed by Perry (1929), whereby centrally located schools (within a quarter-mile, or 402 metres) also act as a local community centre for people of all ages and a wide range of after-school, evening, and weekend activities. McDonald (2010) warns that the incorporation of school siting into local and regional planning requires community planners to be cognizant of this neighbourhood-versus-community issue.

We agree that AST promotion is one of many important considerations in school siting and that educational and financial considerations should take priority. School boards typically consider a variety of competing requirements, such as the size of the property, land affordability, demographics, stability of student population, attendance boundaries and configuration, and travel distance (Tsai and Miller 2005). However, the long-term trend to larger schools spaced farther apart, which deters AST, has also been contested on educational and community-use grounds, and there is a movement to return to smaller community schools, serving more localized neighbourhoods (McDonald 2010).

This research has demonstrated that neighbourhood characteristics alone do not dictate mode choice decisions. Moreover, this research has also demonstrated that despite its near ubiquity among children, home–school travel comprises only a relatively small share of all their travel activities. To encourage active travel by youth to a wide variety of destinations, including elementary schools, we therefore need to focus not simply on community planning policies that include better school sizing and siting, but also more broadly on improved urban design practices and successful behavioural intervention programs. These conclusions are likely to be valid and applicable in all urban-focussed school districts in Canada, though the specifics of their implementation will need to respect local context.

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