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The influence of neighborhood environment and household travel interactions on school travel behavior: an exploration using geographically-weighted models

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ABSTRACT

Professional and popular interest in active school transportation (walking and cycling) is matched by an emerging literature on this topic. This paper explores school travel behavior of 11-year old children in Toronto, Canada. In particular, the effects of the neighborhood environment and caregiver-child travel interactions on travel mode choice were studied. Results indicate that the built environment near both home and school locations was associated with the odds of walking. However, predicted built environment effects were less accurate in some neighborhoods. Availability of adults at the time of school travel likely encouraged driving. School transportation interventions that broadly consider school and neighborhood-oriented policies and enable independent mobility may increase walking rates. Presence of spatial autocorrelation in the prevalence of walking suggests that more research is required to understand inter-household similarities in behaviors that are spatially structured.

1. Background

Western countries have witnessed a major shift in the way children and youth travel to and from school. Following decadal declines in active school transportation (AST: walking or cycling), more students are now being driven than ever before (Buliung et al., 2009; McDonald, 2007; van der Ploeg et al., 2008). Physical activity derived from school travel may have important implications for children's healthy growth (Active Healthy Kids Canada, 2013; TRB, 2005; Tudor-Locke et al., 2001). Hypothetically, those who walk/cycle to school regularly may also appreciate the benefits of sustainable travel practices and an active lifestyle as they age, while attenuating external costs of automobile use (Black et al., 2001).

Quantitatively oriented research has explored the environmental and psychological correlates of children's school travel behavior (e.g., McMillan, 2007; Mitra et al., 2010a; Panter et al., 2010; Yang et al., 2012). Research emphasis on environmental correlates is particularly important in the context of emerging public policy interest in understanding how to plan and engineer built environments to enable walking/cycling among children. For example, the Safe Routes to School (SRTS) programs in the U.S. and the School Travel Planning (STP) initiatives in Canada emphasize mobilization of community and government resources with a view to producing school or site-specific social and environmental solutions to the school travel problem (Buliung et al., 2011; Green Communities Canada, 2013; NCSRS, 2007).

This study addresses several topics that remain largely unaddressed in the current school travel literature. First, household members' school transportation mode choice behavior may not be spatially independent from that of their neighbors; spatial autocorrelation in school travel outcomes is expected. Spatial autocorrelation may also occur when empirical research fails to capture fully the variations/similarities in the built environment across households. The presence of spatial autocorrelation, and a failure to account for it, may limit our understanding of the relationship between a household's travel behavior and the surrounding environment. However, spatial autocorrelation remains an under-recognized and less discussed issue in the school transportation literature (Mitra et al., 2010b; Sidharthan et al., 2011).

Second, the school travel outcome is one of many household activities that are co-located in space and time. The importance of interactions among household members in explaining household travel behavior is widely recognized in the transportation and geography literatures (Gliebe and Koppelman, 2002; Kang and Scott, 2011; Srinivasan and Bhat, 2008). For example, caregiver availability at the time of school travel can be an important aspect

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of the mode choice decision process; school travel mode may depend on whether a child travels alone, with friends, or is escorted by an adult or other caregiver (Mitra, 2013). The relationship between these intra-household travel interactions and mode choice for school transportation remains understudied in the current literature (McDonald, 2008a; McDonald and Aalborg, 2009; Lin and Chang, 2010; Vovsha and Petersen, 2005; Yarlagadda and Srinivasan, 2008).

Lastly, the emerging child-youth-friendly planning practice in Canada (e.g., Metrolinx, 2009; OPPI, 2009) is not supported adequately by local knowledge on this topic. Evidence suggests that planning interventions such as SRTS and STP programs are not necessarily universally successful, a point that supports the need to explore local barriers and enabling social and environmental qualities adequately (Buliung et al., 2011). Unfortunately, local evidence of the correlates of school travel outcome that can and should inform policy development in a Canadian context is limited (Mitra et al., 2010a; Larsen et al., 2012).

This study examines the potential influence of the neighborhood environment and spatial autocorrelation on walking for school transportation. It also investigates the effect of the caregiver-child travel interactions on travel outcomes. School travel behavior of 11-year-old children (5th/6th grade) in Toronto, Canada, was explored. The research advances current knowledge on school transportation behavior, and provides local evidence to inform current policy in the Greater Toronto and Hamilton Area (GTHA), which is Canada's largest and most populous urban region. The findings also provide an essential comparative link to other international case studies, one that facilitates testing of our hypothesis regarding the importance of local knowledge development and use in support of local planning.

2. Study design

The study area is the City of Toronto, Canada's largest city by population. Toronto has a vibrant and dense central city (i.e., the downtown surrounded by inner-city neighborhoods). The inner-city neighborhoods that comprise the pre-politically amalgamated Toronto[1] are typically dominated by medium-density main street developments (i.e., residential neighborhoods with commercial and employment-related land uses along the main streets). Many neighborhoods in the central city have experienced some re-urbanization (i.e., increased density and land-use diversity) and re-vitalization (e.g., improvements in the physical conditions of the buildings) during the last several decades, a trend that has been accelerated in recent years by favorable public policy and market conditions. In contrast, modernist conventional neighborhoods dominate suburban areas that were developed after 1945 (i.e., the places that became part of the city after the political amalgamation in 1998). The literature on metropolitan growth popularly defines this type of suburban places as the *inner-suburbs* or *inner-ring suburbs* within the larger regional landscape (Lee and Leigh, 2005). These suburban neighborhoods were designed, for the most part, based on the neighborhood unit concept with schools at the center (Filion and Hammond, 2003; Hess, 2009). The inner-city and suburban neighborhoods also contain pockets of single-use, high-rise apartment buildings built between the 1960s and 1980s (i.e. the tower neighborhoods). These central-city and suburban places, which have developed over the past two centuries, represent a large diversity in built-environment characteristics that are often identified both in the popular and academic literatures as either enablers or barriers to active transportation.

Previous research has reported that 49% of 11–13 year-old children in Toronto walked or biked to school in 2006; however, AST uptake has been declining over the past 25 years (Buliung et al., 2009). In addition, the current rate sits well below the target of 60%, as indicated in the regional transportation plan for the GTHA (Metrolinx, 2009).

2.1. Data

Travel data were taken from the 2006 Transportation Tomorrow Survey (TTS), which is a repeat cross-sectional survey of travel behavior in Southern Ontario, Canada, that includes the City of Toronto. The survey has been conducted every five years since 1986. The 2006 version, the latest of the series with available data, includes a 5.2% random sample of all households in the study area (150,000 households in total; 51,612 households in Toronto), and reports travel behavior data (e.g., origin/destination, trip start time, purpose, primary travel mode) for a randomly selected weekday in fall or winter (Data Management Group, 2009). Retrospective data for all trips by household members aged $\geqslant$11 years, associated with the day prior to the interview, were proxy reported by an adult household member.

Home-to-school trips taken between the 06h00–09h30 time interval, by 11-year-old children (i.e., likely 5th/6th Grade) were analyzed; data on younger children were not available, and older children/youth were excluded with an expectation that school travel behavior may change when children make the transition to the middle or high school. Only children traveling to public and Catholic schools were studied,[2] these schools accounted for 88% of sampled school trips. The TTS survey collected household socio-demographic data, with information on intra-household travel interactions also available (Table 1). Data were developed from the survey to examine caregiver availability for escort during the school travel period. Previous research found an association between maternal travel patterns and a child's school travel mode (McDonald, 2008a; Yarlagadda and Srinivasan, 2008); father's and mother's travel could not be examined separately here due to the absence of kinship ties information in the survey data.

Data on the neighborhood built environment came from public and private sources; these sources are described in Table 1. Built environment characteristics were measured within a 400-m straight line buffer distance of each child's home and school locations, a distance that is equivalent to a 5-min walking distance for a child. This spatial unit of analysis is consistent with what some other researchers have used to explore school travel behavior (McMillan, 2007; Mitra et al., 2010a; Schlossberg et al., 2006; Yarlagadda and Srinivasan, 2008).

2.2. Logit models of mode choice

Multinomial (conditional) logit models (MNL) were estimated to explore the correlates of four travel modes (walk, transit, school bus, and car). Other excluded modes constituted less than 1% of all

[1] The Amalgamation Bill (Bill 103, the City of Toronto Act) was presented by the Province of Ontario, Canada, in 1996 and was implemented from January 1, 1998. This municipal amalgamation merged one regional (Metro Toronto) and six municipal governments (The former City of Toronto, and five other suburban municipalities - East York, Etobicoke, North York, Scarborough, York) into a single municipality, forming the current boundary of the City of Toronto (Hess and Milroy, 2006; Sewell, 2009).

[2] Toronto's faith-based schools (i.e., Roman Catholic) are publicly funded. Until 1998, these Catholic schools were governed by the Metropolitan Separate School Board. In 1998, the Toronto Catholic School Board (TCDSB) was established, and it now operates 102 schools in the City of Toronto (Toronto Catholic District School Board, 2011). Both the public and Catholic school boards in Toronto maintain a small distance threshold for each school, and children/youth largely attend schools that are closest to their home locations. In contrast, a household's choice of a private/ special school for a child is potentially more prone to selection bias.

Table 1
Independent variables.

Socio-demographics
MALE: 1 if the child was a male; 0 otherwise
CHILDREN (<11 YRS): Number of children aged $\leqslant$ 10 years in the household
SINGLE_ADULT: 1 if there was only one adult household member (>17 yrs); 0 otherwise
VEH_LIC: Number of vehicles in the household per licensed driver
Travel distance
DISTANCE[c]: For walk mode, network distance between home and school locations was used; for car mode, network distance with driving restrictions was used; for school bus and transit modes, straight line distance was used.
$\leqslant$400 m: 1 if travel distance was less than 400 m; 0 otherwise
>1.6 km: 1 if travel distance was more than 1 mile (i.e., 1600 m); 0 otherwise
Household Travel Interactions
SAMESCHOOL: 1 if two or more children (age $\geqslant$ 11 years) from same household went to the same school; 0 otherwise
DIFFSCHOOL: 1 if children (age $\geqslant$ 11 years) from a household went to different schools; 0 otherwise
NO_ADULT_AVAILABLE: 1 if all adult household members (>17 years) started their work/school/facilitating trips (i.e., trips to out-of-home activities with fixed schedule) before the school-trip start time; 0 otherwise
AVG_WORK_DIST: Average work trip length for household adults (km; straight line distance)
CAR_PROPENSITY: Automobile mode share for daily household trips by all members, other than the school trips
Built environment[a]
NO_STREETCROSS[c]: 1 if a child did not have to cross a major street (primary highway, secondary highway, and major/arterial roads) on the way to school; 0 otherwise
INDIRECT[c]: The ratio between network distance and straight line distance between home and school locations. Values start from 1; higher value means lower street connectivity
MIX_RETAIL[e]: Total number of retail, ambulatory health care, personal & laundry services related destinations within a 400 m buffer
1st Quartile: 1 if belongs to the lowest quartile; 0 otherwise
4th Quartile: 1 if belongs to the top quartile; 0 otherwise
MIX_OTHER[b,e]: Total number of non-residential destinations within a 400 m buffer, except those related to retail, ambulatory health care, personal & laundry services
1st Quartile: 1 if belongs to the lowest quartile; 0 otherwise
4th Quartile: 1 if belongs to the top quartile; 0 otherwise
BLOCK_DENSITY[f]: Number of street-blocks within a 400 m buffer
FOURWAY_DENSITY[b,c]: Proportion of 4-way street intersections- the ratio of 4-way intersections to total number of street intersections
DEADEND_DENSITY[c]: Proportion of dead ends and cul-de-sacs. The ratio of dead-ends plus cul-de-sacs to total number of street intersections
LIGHT_DENSITY[c,d]: Proportion of intersections that are signalized. The ratio of intersections with traffic signal lights to total number of street intersections
LOWINCOME_NH[g]: 1 if the median household income for all DAs within a 400 m buffer was less than the low income cut off (i.e., economically disadvantaged neighborhood)
Other (Policy/social-political context/natural environment)
TRANSIT_ACCESS[h]: Total number of transit routes available within a 400 m buffer
CATHOLIC: 1 if the child went to a Catholic school; 0 if the child went to public school
WINTER: 1 if travel data was collected on a winter week-day (i.e., between the weeks ending on 24th December, 2006, and 19th February, 2007); 0 if data was collected on a fall weekday (i.e., between the weeks ending on September 10th, 2006, and December 17th, 2006)

[a] Each built environment variable was estimated separately for the home, and the school location.
[b] Variables in italics were excluded from the multivariate logit model specifications.
[c] Street network characteristics were computed using the DMTI CanMap© RouteLogistics file (version 2007.3).
[d] Data on street-lights were collected from City of Toronto's Transportation Department.
[e] Obtained from Canadian Business Data (2010.04) provided by Pitney Bowes Software Inc.
[f] Block density was calculated based on the 2006 census boundary files by Statistics Canada.
[g] Data obtained from Statistics Canada (2010). Average household size for the sample was 4.3 (sd = 1.28). In a large metropolitan area such as Toronto (i.e., population >500,000), the low income cut-off in 2006, defined by Statistics Canada, is CAD 39,399 for a four-member household. The low-income neighborhoods were identified based on this cut-off value.
[h] Data on transit routes came from the Toronto Transit Commission (TTC). Data on transit stops was not available.

school trips. Only children living within 3.2 km (2 mi) network distance from their schools were included in the analysis; preliminary analysis of TTS data showed that only 1.6% of all students walked to school beyond 3.2 km. Adjusting for missing data and outliers, the final dataset included 945 home-to-school trips. Table 2 provides a description of the sample.

The neighborhood built environment is assumed here primarily to influence the decision between walking and other modes. Prior to multivariate logit estimation, the degree of multi-collinearity among built environment variables was examined. When two or more variables were correlated at $r \geqslant 0.50$ (e.g., MIX_RETAIL and MIX_OTHERS; BLOCK_DENSITY and FOURWAY_DENSITY), they were entered into the multivariate models one at a time; the one having a statistically weaker association (e.g., MIX_OTHERS; FOURWAY_DENSITY) was excluded from analysis. Individual built environment variables, measured separately around the residence and school, were also highly correlated. To overcome this collinearity problem, and as previously done in Mitra and Buliung (2012), separate home and school end models were specified and estimated.

2.3. Spatial autocorrelation

Spatial autocorrelation occurs when values of an observed outcome, sampled at nearby locations, are not independent from each other (Anselin and Griffith, 1988; Cliff and Ord, 1970). Within the context of this study, households living in close proximity may demonstrate similar mode-choice behavior; i.e., they may engage in some modeling of one another's travel practices, compared to those living farther apart. In addition, statistical model specifications might not include one or more environmental determinants of mode choice that are spatially structured (Legendre, 1993). An exploration of spatial autocorrelation is warranted in order to understand the geographical limitations of travel behavior analysis, yet failing to control for spatial effects can produce unreliable parameter estimates. For policy and practice, spatial autocorrelation in travel outcomes may suggest the presence of an unexplored opportunity for potential intervention(s) that can be implemented at the neighborhood level. In order to account for spatial autocorrelation in the prevalence of walking versus not walking, this study extends a logit model by including an auto-covariate parameter as

Table 2
Summary statistics, for children living within 3.2 km of their schools.

	11 Year-olds ($n = 945$)	
	Freq.	%
Sex		
Female	444	46.98
Male	501	53.02
Household composition		
Single-adult household	119	12.59
Multiple adults in household	826	87.41
Access to personal vehicles		
No vehicle	140	14.81
One vehicle	508	53.76
Two or more vehicles	297	31.43
School type		
Catholic	237	25.08
Public	708	74.92
Period of data collection		
Fall	753	79.68
Winter	192	20.32
School travel distance		
⩽400 m	178	18.83
401 m to 1.6 km	642	67.94
>1.6 km	125	13.23
Travel mode (trip to school)		
Walk	581	61.48
Transit	44	4.66
School bus	101	10.69
Car	219	23.17

an explanatory variable (Augustin et al., 1996; Dormann et al., 2007). The auto-covariate variable captures spatial interaction among the error terms for each student and his/her neighbors (Dormann et al., 2007). The approach for diagnosing the presence of spatial effects was as follows: first, for each child, the residual for walk mode was computed by subtracting the predicted mode choice probability from a dummy indicator of the observed mode choice (i.e., 1 if a child walked to school, 0 otherwise) (Fosgerau, 2008). Next, a spatial weight matrix was computed, with a maximum number of neighbors $k_{maximum} = 20$. The weight matrix reflects the conceptualization of a distance-related influence between nearest neighbors on school travel decisions and outcomes. An inverse-distance-based conceptualization (i.e., $\frac{1}{d}$, where d = network distance between household locations, $\leqslant 3.2$ km) was adopted to generate this spatial weight matrix. A global analysis of spatial autocorrelation (i.e., global Moran's I) using this matrix produced statistically significant ($p < 0.01$) results, indicating the presence of spatial dependency among the residuals.

The auto-covariate parameter for an individual student i was then calculated as a weighted average of the residual values from the nearest neighbors of i's home location (Augustin et al., 1996):

$$\text{AUTO\_COV}_i = \frac{\sum_{j \in k_i} w_{ij} e_j}{\sum_{j \in k_i} w_{ij}} \quad (1)$$

where e_j is the value of the residual for j^{th} neighbor among i's set of k_i ($\leqslant 20$) neighbors; w_{ij} is the spatial weight of j^{th} neighbor over i, obtained from the spatial weight matrix formulated earlier. Two such parameters were calculated for each child (home and school-end). The resulting AUTO_COV variables were then used in the multivariate analysis. A statistically significant AUTO_COV coefficient represents the un-confounded (i.e., adjusted) correlation between walk mode choice and any unobservable effects that are spatially structured. The intention of this research was to investigate, in an exploratory manner, the potential influence of spatial autocorrelation on school travel mode-choice behavior. The proposed method begins to improve our current understanding on this subject, within a context where there is no widely acknowledged method for this purpose (Dormann et al., 2007; Sidharthan et al., 2011).

3. Results and discussion

Mode-choice behavior was analyzed for the journey to school of children who lived within 3.2 km of their schools. The convergence of the models was satisfactory. Distance was the most important factor that explained mode choice for school transportation, followed by variables related to intra-household travel interactions (Table 3). Environmental characteristics, collectively, had a relatively smaller impact on model fit. The built environment correlates of school travel modes are introduced first here, followed by intra-household travel interaction-related findings, and then other influences.

3.1. The built environment

Distance between home and school locations remained an important factor after controlling for other variables, confirming findings from past research (Ewing et al., 2004; McDonald, 2008b; Schlossberg et al., 2006) (Table 4). The distance effect supports the case for smaller neighborhood schools, particularly in a dense urban area such as Toronto, as a means to increase AST rates (McDonald, 2008b; Mitra et al., 2010a). Beyond distance, built environment near both home and school locations, and the characteristics of the travel route, were also associated with walking. A neighborhood environment that is expected to provide a sense of personal and traffic safety, such as no major streets en-route to school, and higher land-use mix (i.e., more retail/service related land use and, hence, more "eyes on street"), increased the odds of walking. These results are comparable to other studies (McMillan, 2007; Panter et al., 2010). Home and school neighborhoods

Table 3
Summery of model results- improvements in the goodness of fit.

	11-year olds ($n = 945$)			
	Home-model		School-model	
	−2 [L(c) − L(β)] (p)	McFadden's ρ^2 (adjusted ρ^2)	−2 [L(c) − L(β)] (p)	McFadden's ρ^2 (adjusted ρ^2)
Constants *plus* SES *plus* Others	101.32 *(<0.001)*	0.105 (0.100)	101.32 *(<0.001)*	0.105 (0.100)
Constants *plus* SES *plus* Others *plus* Distance	223.72 *(<0.001)*	0.232 (0.226)	223.72 *(<0.001)*	0.232 (0.226)
Constants *plus* SES *plus* Others *plus* Distance *plus* HH travel interactions	289.00 *(<0.001)*	0.300 (0.291)	289.00 *(<0.001)*	0.300 (0.291)
Constants *plus* SES *plus* Others *plus* Distance *plus* HH travel interactions *plus* Built environment	306.96 *(<0.001)*	0.319 (0.308)	304.22 *(<0.001)*	0.316 (0.305)
Constants *plus* SES *plus* Others *plus* Distance *plus* HH travel interactions *plus* Built environment *plus* Spatial autocorrelation	310.89 *(<0.001)*	0.323 (0.312)	308.86 *(<0.001)*	0.321 (0.310)

Table 4
Correlates of mode choice for trips-to-school (11-year old children).

	Home model				School model			
	Walk Coef. (SE)	Transit Coef. (SE)	School Bus Coef. (SE)	Car Coef. (SE)	Walk Coef. (SE)	Transit Coef. (SE)	School Bus Coef. (SE)	Car Coef. (SE)
Socio-demographics								
MALE[a]	0.23 (0.19)	−0.04 (0.36)	***0.67 (0.29)***		0.23 (0.19)	0.03 (0.37)	***0.68 (0.29)***	
CHILDREN (<11 YRS)	0.19 (0.12)	−0.14 (0.27)	0.16 (0.19)		0.20 (0.12)	−0.10 (0.27)	0.19 (0.19)	
SINGLE_ADULT[a]	−0.19 (0.38)	0.59 (0.51)	−0.28 (0.50)		−0.04 (0.38)	0.65 (0.51)	−0.10 (0.50)	
VEH_LIC				**0.85 (0.27)**				**0.83 (0.27)**
Travel distance								
⩽400 m[a]	**1.86 (0.35)**	−1.99 (1.03)	**−1.45 (0.55)**		**1.81 (0.35)**	***−2.07 (1.04)***	**−1.48 (0.55)**	
>1.6 km (1 mi)[a]	**−2.00 (0.26)**	**1.07 (0.42)**	0.05 (0.39)		**−1.98 (0.26)**	***1.02 (0.42)***	0.04 (0.39)	
Household activity–travel interactions and behavior								
SAMESCHOOL[a]	**1.10 (0.33)**	***1.25 (0.53)***	0.71 (0.43)		**1.11 (0.33)**	***1.18 (0.54)***	0.69 (0.43)	
DIFFSCHOOL[a]	**0.73 (0.26)**	**1.59 (0.43)**	0.74 (0.40)		**0.75 (0.26)**	**1.53 (0.43)**	0.70 (0.40)	
NO_ADULT_AVAILABLE[a]	**1.56 (0.44)**	***1.29 (0.63)***	**1.81 (0.53)**		**1.62 (0.44)**	***1.28 (0.63)***	**1.80 (0.53)**	
AVG_WORK_DIST				−0.02 (0.01)				−0.02 (0.01)
CAR_PROPENSITY				**2.93 (0.39)**				**2.94 (0.38)**
Neighbourhood built environment								
NO_STREETCROSS[a]	***0.44 (0.18)***				***0.45 (0.19)***			
INDIRECT	**0.67 (0.22)**				**0.56 (0.21)**			
MIX_RETAIL (1st quartile)[a]	0.04 (0.21)				−0.03 (0.21)			
MIX_RETAIL (4th quartile)[a]	***0.52 (0.23)***				**0.63 (0.26)**			
BLOCK_DENSITY	***0.04 (0.02)***				0.02 (0.02)			
DEADEND_DENSITY	0.15 (0.99)				1.25 (1.06)			
LIGHT_DENSITY	1.15 (1.20)				−0.06 (1.27)			
LOWINCOME_NH[a]	0.35 (0.33)	0.57 (0.48)	0.45 (0.43)		0.71 (0.48)	0.56 (0.86)	0.46 (0.74)	
Spatial autocorrelation								
AUTO_COV	**1.23 (0.44)**				**1.34 (0.44)**			
Other								
TRANSIT_ACCESS		−0.00 (0.05)				0.07 (0.04)		
CATHOLIC[a]			**2.61 (0.27)**				**2.68 (0.27)**	
WINTER[a]	−0.26 (0.22)	−0.15 (0.45)			−0.18 (0.21)	−0.15 (0.45)		
Constant	***1.32 (0.61)***	0.37 (0.59)	0.03 (0.49)		**1.64 (0.61)**	−0.03 (0.56)	0.02 (0.48)	

Coefs in **bold** are significant at $\alpha = 0.01$; coefs in ***bold italics*** are significant at $\alpha = 0.05$; coefs in *italics* are significant at $\alpha = 0.10$.
[a] Dummy variables.

with smaller blocks, which largely represent (at least conceptually) urban, safe, attractive, and walkable neighborhoods, also increased the likelihood of walking.

Similar to previous research (Panter et al., 2010; Timperio et al., 2006), a positive association was observed between the potential indirectness of school travel route and walking. This finding suggests that although direct travel routes are expected to encourage walking among adults (Ewing and Cervero, 2010), a different reality may exist for children. Closer scrutiny of the home and school locations (using a current digital orthophoto map of Toronto) revealed that students with low INDIRECT scores largely lived on major streets, and their schools were also located on major streets. The model result, then, was not surprising. Perhaps perceived risks related to traffic safety (which would discourage walking) outweigh perceived connectivity (which would encourage walking) due to the directness of a school travel route. Some children may also enjoy taking quieter and more indirect routes through the neighborhoods, where students can contemplate or walk together with other children (Buliung et al., 2013; Fusco et al., 2012).

A propensity map was generated to explore the geography of built environment effects (Yoon et al., 2011). To estimate a child's propensity to walk due to the built environment near the home location, the values of each statistically significant variable were first standardized (i.e., the difference from the mean for INDIRECT and BLOCK_DENSITY; 0 or 1 for NO_STREETCROSS and MIX_RETAIL), and then were multiplied by the estimated coefficient (β_i) value for that variable. Due to confidentiality reasons, Fig. 1 displays students' home locations at the residential block level. In cases where multiple students lived within the same block, the mean (INDIRECT, BLOCK_DENSITY) or the maximum (NO_STREETCROSS, MIX_RETAIL) propensity values for all students within a block were used. The four individual propensities were then summed to obtain an estimated cumulative propensity to walk for each child. In Fig. 1, then, a block with a positive value (>0) identifies a residential location within the City of Toronto where the built environment (as measured here) was positively associated with walking. Similarly, propensity <0 demonstrates a negative correlation.

The data indicate that the built environment prevalent within the central city (i.e., downtown Toronto and the inner-city neighborhoods) was largely associated with walking. Within neighborhoods at suburban locations, the effect of the built environment remained mixed. Further qualitative inspection of orthophotography revealed noticeable variation in urban design characteristics across Toronto's suburban neighborhoods. The propensity map suggests that a suburban place that possesses design qualities associated with walking may produce walking school trips, despite its suburban locale. Several examples of the relationship between neighborhood built environment and walking are presented (Fig. 1: inserts 1–4).

Some differences between the modeled and actual mode-choice outcome were observed, which is not surprising in the context of a moderate model fit (adjusted $\rho^2 = 0.312$) (Table 3). However, the objectively measured built environment characteristics were

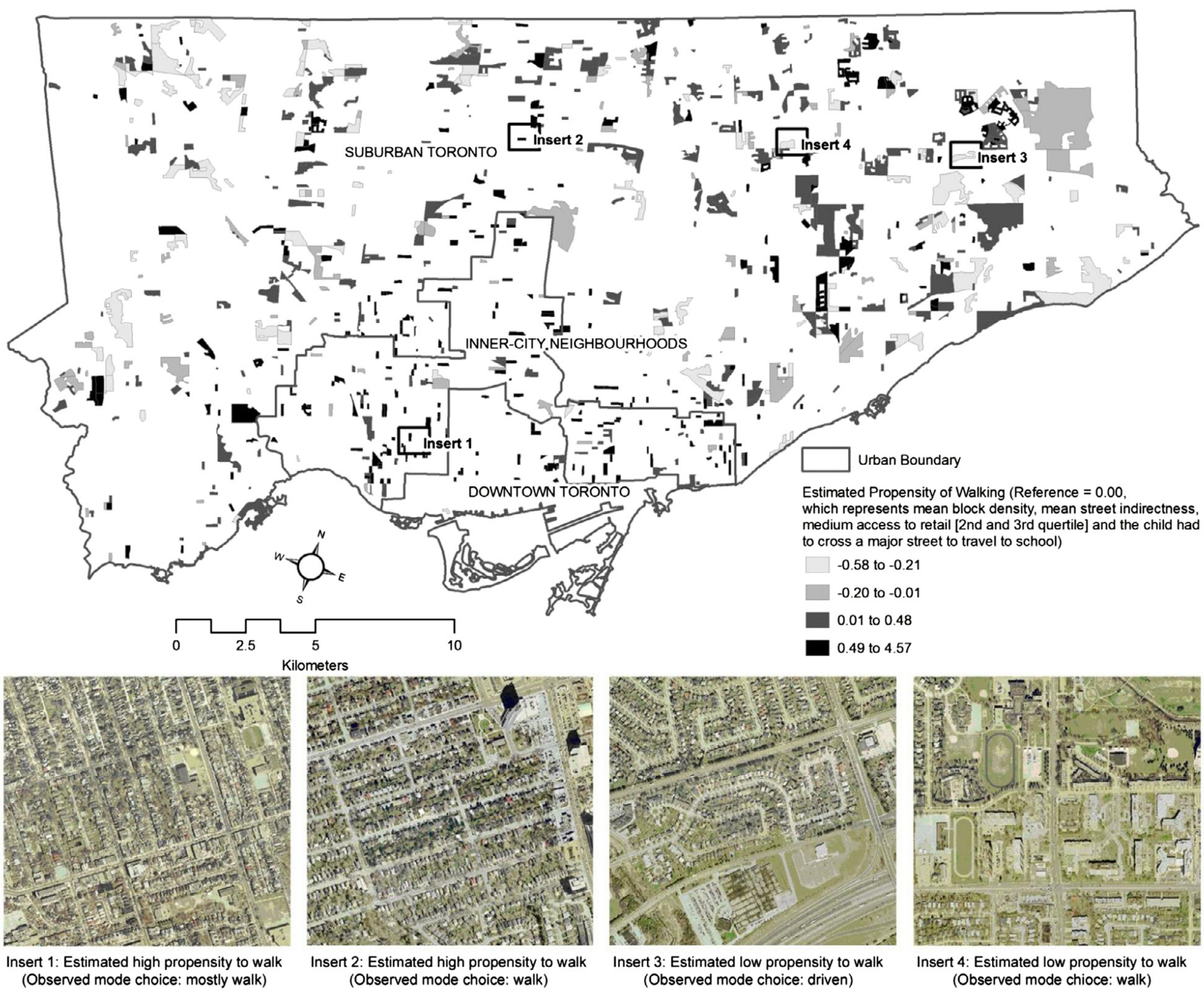

Fig. 1. Children's propensity to walk to school, related to the built environment near home locations.

particularly weak in predicting the travel behavior of students who, for instance, lived within the tower-neighborhoods that are commonly found in suburban Toronto. Insert 4 in Fig. 1 demonstrates an example. The Tower Neighborhoods were largely built during the 1960–80 period; and there are approximately 1200 apartment towers in the City of Toronto, which represent 48% of the city's rental housing stock. These towers were built as a result of urban policies that encouraged the "tower in the park" housing model: high-density apartment clusters in the newer suburban neighborhoods (E.R.A., 2010). The towers are often clustered together within one or more super-blocks, forming neighborhoods of their own (hence, the tower neighborhoods).

The poor match between modeled walking propensity and the actual travel outcome in these tower neighborhoods points to a broader problem related to the use of objectively measured built environment characteristics in understanding mode choice behavior. Empirical research in urban planning tends to measure neighborhood design qualities in terms of a combination of individual characteristics such as grid versus curvilinear streets, mixed versus segregated land use, and small versus large blocks. The range of these measures is usually set by traditional central-city (e.g., grid streets, mixed land use, small blocks) and conventional suburban (e.g., curvilinear streets, segregated land use, large blocks) neighborhoods. The qualities of other neighborhoods are determined based on where they fit along this continuum. This approach was applied in this study, and the built environment measures relatively accurately predicted walking mode choice for typical central-city or suburban neighborhood types. However, the results were less accurate at the intersection of neighborhoods that, as a whole, did not fit well to the abovementioned "typical" measures of design qualities, but are rather common neighborhood types in the context of a large North American city (e.g., the tower/apartment-neighborhoods). In Toronto, the average household income in most tower-neighborhoods is low. Thus, socio-economic factors may dictate walking in a less-than-ideal environment (Hess and Farrow, 2010). However, it is possible that these neighborhoods are indeed walkable due to their social (e.g., everyone walks) and physical (e.g., informal pathways) settings, even though some design elements (larger blocks, auto-oriented street design, lack of land-use mix) are assumed, by convention, to discourage walking.

In addition to neighborhood characteristics, the auto-covariate parameter was positively associated with walking. While the exact qualities driving this spatial dependency could not be identified conclusively in this research, the result warrants some informed speculation with regard to meaning. First, this study examined several neighborhood characteristics, but there may be other important characteristics (objective or perceived) that remain unexplored, that speaks to one of the root causes underlying the presence of spatial dependence. The auto-covariate parameter estimate may describe spatial variation in travel outcome related to these potentially unexplored characteristics. Second, the AUTO_COV coefficient may capture any form of social norm/modeling behavior around travel mode that operates at the local neighborhood level and is adopted by the households living in a neighborhood. Lastly, household mode-choice behavior can also be influenced by household attitudes toward travel or the built environment (Boarnet and Crane, 2001; Cao et al., 2009; Kitamura et al., 1997; Yang et al., 2012). A household may choose to live in a walkable or a drivable neighborhood based on its choice or preference (commonly known as "self-selection" in urban planning literature). Collectively, then, similar school-travel outcomes within close proximity may reflect common household attitudes about housing, amenities, and transport. The potential relationship between neighborhood self-selection, transport norms, and AST has yet to be addressed systematically in the literature.

3.2. Intra-household travel interactions

An association was found between a child's school travel mode and the travel characteristics of other household members (Table 4), which is broadly similar to what has been reported in limited previous research (McDonald, 2008a; McDonald and Aalborg, 2009; Lin and Chang, 2010; Vovsha and Petersen, 2005; Yarlagadda and Srinivasan, 2008). In particular, our findings support the "availability" hypothesis discussed earlier in this paper, and indicate that when an adult caregiver was available at home at the time of school travel, a child was more likely to be escorted to school, increasing the odds of a car trip. In contrast, the absence of an adult caregiver, and hence the possibility of independent mobility (i.e., travel without an accompanying adult caregiver), increased the likelihood of walking, taking transit, or riding a school bus. Additionally, in a household with two or more children traveling to school, the odds of taking a non-auto mode was higher, compared to a single-child household. Perhaps, in many households where multiple children are aged $\geqslant 11$ years, the children accompany each other instead of being escorted by adults. In addition, car trips were more common among children from auto-dependent households (Table 4). This observation is not surprising in the context of evidence suggesting that, given a fixed number of daily household activities, dependency on one travel mode (in this case, private automobile) for some daily activities (e.g., work) may discourage the use of other modes of travel to other destinations (e.g., school) (Cervero and Radisch, 1996).

3.3. Other potential influences

A household's access to private automobiles increased the odds of a car trip (Table 4). By contrast, access to transit was not associated with transit mode choice. Also at the age of 11 years, there was no difference in walking between boys and girls, a result that is similar to what has been reported in some recent studies (Johansson et al., 2012; McDonald, 2012; Mitra and Buliung, 2012). Children going to Catholic schools were more likely to take a school bus compared to those going to public schools. Seasonality (WINTER) was not associated with mode choice of these elementary school children, which confirms the findings from previous research (Mitra and Faulkner, 2012; Sirard et al., 2005).

4. Implications for policy and practice

In the U.S., the Federal government has devoted $862 million since 2005 to the implementation of Safe Routes to School (SRTS) programs (NCSRS, 2010). This centralized (Federal) funding model to school transportation planning is not the norm in Canada, reflecting a long-standing, piecemeal, often highly politicized approach to Federal investment in transportation infrastructure and services in urban Canada. In 2007, a community-based organization, Green Communities Canada, began implementing a pilot School Travel Planning (STP) framework across Canada, with financial support from the Public Health Agency of Canada (Buliung et al., 2011; Green Communities Canada, 2013). Key community stakeholders (school boards, urban/transportation planners, public health professionals, police, parents, students and teachers) collaborate to identify barriers to active transportation for a school, and develop an action plan to address and overcome those barriers. An STP may include the implementation of transportation infrastructure (e.g., pedestrian crossings, bike-racks), educational programs (e.g., safety of pedestrians and cyclists), community mobilization programs (e.g., walking school bus), and encouragement programs (e.g., event days) (Green Communities Canada, 2013).

From 2009 to 2011, the provincial transportation authority for the GTHA, the Metrolinx (2011), partnered with Green Communities Canada in implementing the "Stepping it Up" initiative, which introduced the STP model to 30 grade schools across the region. This pilot program received funding from Transport Canada. Since 2011, no longer-term revenue stream has been identified. However, Metrolinx continues to support walking, cycling, and transit use for school transportation through community mobilization.

Within this context, a better understanding of the correlates of school travel mode choice can be important in identifying locational foci for school and community-level interventions, with a view to optimizing expenditure from limited program resources. Findings from this study may inform development of specific interventions within the broader scope of STP initiatives. At the municipality level, the planning and design of the neighborhoods and school policy may also play potentially important roles in enabling AST among children. The main lessons from this work are:

4.1. The built environment near both home and school locations is important

Canadian STP initiatives emphasize changes to the built environment at and near schools. Results from this study indicated that environmental interventions may increase walking school trips, but these interventions could be effective if implemented at the home and/or school end. In other words, considerations for AST should be incorporated in the neighborhood planning practice, above and beyond the STP exercise. Neighborhoods with smaller blocks, higher land-use mix (retail and residential), and more local streets increased the odds of walking in Toronto. Some other transportation infrastructures (e.g., density of intersections with signal-lights, dead-end streets) were not correlated with walking.

4.2. Expectation regarding design-based interventions should be modest

The design concerns explored in this study, however, only explained part of the spatial variation in school travel mode choice outcomes in Toronto, similar to what has been observed in other places. Expectations regarding the success of a design-based intervention, therefore, should be modest. In addition, results from this research indicate that city-wide modeling of travel behavior, and planning practice based on those model results, may perform poorly with regard to understanding and changing mode-choice outcomes within places that are poorly matched to the conventional design perspectives concerning "walkable" and "non-walkable" neighborhoods. Initiatives such as STP should give particular importance to exploring environment-travel interactions within neighborhoods that do not conform to design-place stereotypes (e.g., tower-neighborhoods in the suburbs).

4.3. Promoting independent travel may increase the rates of walking

Current research has demonstrated that children's independent mobility, or freedom to explore their neighbourhood unsupervised, has important implications for their physical, social, and psychological development (Carver et al., 2008; Prezza and Pacilli, 2007; Tranter and Whitelegg, 1994). The importance of independent mobility is beginning to be recognized in Canada (Active Healthy Kids Canada, 2013). Independent mobility, at least conceptually, can also be linked to AST (Mitra, 2013). Obviously, when children are traveling independently, they are likely not being driven. The results from this study support this hypothesis by suggesting indirectly that children who were escorted by adult caregivers were more likely to be driven to school. It appears that programs that encourage independent or autonomous traveling to school (i.e., not accompanied by adult caregivers) could potentially enable AST. For example, community mobilization that encourages school travel without direct adult supervision while ensuring adult presence (e.g., walking school bus) may increase rates of walking in Toronto. These community initiatives may particularly target stay-home (or part-time working) caregivers who usually accompany their children during school travel, and encourage them to lead walking groups, act as volunteers, or even as crossing guards.

4.4. School policy has a potentially important role in the promotion of AST

A limited existing research has documented an association between school types and walking. For example, children attending choice schools (i.e., public schools where attendance is not tied to the neighborhood of residence) are more likely to be driven compared to neighborhood public schools, largely because of the differences in typical travel distance and parental attitudes toward a child's mobility (Yang et al., 2012). In the context of Toronto, it appears that the governance of school transport may indeed have a major role in moderating mode choice at the individual level. Students attending Catholic schools were more likely to travel by school bus, compared to students in public schools, perhaps due to the flexible school transportation policy of the Catholic school board. While Toronto's public schools apply a strictly implemented distance threshold to limit service eligibility, Catholic schools are more flexible in applying their distance policy for busing. Transportation is often provided to students living less than 1.5 km from school, arguably to encourage students to attend Catholic neighborhood schools with dwindling attendance.

5. Limitations

This research draws attention to some broader limitations of an empirical investigation in understanding the relationship between the built environment and travel behavior. First, some spatial variation in mode-choice behavior was correlated with unobservable characteristics likely shared among neighboring households. Further research focused on localized variation in perceptions, attitudes, and social norms around transportation decisions is likely to be a useful direction for additional study. Second, the built environment correlates were less accurate for the neighborhoods that generally did not fit well with the "typical" qualities of a traditional central-city or a conventional suburban neighborhood. In addition, with regard to the observable built environment characteristics, previous research has reported mixed results regarding the association between sidewalks and the odds of walking (Ewing et al., 2004; McMillan, 2007). However, most streets in Toronto have sidewalks. Conceptually, then, sidewalks may not be an important factor that explains the difference in walking rates across space within the Toronto metropolitan area. At the time of analysis, data on informal footpaths, shortcuts, or pathways (i.e., those that are not formally planned or managed by the city) were also not available. Conceivably, such informal infrastructures would offer opportunities for active travel for children in any neighborhood (Buliung et al., 2013; Fusco et al., 2012). In the context of our study, informal shortcuts or pathways may, at least partly, explain unexpected walking rates in some inner-suburban neighborhoods in Toronto, as discussed in Section 3.1. A closer examination of this topic remains subject to future research.

Findings from this research also begin to provide insights into the relationship between travel negotiations among household members and school travel-mode choice. However, the behavioral processes that determine or moderate such negotiations could not be fully investigated here. Broader behavioral understandings may emerge through further quantitative and qualitative exploration of school travel within the context of a household's activity-travel demands and constraints.

6. Conclusion

This study adopted a geographically weighted modeling approach to investigate school travel-mode choice in Toronto, Canada's largest city by population. Quantitative models were estimated using data from a large and population-representative transportation survey. First, with regard to the neighborhood environment, our results indicate that built environment characteristics related to safety and neighborhood aesthetics/walkability explained mode choice, even when travel distance was controlled. Second, with regard to the intra-household travel interactions, the results suggest that the availability of caregivers at the time of school travel, which perhaps facilitated escorted school trips, was associated with driving. The presence of siblings aged $\geqslant 11$ years, on the contrary, was associated with walking and the use of transit. Lastly, with regard to the universality of the enablers and barriers to AST, our results related to the neighborhood environment were largely similar to what has been reported previously. However, these findings were not generalizable to all neighborhoods within Toronto. The predicted built environment effects were more accurate in some types of neighborhood, but relatively less accurate in some other types of neighborhoods, a finding that emphasizes the importance of exploring environment-AST interactions at the local level. In addition, students going to Catholic schools were more likely to take a school bus compared to students in public schools, perhaps reflecting the less spatially rigid busing strategy of Toronto's Catholic school board.

Our findings improve current knowledge on the correlates of AST, challenge the assumptions around the generalizability of observed built environment effects across all neighborhood types, and provide local evidence that may inform school transportation planning practice, such as the STP initiative, in Canada. The study also advances school transportation research by addressing the spatial autocorrelation problem in a quantitative investigation of school travel behavior. There are potential benefits in extending the proposed conceptual and methodological approach in the exploration of school travel, childhood mobility, and physical activity. An improved knowledge of these potentially modifiable human behaviors could benefit policy that is focused on healthy and sustainable urban communities.

Conflict of Interest Statement

The authors declare that there are no conflicts of interest.

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