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Route-Based Analysis to Capture the Environmental Influences on a Child's Mode of Travel between Home and School

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This study examined environmental influences on a child's mode of travel between home and school. Grade 7 and 8 students ($n = 614$) from twenty-one schools throughout London, Ontario, participated in a school-based travel mode survey. Geographic information systems (GIS) were employed to examine environmental characteristics of the child's mode of travel between home and school measured at the scale of the likely travel route. Logistic regression was used to assess what factors influence both the to- and from-school trip. Over 62 percent of students living within 1.6 kilometers (1 mile) of school walked or biked to school and 72 percent walked or biked home from school. Actively commuting to school was positively associated with shorter trips, with distance being the most important correlate. Boys were significantly more likely to use active travel modes than girls. Higher traffic volume along the route was negatively related to rates of active travel and children from higher income neighborhoods were less likely to actively travel than children from lower income neighborhoods. In terms of environmental characteristics, the presence of street trees was positively associated and higher residential densities and mixed land uses were negatively associated with active travel to school. For the journey home, crossing major streets and increased intersection density were negatively associated with active travel. The findings of this research give evidence that active travel is associated with the environmental characteristics of walking routes. This information should be considered for urban planning and school planning purposes to improve children's walking environments. *Key Words:* active travel, built environment, children's health, GIS, walkability.

本研究探索环境的影响对孩子在家和学校之间的出行方式的影响。来自整个伦敦，安大略省二十一所学校的第 7 和第 8 年级的学生 ($N = 614$) 参与了一个以学校为基础的出行模式的调查。运用地理信息系统 (GIS) 来检查在可能的出行路线的规模所测量的，孩子在家和学校之间出行方式的环境特点。用逻辑回归来评估哪些影响来和去上学旅程的因素。生活在离学校的 1.6 公里 (1 英里) 以内的，超过 62% 的学生步行或骑自行车到学校，并且有 72% 的学生步行或骑自行车从学校回家。积极通勤上学与较短的路程呈正相关，距离是最重要的关联。男孩比女孩明显更倾向于使用积极的出行方式。沿上学路线的更高的交通流量与积极的出行方式呈负相关，并且来自较高收入的街区的孩子积极出行的几率远小于来自收入较低的居民区的孩子。在环境特性方面，人行道上树的存在与积极的出行正相关，较高的居住密度和混合土地用途与积极的出行呈负相关。在回家的途中，穿越主要街道的数量和增加的路口密度与积极的出行呈负相关。这项研究的结果证明积极的出行与步行路线的环境特点相关。此信息应被考虑到城市规划和学校规划的目的中，以改善孩子的步行环境。关键词：主动出行，建筑环境，孩子的健康，地理信息系统，可行性。

En este estudio se examinan las influencias ambientales sobre el modo de desplazarse de un niño de la casa a la escuela. Los estudiantes de los niveles 7 y 8 ($n=614$) de veintiuna escuelas dispersas a través de London, Ontario, participaron en un reconocimiento sobre el modo de viaje a partir de la escuela. Se emplearon sistemas de información geográfica (SIG) para examinar las características ambientales del modo de viajar del niño entre la casa y la escuela, medidas a la escala de la ruta probable de viaje. Se utilizó la regresión logística para evaluar qué factores influyen el viaje hacia y desde la escuela. Más del 62 por ciento de los estudiantes que viven hasta 1.6 kilómetros (1 milla) de la escuela caminaban o se desplazaban en bicicleta a la escuela, y el 72 por ciento caminaban o iban en cicla a la casa desde la escuela. El conmutar activamente a la escuela estaba positivamente asociado con viajes más cortos, siendo en este caso la distancia el factor de correlación más importante. Los niños eran significativamente más propensos a usar modos activos de viaje que las niñas. El alto volumen de tráfico a lo largo de la ruta está negativamente asociado con las tasas de viaje activo y los niños de vecindarios

de mayores ingresos son menos propensos al viaje activo que aquellos de vecindarios de ingresos más bajos. En cuanto a características ambientales se refiere, la existencia de árboles en la calle está positivamente asociada en tanto que una mayor densidad residencial y usos del suelo mixtos se asocian negativamente con el viaje activo hacia la escuela. En cuanto al desplazamiento hacia la casa, el cruzar calles mayores lo mismo que una mayor densidad de intersecciones resultaron asociadas negativamente con el viaje activo. Los hallazgos de esta investigación proveen evidencia de que el viaje activo está asociado con las características ambientales de las rutas peatonales. Esta información debe tenerse en cuenta para los propósitos de planificación urbana y escolar para mejorar los entornos peatonales de los niños. *Palabras clave:* viaje activo, medio ambiente construido, salud infantil, SIG, transitabilidad peatonal.

In recent years, an enormous research effort has focused on understanding relationships between the built environment and public health, especially how rising rates of obesity and physical inactivity might be tied to sprawling, automobile-orientated forms of development (e.g., Ewing et al. 2003; Northridge, Sclar, and Biswas 2003; C. Lee and Moudon 2004; Frank, Saelens, et al. 2007; Saelens and Handy 2008; Gilliland 2010). In parallel, designers and planners have been working to create environments that encourage reduced rates of automobile use and increased rates of walking by creating more mixed-use, compact, and better connected neighborhoods (Saelens, Sallis, and Frank 2003; Southworth 2005; Frank et al. 2006; C. Lee and Moudon 2006).

The interest in encouraging active lifestyles including walking and cycling as a normal part of children's travel routines is clear. Rising rates of childhood obesity, diabetes, and asthma are well documented in most developed countries, with Canada and the United States, in particular, showing alarming rates of increase (Mannino et al. 1998; Ludwig and Ebbeling 2001; Ogden et al. 2002; Bélanger-Ducharme and Tremblay 2005). As with adults, increasing rates of childhood obesity are hypothesized to be related to decreasing levels of physical activity and have been linked to environments that encourage sedentary behaviors such as automobile usage (Goran 1997; Weinsier et al. 1998; French, Story, and Jeffery 2001; Catford 2003; Epstein et al. 2008). This is worrisome, as regular physical activity lowers the risk of obesity, coronary heart disease, and a variety of other diseases, including hypertension, Type 2 diabetes, and socio-psychological problems such as depression (Figueroa-Colon et al. 1997; Fagot-Campagna et al. 2000; Figueroa-Munoz, Chinn, and Rona 2001; Janssen and LeBlanc 2010). Increasing levels of physical activity at a young age is extremely important, as physically active children are more likely to remain active as adults (Vanreusel et al. 1997; Conroy et al. 2005; Telama et al. 2005). The most common form of physical activity for

people of all ages is walking (Saelens, Sallis, and Frank 2003), and for children and youth, the journey to school represents an important opportunity to potentially increase daily levels of physical activity by using active travel modes, such as walking and biking, as part of their normal routine (Tudor-Locke et al. 2002; Cooper et al. 2003; Cooper et al. 2005; Kerr et al. 2006). This makes increased understandings of the determinants of children walking to school salient to public health research and public policy decisions. With rates of active travel to school decreasing in recent decades (McDonald 2007; Ham, Martin, and Kohl 2008; Buliung, Mitra, and Faulkner 2009), this is particularly important if policy responses are to successfully reverse current trends.

Rates of Active Travel to and from School

Studies on children's travel to date have found a wide range in the rates of using active travel modes for the trip to and from school, although comparisons are difficult because of large differences in study settings and methodologies. Still, rates are instructive as general context. For instance, a study of fifty-one schools in south and central England found that 67 percent of students walked to school, 32 percent used motorized travel, and only 1 percent of students rode a bicycle (Black, Collins, and Snell 2000). Total rates of active travel in Odense, Denmark, were found to be similar, accounting for 63 percent of school trips, but bicycling, at 39 percent of the total, was the most utilized mode (Cooper et al. 2005). A study of Australian children found substantially lower rates, with only one third of students (33 percent) in West Sydney using an active travel mode on the journey to or from school at least five times per week (Wen et al. 2008). Rates for active school travel in China are quite high, as 88 percent of children were found to actively travel to school in Jiangsu Province and 84 percent at the nationwide level

(Tudor-Locke, Ainsworth, Adair, Du, et al. 2003; Shi et al. 2006). Rates might not be this high for all of Asia, as only 41 percent of Filipino youth actively commuted to school (Tudor-Locke, Ainsworth, Adair, and Popkin 2003). Levels of active travel to school in the United States are generally lower still. A study conducted at thirty-four elementary schools in California found 37 percent of children walking or biking to school (Braza, Shoemaker, and Seeley 2004). Even further down the scale, Evenson et al. (2003) found that only 9 percent of students walked and 4 percent biked to elementary school in North Carolina at least one day a week, and in South Carolina, Sirard et al. (2005) found that as few as 5 percent of elementary children used active commute modes to school.

Factors such as how the study population is defined in terms of age group, geographic scale, and other issues need to be controlled to make these comparisons more useful, but distance emerges as a key factor in all studies. For example, when the data are restricted to a population living within 1.6 kilometers of their school, Martin, Lee, and Lowry (2007) found that 48 percent of children in a U.S. study were active travelers, and Schlossberg et al. (2006) found that 32 percent of students in Oregon walked to school, with rates increasing to 52 percent on the return journey home from school. What might be more important than the rates themselves is the general trend that rates of active travel are steadily declining in many developed nations. In Canada, for example, Buliung, Mitra, and Faulkner (2009) found a nearly 10 percent decline over the past twenty years in the greater Toronto area, with 53 percent of children (aged eleven to thirteen) actively commuting to school in 1986 compared to only 42 percent in 2006. Likewise, Pooley, Turnbull, and Adams (2005) have shown in the United Kingdom that the percentage of children aged five to ten who are actively traveling to school has decreased from 75 percent to 53 percent over the past thirty years, and for older children, aged eleven to sixteen, rates have declined from 60 percent to 44 percent. In the United States, the story is even more stark, with rates of children actively traveling to school dropping from 41 percent in 1969 to a mere 13 percent in 2001 (McDonald 2007; Ham, Martin, and Kohl 2008). Understanding the reasons for these declines is a pressing policy concern. Declining rates might be related to changes in the built environment; people might be living in more suburban areas farther from their schools or no longer attending the local neighborhood school. These changes can influence the distance one must travel, which is the largest contribu-

tor in determining travel mode (Timperio et al. 2004; Ziviani, Scott, and Wadley 2004; Merom et al. 2006; Schlossberg et al. 2006; McDonald 2007).

Physical Activity and the Built Environment

The built environment, including buildings, parks and open spaces, and the transportation system (streets and sidewalks), have been associated with promoting and hindering energy expenditure (Humpel, Owen, and Leslie 2002; C. Lee and Moudon 2004; Lake and Townshend 2006). Access to facilities such as parks, recreation centers, or health clubs can support and encourage physical activity (Sallis et al. 1997; Gordon-Larsen, McMurray, and Popkin 2000; Brownson et al. 2001; Huston et al. 2003; Molnar et al. 2004; Norman et al. 2006; Motl et al. 2007), and neighborhood walkability and street design have also been associated with higher levels of physical activity (Frank 2000; Handy et al. 2002; Frumkin, Frank, and Jackson 2004). Neighborhood environmental features such as the presence of sidewalks, the configuration of the street system, residential densities, and the relative mix of land uses have all been identified as influencing travel modes among adults (Holtzclaw 1994; Handy 1996; Cervero and Kockelman 1997; Frank, Engelke, and Schmid 2003; Humpel et al. 2004; Owen et al. 2004; Li et al. 2005; Frank et al. 2006).

Less is known about the influences of the built environment on travel modes among children (Ewing, Schroeder, and Greene 2004; McMillan 2005), despite the fact that younger populations are more "captive" to the features in their local surroundings. Because children have fewer transportation options, they are generally more susceptible to the opportunity structures in their local environments (Kytta 2004). Opportunity structures are features of the environment that promote or damage health either directly or indirectly through the possibilities they provide for people to live healthy lives (Gilliland and Ross 2005; Larsen and Gilliland 2008). Environmental changes might be even more important for this vulnerable population as children are more likely to benefit from increasing neighborhood "walkability."

Distance between home and school has commonly been the most important factor in determining a child's mode of travel: As distance increases, the probability of active commuting decreases (Timperio et al. 2004; Ziviani, Scott, and Wadley 2004; Merom et al. 2006;

Schlossberg et al. 2006; McDonald 2007). Other characteristics of the built environment also play important roles in determining commuting modes, however. Commonly identified factors for children include the "connectivity" of the pedestrian travel network, residential density, land use mix, the presence of a continuous sidewalk system, and both real and perceived safety from traffic and crime (Boarnet, Day, et al. 2005; Schlossberg et al. 2006; Frank, Kerr, et al. 2007; Kerr et al. 2007; McMillan 2007; McDonald and Aalborg 2009).

The evidence in child-focused studies is much more mixed than in adult studies. Some child-focused studies have found that connectivity (as measured by intersection density) is positively associated with rates of active transportation (Braza, Shoemaker, and Seeley 2004; Schlossberg et al. 2006; Frank, Kerr, et al. 2007; Kerr et al. 2007), but others have found a negative relationship (Timperio et al. 2004; Ulfarsson and Shankar 2008). Associations between street connectivity and active travel among children are unclear. More connected street networks have more route options than less connected networks but also have more streets that children must cross as part of their route.

Higher residential densities are thought to be a proxy variable associated with environmental characteristics that discourage driving such as limited parking availability and characteristics that support good street environments for pedestrians. To date, evidence is contradictory and no clear relationship exists with regard to residential density and mode of travel among children. Ewing, Schroeder, and Greene (2004), for example, found no relationship between residential density and rates for walking to school, but other studies have suggested that higher densities are positively associated with children's active travel (Braza, Shoemaker, and Seeley 2004; Frank, Kerr, et al. 2007; Kerr et al. 2007). Once again, no clear connection exists between mixed land uses, which increases the number of potential destinations accessible by foot, and children's travel. At least two studies have found a positive association between land use mix and active travel to school (Kerr et al. 2006; McMillan 2007), whereas Ewing, Schroeder, and Greene (2004) found no relationship.

The safety of places is key to understanding children's travel. Safety, both objectively measured (e.g., with personal crime or motor vehicle collision statistics) and as perceived by children or parents, incorporates aspects of both the social environment (as an issue of personal security) and the physical environment (as an issue of

traffic safety; DiGuseppi et al. 1998; Bradshaw 2001; Collins and Kearns 2001; Ziviani, Scott, and Wadley 2004; Boarnet, Anderson, et al. 2005; McMillan 2005). On the social side, fear of crime is pervasive and is a common reason parents report for driving their children to school (Joshi and MacLean, 1995; DiGuseppi et al. 1998; McDonald and Aalborg 2009). Ahlport et al. (2008), for example, found that parents feel uncomfortable letting their children walk to school because they do not know whether or not their children have arrived safely. On the physical environment side, perceptions of safety from traffic along the route to school are an important parental concern (Martin and Carlson 2005; Schlossberg et al. 2006; McMillan 2007; Ahlport et al. 2008). Surprisingly, only a few studies have carefully examined this relationship. Street and railway crossings, for example, are a key element of pedestrian and cycling safety, but there is no strong evidence on the relationship of children's travel mode to school with these types of crossings. An Australian study reported that many children are driven to school because of dangerous road crossings (Wen et al. 2008), but Schlossberg et al. (2006) found no evidence in an American study to suggest that they have an important influence in travel choices.

The presence of a good network of sidewalks is related to traffic safety (Frank, Engelke, and Schmid 2003; Frumkin, Frank, and Jackson 2004) and has been positively associated with higher rates of active travel for the journey to school in some studies (Boarnet, Day, et al. 2005; Fulton et al. 2005; Kerr et al. 2006). Other potentially important elements of the pedestrian environment for children are even more understudied. These include the presence of tree cover in school neighborhoods, which provides shade, improves aesthetics, and might increase the likelihood of children walking to school (McMillan 2003). Although understudied in the active school transport literature, a few studies have examined the association between proximity to greenspace in relation to levels of physical activity or body mass index (BMI; Liu et al. 2007; Bell, Wilson, and Liu 2008; Wolch et al. 2010). For a sample of children surveyed in Indianapolis, higher levels of greenspace or the Normalized Difference Vegetation Index were significantly associated with walking environments that children perceived to be more pleasant (Liu et al. 2007). Recent research has also found that children who had better access to greenspace are more physically active and have a lower BMIs (Bell, Wilson, and Liu 2008; Wolch et al. 2010).

Sociodemographic Variables

Personal and social characteristics can also be related to travel mode, as most studies use household income as a basic socioeconomic indicator. Lower income households more commonly have higher rates of active school travel (McMillan et al. 2006; Vovsha and Petersen 2005; Frank, Kerr, et al. 2007; Chillon et al. 2009), suggesting that families of lower socioeconomic status are less likely to use an automobile, perhaps because of lower ownership rates. Studies also often test for household automobile ownership as a separate variable from income but have not shown that the number of vehicles per household clearly affects the mode used for school trips (DiGuseppi et al. 1998; Vovsha and Petersen 2005; Schlossberg et al. 2006). This might relate to extremely high automobile ownership rates in North America.

At the level of individual characteristics, gender has been shown to be an important variable in understanding children's travel. A study by McMillan and colleagues (2006) found that girls were 40 percent less likely than boys to actively commute to school. Other studies have had similar results, with walking or biking to school much more prevalent among males than females (Evenson et al. 2003; Fulton et al. 2005; Merom et al. 2006; Yarlagadda and Srinivasan 2008). Although several studies have found associations, no consistent finding has been determined to date with regard to gender (Metcalf et al. 2004; Dollman and Lewis 2007; M. C. Lee, Orenstein, and Richardson 2008).

GIS Methods Used in Previous Research

Most studies use spatially aggregated neighborhood data to examine the link between environment and mode of travel. The location of the school (destination based) or home has commonly been used as the center point around which the potential area or neighborhood will be examined (Braza, Shoemaker, and Seeley 2004; Kerr et al. 2006; Frank, Saelens, et al. 2007; McMillan 2007). The boundaries around either the residence or school are calculated within geographic information system (GIS) software using a simple straight line buffer, defined as the area within a set distance around either the residence or school (Braza, Shoemaker, and Seeley 2004; Kerr et al. 2006; Frank, Saelens, et al. 2007; McMillan 2007; Larsen et al. 2009) or a network service area (Kerr et al. 2006; Frank, Saelens, et al. 2007). A network service area is computed based on a set dis-

tance someone can travel in any direction along the actual street network, creating a nonsymmetrical, more spatially accurate neighborhood. The latter method still assumes that all routes are equally likely to be traveled and environmental conditions are spatially aggregated across the entire service area.

A few recent studies have used the shortest travel route along the street network to measure their exposure to the potential travel environment (Schlossberg et al. 2006; Timperio et al. 2006). Schlossberg et al. (2006) used a buffer of 200 meters on either side of these routes to measure environmental characteristics. Similarly, work by Timperio et al. (2006) focused on examining attributes directly associated with the shortest path that do not need to be buffered such as street crossings, traveling along busy streets, route directness, and steep inclines. This study aims to build on these advancements by using a route-based analysis and improving the modeling of the environmental characteristics to which children are potentially exposed.

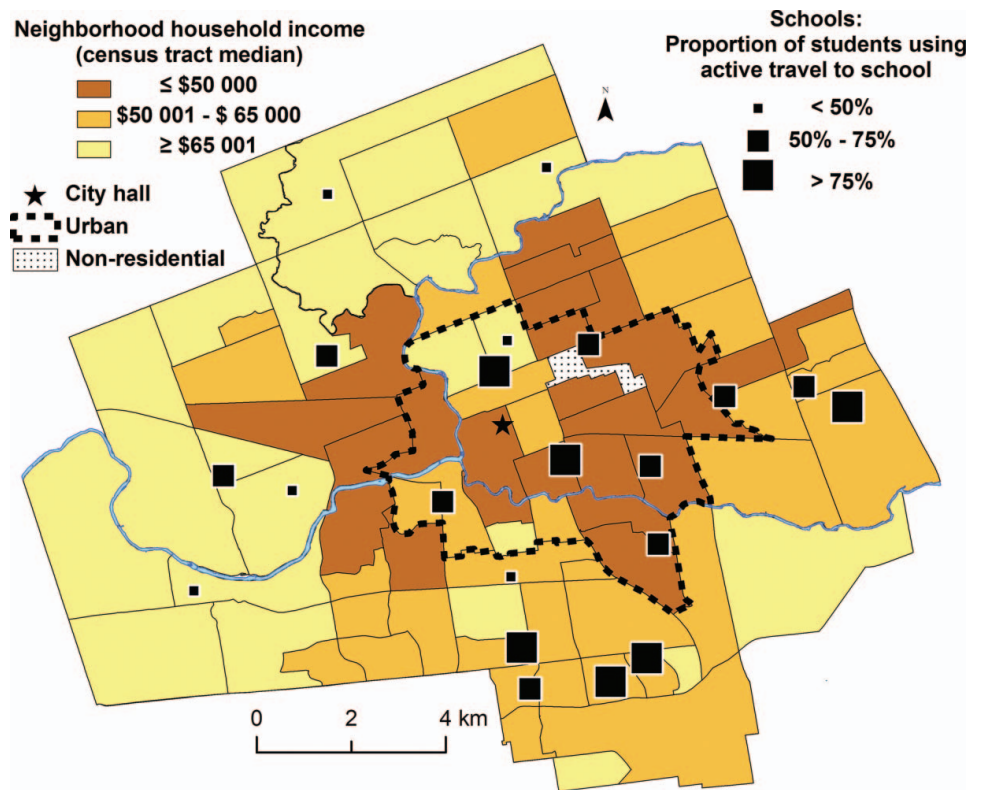
Methods

Study Sample and Active School Travel Survey

A travel mode questionnaire was completed by grade 7 and 8 students at a sample of elementary schools within the city of London, Ontario, Canada. Prior to the commencement of school recruitment, ethics approval was obtained from the University of Western Ontario's Research Ethics Board and the ethics boards at both the Thames Valley District School Board (TVDSB) and the London District Catholic School Board (LDCSB). In total, there were fifty-one elementary schools eligible for participation, and twenty-one agreed to take part in the study (a school response rate of 41 percent). Of the schools participating, eleven were from the LDCSB and ten from the TVDSB. The sampled schools were located in neighborhoods of varying income and built environments, allowing for assessment of the social and physical factors children experience on their journey to school. Figure 1 displays the distribution of the sampled schools along with median household income by census tract in urbanized London.

A total of 1,666 grade 7 and 8 students from both school boards were eligible to participate; 810 obtained parental consent and were in attendance on the day of data collection (a response rate of 49 percent). The questionnaire completed by students asked the method of travel for both the to-school and from-school trip, gender, home postal code, neighborhood

Figure 1. Proportion of students using active travel to school, median household income by census tract, and urban versus suburban neighborhoods. *Sources:* School survey, 2006–2007; Statistics Canada (2001); City of London (2007). (Color figure available online.)



characteristics, and behavioral, dietary, and environmental questions. Parental surveys were also sent out with the children's permission forms to obtain individual-level social and demographic characteristics for each household.

In an effort to control for school board busing practices, only children living within 1.6 kilometers of their school were used in the analysis because, except in exceptional cases, they are not eligible to take school buses.¹ Previous research also suggests that living within this distance from a school considerably increases the likelihood of walking (Timperio et al. 2004; Schlossberg et al. 2006; McDonald 2007; McMillan 2007), so the decision was made to look at only the population of students who were within a reasonable walking distance. This created a final sample of 614 students.

GIS Analysis of the Shortest Path

This study makes methodological improvements over previous research in how it models potential travel environments. Following Schlossberg et al. (2006), environmental features were modeled along travel corridors based on the shortest route between a participant's home address and school. The home location was geocoded as the geographic center of the

reported home postal codes rather than addresses to protect the anonymity of participants in the survey process. Postal codes, in Canada, are much smaller than American ZIP codes and in an urbanized area can identify the location of a residence down to the block. The median area of a postal code in the study area was less than 10,000 square meters (one hectare); thus postal codes are a reasonable spatial proxy for the home address. The school end of routes was geocoded precisely as the front entrance of the school building.

Data on sidewalks, road networks, street trees, pathways, railways, traffic volumes, and land use types were obtained from the City of London Planning Department and validated by researchers through field surveys and inspection of air photos. Environmental audits were completed by the authors for eleven of the schools, creating a high degree of confidence in the interpretation of the aerial photographs. Data on traffic volumes and street trees are important to modeling the potential travel environment but are included in only a few previous studies. The traffic data used in this study were compiled by the City of London's Environmental and Engineering Services Division and updated in 2005 through automated traffic recorders and manual vehicle counts at intersections. The street tree data were derived from an inventory conducted by the City's Forestry Group in

2002. It is based on field surveys and is updated regularly. All data for this study were updated in autumn of 2006. Finally, data on crime were based on reported residential burglaries obtained from the London Police Services, for the years 1998 through 2003. Crime data were geocoded to the appropriate street segment, and the number of incidents per segment was summed for the six years of data. To improve the accuracy of likely pedestrian routes, the study went beyond previous efforts that define potential travel routes using the street network only. Previous work has calculated the shortest path between home and school based on the road network. Most road networks do not include pedestrian walkways, sidewalks, or informal pathways commonly used for the journey to school. Here, a “circulation system” file was built using a combination of the street network, trails, and pathways file. These data were manually updated to ensure accuracy using 2007 aerial photography (15-cm resolution) and field surveys. This file allowed researchers to determine all possible walking routes, including informal pathways such as shortcuts through parks, schoolyards, and so on, within the city. Network analysis was employed within a GIS to calculate the shortest path between each respondent’s home postal code and his or her school using the circulation system file.

Each estimated route was then buffered by 50 meters, creating a 100-meter-wide travel corridor, where features of the built environment were examined (Figure 2). Within these corridors the pedestrian experience was modeled through measurements of the traffic environment, street and railway crossings, network connectivity, sidewalk density, street tree density, percentage of single detached dwellings (as a measure of density), and land use mix. In terms of exposure to traffic, there is little evidence-based guidance as to how traffic exposure affects the decision to use active travel modes; for example, whether average levels of exposure along the route, or particular segments with high exposure, have higher likely impacts. We used the latter assumption and identified the street segment with the highest level of traffic for each travel corridor. Additionally, to model the impact of crossing major streets and railways, the number of crossings of streets classified as arterial roads or highways and active railway tracks between home and school was assigned to each route.

The connectivity of the circulation system along each route was measured as the density of three- or four-way intersections per square kilometer within each route buffer. The directness of travel routes is also associated with network connectivity. Because the role of

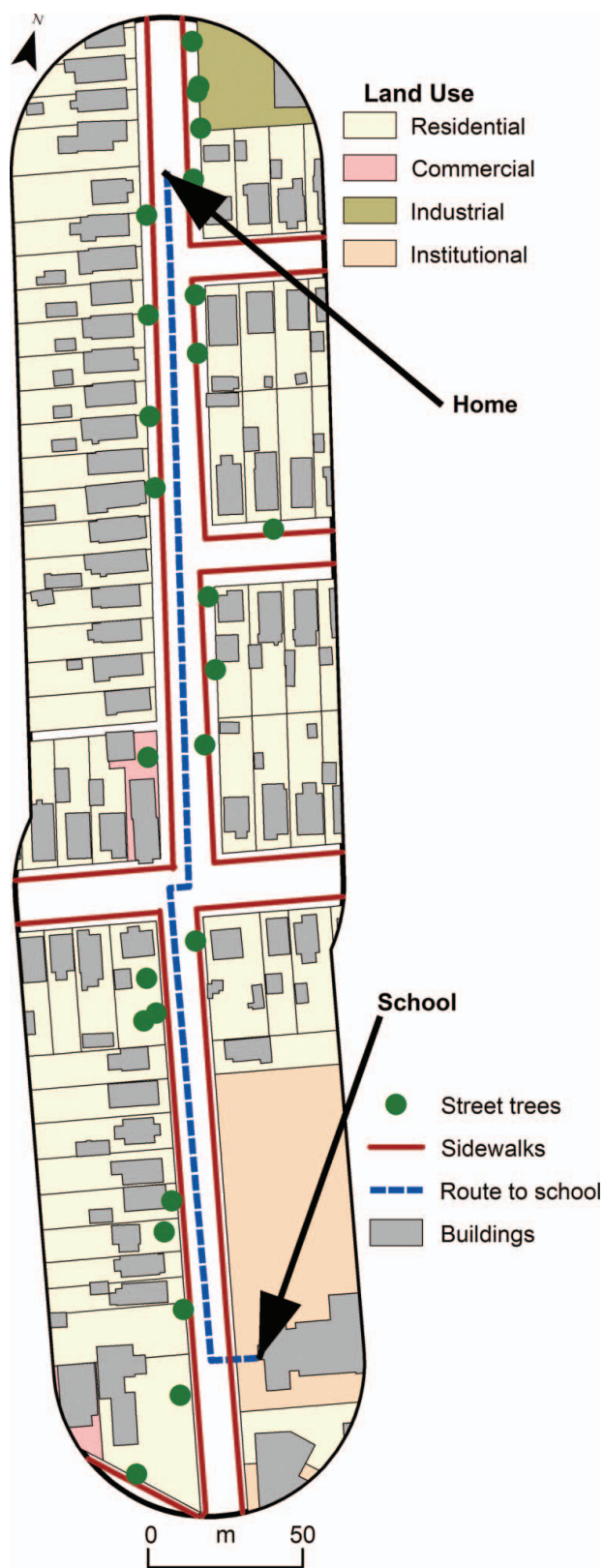


Figure 2. Example of a route buffer: Characteristics of a child’s journey between home and school. Sources: School survey, 2006–2007; City of London (2007). (Color figure available online.)

route-directness on children's travel is not clear, route-directness was calculated separately as the distance between the child's residence and school measured as a straight line, divided by the shortest path distance between the residence and school along the circulation system. Theoretically, the measure can vary between one, with completely straight, direct travel routes, and numbers closer to zero, with very indirect, circuitous travel routes. The final measure of the circulation network modeled was the coverage of the sidewalk system within the corridor, calculated by dividing the total length of sidewalks measured along the network within the route buffer by the distance between the residence and school. High numbers (>1) represent routes with good, complete, or nearly complete sidewalk systems, whereas low numbers correspond to corridors with limited sidewalk systems.

Moving to more general environmental conditions, street tree cover was measured by summing the total number of trees located within 5 meters of a roadway edge, divided by the area within each route buffer. This restricted distance was used to eliminate trees found in backyards on the assumption that they have less impact on pedestrians. Land use mix and the percentage of single detached dwellings were measured for the whole 50-meter buffer area. The percentage of single detached dwellings was measured as the percentage of total land dedicated to single detached houses divided by the total area within each buffer. This was used instead of typical net residential densities because data at the parcel level could be used to create a more precise measurement than using residential and dwelling data at the aggregated census block level. Land use mix was calculated using an entropy index following previous studies (Frank, Andresen, and Schmid 2004; Leslie et al. 2007). The measure calculates the evenness of the distribution of the amount of land in different categories. Here, every parcel of land was classified according to five classes defined by the City of London: recreational, residential, institutional, industrial, and commercial. The total area for each was calculated within each individual buffer and the entropy index of distribution was calculated as follows:

$$[LUM = - \sum_u (\rho_u \ln \rho_u) / \ln n],$$

where u is the land use classification, ρ is the proportion of land area dedicated to a particular land use, and n is the total number of land use classifications. Scores range from zero to one, with zero representing all land

in a corridor as in a single land use (e.g., all residential) and one representing an even distribution of all five land use classifications.

Variables related to the social environment included burglary rates and neighborhood income. Crime was measured similarly to traffic in that the street segment with the highest number of burglaries summed over six years of data was assigned to each route. Data for median household income were obtained from the 2001 Census of Canada at the census tract scale. Income data for each buffer were weighted according to the proportion of area within the corresponding census tract. For example, if 60 percent of a corridor was in a census tract with a median household income of \$80,000 and 40 percent in a tract at \$50,000, the assigned median household income would be \$68,000: $(\$80,000 \times 0.6) + (\$50,000 \times 0.4)$.

Data Analysis

Univariate logistic regression was employed to determine which variables (environmental and social) had statistically significant associations with the journey to and from school. A correlation matrix was used to test for cross-correlations. Although it was originally thought that certain features such as maximum traffic, intersection density, and major street crossings might be correlated, results found no such multicollinearity issues. Backward conditional logistic regression models were created for both to and from school, with active travel as the dependent variable. The following variables were included in the logistic regression model: land use mix, percentage single detached homes, distance to school, maximum traffic in buffer, number of rail crossings on route, density of street trees in buffer, sidewalk coverage, route directness, median household income, intersection density, crime along route (max), gender, and major streets crossed.

To test the strength and reliability of the models, both the Hosmer and Lemeshow test and Nagelkerke R-square values are reported. The Hosmer and Lemeshow test examines whether the model for the predicted probabilities is a good match; in this test a large p -value (>0.05) is required (Lemeshow and Hosmer 1982). Hosmer and Lemeshow test values for both the to and from school trip were well above the required 0.05. The Nagelkerke R-square value attempts to explain the proportion of variance explained by logistic regression (Nagelkerke 1991); in the model for the journey to school, a value of 0.355 was found, which would

predict 36 percent of the cases. For the trip home from school, the Nagelkerke R-square value was even higher, at 0.454 or 45 percent of cases.

Results

Descriptive Statistics

Almost three quarters of the 614 students in the sample reported living in single detached houses (71 percent), 10 percent reported living in an apartment building, 9 percent in a row house, and 7 percent in a semidetached dwelling. Nearly 95 percent of households had access to at least one working automobile, and the majority (53 percent) had two vehicles. In terms of income, response rates on parental questionnaires were considered too low to use for individual analysis (~60 percent). Instead, a weighted ecological variable was constructed using data for median household income using 2001 Canadian Census data at the census tract level, based on the proportion of route in each tract. The median household income of the respondent's home census tract was \$60,179. The average age of students in the sample was twelve years and eight months.

The median distance between home and school for the sample was 998 meters along the shortest path on the circulation system including streets and off-street pathways. Travel times were short, with over two thirds (68 percent) of students reporting that it took them less than ten minutes to travel to school and another 26 percent stating it took them between ten and twenty minutes.

Nearly two out of three, or 62 percent, of students living within 1.6 kilometers of their school, used an active travel mode, and 72 percent used an active mode on the journey home from school (Table 1 and Figure 1). On the trip to school, walking dominates as the active mode, accounting for 59 percent of all to school trips by sampled students. Other active modes account for only a minor share of these trips, with 2.8 percent by bicycle or scooter and a mere 0.8 percent by skateboard or inline skates. For students who used a motorized vehicle to get to school in the morning, 22 percent were driven in an automobile, whereas 15.5 percent rode the school bus,¹ and only 0.5 percent used public transit. More students walked on the journey home from school (67 percent) than the journey to school, with the number of students driven home from school almost 10 percent lower than those driven to school. Survey results found that almost 60 percent of students reported that the driver of their

Table 1. Travel mode to and from school

	Total n (%)	Boys n (%)	Girls n (%)
Respondents	614	273	314
Mode of travel to school			
Walk (alone)	177 (28.8)	90 (33.3)	79 (25.2)
Walk (with friend or parent)	183 (29.8)	68 (25.2)	101 (32.3)
Bike or scooter	17 (2.8)	15 (5.6)	2 (0.6)
Skateboard or rollerblade	5 (0.8)	5 (1.9)	0 (0.0)
Active travel total	382 (62.2)	178 (66.0)	182 (58.1)
School bus	95 (15.5)	44 (16.3)	49 (15.7)
City bus	3 (0.5)	2 (0.7)	1 (0.3)
Driven in an automobile	134 (21.8)	46 (17.0)	81 (25.9)
Motorized travel total	232 (37.8)	92 (34.0)	131 (41.9)
Mode of travel from school			
Walk (alone)	135 (22.0)	58 (21.3)	71 (22.7)
Walk (with friend/parent)	278 (45.3)	120 (44.1)	143 (45.7)
Bike or scooter	19 (3.1)	16 (5.9)	2 (0.6)
Skateboard or rollerblade	10 (1.6)	7 (2.6)	2 (0.6)
Active travel total	442 (72.0)	201 (73.9)	218 (69.6)
School bus	96 (15.6)	44 (16.2)	49 (15.7)
City bus	3 (0.5)	2 (0.7)	1 (0.3)
Driven in an automobile	73 (11.9)	25 (9.2)	45 (14.4)
Motorized travel total	172 (28.0)	71 (26.1)	95 (30.4)

vehicle was going somewhere else (besides home) after the drop off.

The sample was 53 percent female and 47 percent male (Table 1). Walking rates for boys and girls traveling to school are nearly the same, at 58.5 percent and 57.5 percent, respectively. The use of other forms of active travel is highly gendered, however, with 5.6 percent of boys bicycling and only 0.6 percent of girls doing so. Likewise, only 0.8 percent of boys used skateboards or rollerblades, and no girls reported using these modes. Thus, overall, active travel rates were higher for boys than girls, at 66 percent for boys and 58.1 percent for girls. Correspondingly, a higher percentage of girls than boys were driven in an automobile (25.9 percent and 17 percent, respectively).

Parents are clearly involved in these modal decisions. Considering the entire sample, more children walked to school, 59 percent, than reported that this was their preferred mode of travel, only 44 percent. For other active modes, however, many more students reported

using these modes than actually did so. For bicycling and scooters, the difference is dramatic, with 22 percent reporting these as a preferred mode but only 3 percent actually using them to get to school. Similarly, only 1 percent of students used a skateboard or inline skates (i.e., rollerblades), although as many as 10 percent favor this method of travel. For motorized modes, including being driven in a private vehicle or school bus, actual rates are higher than stated preferences. Whereas 22 percent of students were driven to school in a private vehicle and another 16 percent in a school bus, only 16 percent of students wanted to be driven to school in a vehicle and 7 percent preferred the school bus, a combined decrease of 15 percent from actual modes of travel. In total, 76 percent of students would rather travel using a physically active mode; however, nearly 12 percent fewer students actually do so.

An examination of preferences by gender reveals that when looking across active modes, boys' and girls' preferences are fairly similar, with about 79 percent of boys preferring to travel by an active mode and 74 percent of girls reporting this preference. Important differences

do exist, however, when looking at individual modes. Walking was more preferred by girls, and other active modes such as bicycles, skateboards, scooters, and rollerblades were more preferred by boys. Still, a substantial percentage of girls reported preferring modes that almost no girls actually use, with bicycling, preferred by 18 percent, standing out in particular. Overall, preferences for motorized modes of transportation were very similar for both girls and boys, with nearly one in four preferring to be driven to school.

Modeled Analyses

Consistent with previous studies, model results for the to-school trip show that the distance between the residence and school is the most important predictor in determining a child's travel mode (Table 2). As the distance increases, the likelihood of a child using a form of active travel significantly decreases. Figure 3 visualizes relationships between the residence location and distance between home and school and, as expected, schools with sampled students clustered in close

Table 2. Correlates of active travel

						95% CI	
	Coefficient	SE	Wald	p Value	Odds ratio	Lower	Upper
To school							
Distance to school (km) ^a	−1.768	0.196	81.721	<0.001	0.171	0.116	0.250
Maximum traffic in buffer ^b	−0.031	0.011	8.356	0.004	0.969	0.949	0.990
Gender ^c	0.552	0.204	7.329	0.007	1.737	1.165	2.591
Percentage single detached homes ^d	−1.500	0.653	5.275	0.022	0.223	0.062	0.802
Land use mix	−1.360	0.615	4.892	0.027	0.257	0.077	0.857
Density of street trees ^e	0.005	0.002	3.980	0.046	1.005	1.000	1.009
Median household income ^f	−0.015	0.008	3.204	0.073	0.985	0.970	1.001
Constant	4.354	0.721	36.430	<0.001	77.784		
Home from school							
Distance to school (km) ^a	−2.081	0.219	89.988	<0.001	0.125	0.081	0.192
Median household income ^f	−0.034	0.009	13.728	<0.001	0.966	0.949	0.984
Maximum traffic in buffer ^b	−0.037	0.011	10.519	0.001	0.964	0.942	0.985
Major streets crossed ^g	−0.422	0.179	5.542	0.019	0.656	0.462	0.932
Intersection density ^h	0.009	0.005	3.633	0.057	1.009	1.000	1.018
Gender ^c	0.425	0.238	3.199	0.074	1.530	0.960	2.439
Constant	5.733	0.781	53.834	<0.001	308.857		

Note: Active travel as dependent variable, only significant variables are displayed.

^aShortest path from home postal code to school.

^bRoad segment with highest traffic volume in buffer.

^cFemale as referent.

^dPercentage of land use in buffer dedicated to single detached homes.

^eNumber of street trees within 5 m of road edge in groups of 10 per square km.

^fIn \$1,000s.

^gNumber of major streets crossed on route to school.

^hNumber of intersections in buffer per square km.

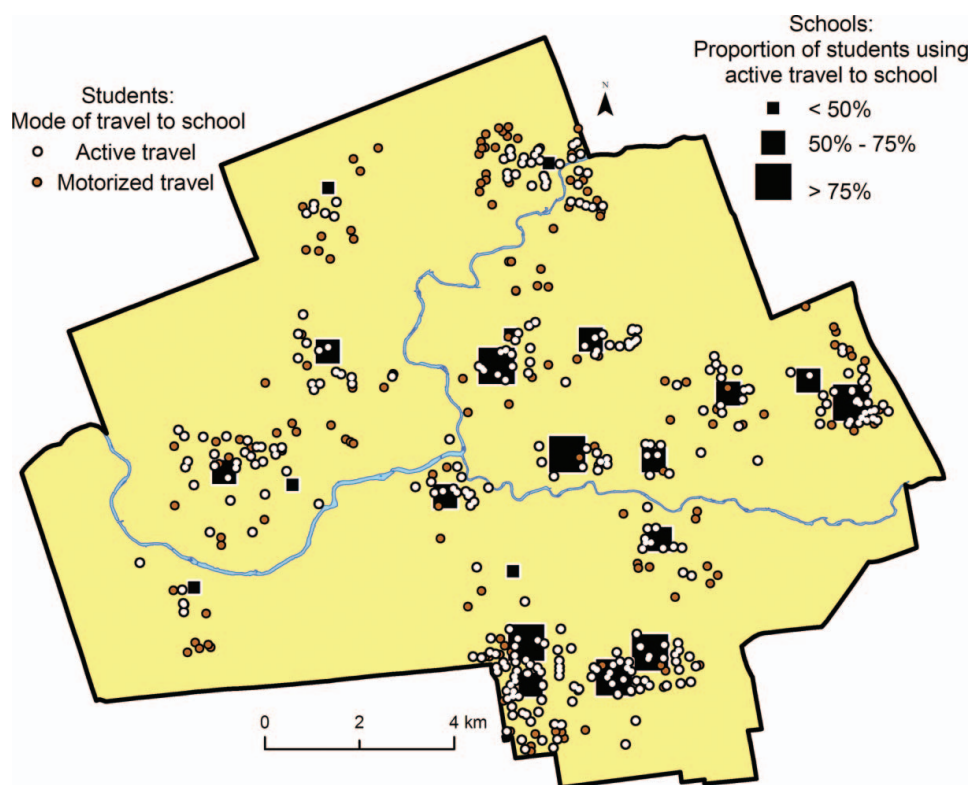


Figure 3. Proportion of students using active travel to school, location of students' home postal code, and mode of travel to school. Sources: School survey, 2006–2007; Statistics Canada (2001); City of London (2007). (Color figure available online.)

proximity clearly show larger percentages of active travel than schools with more spatially dispersed students.

As in previous research, median household income also decreases the odds of children walking or biking to school. The level of vehicular traffic, measured as the highest volume along any network link in the modeled travel route, is a negative factor for the use of active travel modes, with more traffic associated with a decrease in the probability of a child walking or biking to school. A child's gender is also a statistically significant factor in modal choice, with boys 1.7 times more likely to walk to school in the morning than girls.

In terms of land use variables for the to-school trip, the percentage of single detached homes and land use mix in the travel corridor are both statistically significant in the model. Higher percentages of single detached dwellings as well as more mixed land uses decrease the odds of a student actively commuting to school. Finally, as the density of street trees increases in the travel corridor, so do the odds of a child using active travel on the journey to school.

The model for journey home from school shows similar results. Distance to school, median household income, and maximum traffic in the buffer were again related to decreased odds of using active travel modes,

and males were 1.5 times as likely to walk or bike home from school (Table 2). A few differences were found between the two models, as the percentage of single detached homes, land use mix, and density of street trees were not statistically significant in the school to residence model. Additionally, crossing major streets and increased connectivity also appear as significant characteristics in the school-to-home, but not the home-to-school model. Crossing major streets decreased the odds of using active modes to get home from school, and intersection density increased the likelihood of walking or biking home from school.

Discussion

As expected, distance between home and school was the most important variable in models predicting the mode of travel for the journey to and from school. Simply put, children will not use active travel modes, even in supportive environments, if distances are too long. In recognition of this fact, the local school boards provide bus service for students who live beyond 1.6 kilometers (1 mile) from school. On the other hand, if the residence and school are close enough, most children will use active travel modes, even in environments that are

otherwise unsupportive of walking or cycling (e.g., 94 percent of children living within 400 meters of school use an active mode of travel home from school). It is at the intermediate distances where other built environment variables likely come into play. In this study, key environmental variables include density, land use mix, street trees, the crossing of major streets, and intersection density (street connectivity). Other variables of particular interest were vehicular traffic, gender, and median household income. These findings have direct implications for planners, public health professionals, and local school boards seeking to increase rates of active commuting to and from school.

Relevant Environmental Characteristics

The role of street trees is commonly ignored in the academic literature on children's travel behaviors. At least one other study found street trees to be an important predictor (McMillan 2003), and this study adds to the evidence. Street trees provide shade from the sun's harmful ultraviolet rays, thereby providing a safer and, during hot weather, more enjoyable journey. Shade could be of even greater importance in cities with warmer climates or more sunny climates than London, Ontario. Furthermore, beyond their shading properties, street trees contribute to improved neighborhood aesthetics, which can influence how people perceive the walking (and even social) environment and increase the desire for both children and their parents to walk to school. This finding is particularly important because changes to land uses or the street system are difficult and long-term changes; tree planting programs are a relatively easy, affordable, and rapid way to alter an environment to encourage active travel to school.

Increased land use mix is commonly attributed to higher rates of walking among adults (Frank, Engelke, and Schmid 2003), as it increases potential destinations available within a short distance. The relationship to children's travel is less clear. This study provides further evidence that areas of mixed land use might be a negative factor for young children actively traveling to school. This finding clearly needs additional evidence and elaboration, as the entropy variable used is a coarse measure of mix. Older, main street environments with stores fronting sidewalks can have very different influences than more suburban strip malls with parking lots and high volumes of vehicular traffic. More recent retail developments commonly include large parking lots designed for automobile travel, which can create parental traffic safety concerns. Likewise, industrial areas, recre-

ational areas, and retail uses would also be expected to have different effects on the travel decisions made by or for children. Few measures of use mixture have explored what is actually being captured or proxied by this variable. It is important to understand these issues, as they likely have different impacts on adults and children.

Residential density is another variable that can have different relationships to adult and children's travel. In studies with adults, increased residential densities are consistently associated with increased walking levels, but results for studies involving younger populations are mixed (Ewing, Schroeder, and Greene 2004). This study supports the belief that the relationship for children is in the same direction as for adults, with routes that are predominantly single, detached dwellings decreasing the likelihood of walking to school. Residential neighborhoods appear to be better than areas of mixed used in increasing the probability of actively commuting to school, but the presence of mixed housing types appears to also be important. Why this might be the case is not clear. It might be that the variable used in this study is a proxy for other real and perceived characteristics of the built environment.

Traffic volume, intersection density (or connectivity), and major street crossings are all interrelated, but no significant cross-correlation was present and the variables in the study appear to be picking up different elements of the travel environment. This could relate to how variables representing these features were measured: Intersection density is an area-based measure, maximum traffic simply relates to the highest traffic volume on any street within the route buffer, and the number of major streets crossed is the number of arterials and highways crossed in each route. Combined, however, they all relate to issues of traffic safety. Multiple studies have reported that parental safety concerns are a basic reason why children do not actively commute to school (DiGiuseppi et al. 1998; Bradshaw 2001; Collins and Kearns 2001; Ziviani, Scott, and Wadley 2004; Boarnet, Anderson, et al. 2005; McMillan 2005). The crossing of major streets was explored in a previous American study (Schlossberg et al. 2006) but was not shown to be a significant predictor. Here, major street crossings were statistically significant in only one travel direction, from the school to the residence, but were missing on the journey to school. Likewise, intersection density increased the likelihood of using active travel on the way home but not to school. Although this suggests that large numbers of crossings, as long as they are minor streets, are not problematic for pedestrians, it is not clear why the models show this to be significant

in one direction only. The study does show that parents are more likely to accompany children to school than home and that more children actively travel on the return trip, probably because of differences in the opportunities for working adults to pick up their children in the afternoon. Parents might assess environmental hazards like street crossing differently when their children are walking without supervision, so it is reasonable that different variables come into play in these decisions, but the interplay between these issues is not clear. Results for traversing a street segment with high traffic volume were more straightforward, as this was found to be a negative factor for active travel for trips both to and from school.

Following the results of previous literature (McMillan et al. 2006; Vovsha and Petersen 2005; Frank, Kerr, et al. 2007), the influence of neighborhood median household income, a key indicator of an area's socioeconomic status, was associated with rates of active travel. Neighborhoods of higher household income levels were linked to lower rates of active travel on both the journey to and from school. Income obviously proxies many other relationships: Families with higher income might have more flexible working hours or might only have one parent working, which allows parents to drive their children to or from school. How these dynamics work is unknown, however, as the children's travel literature has barely approached this question. Children's preferences might also play a role, but it is important to emphasize that stated preferences should not be equated with the modes children would actually use if given the opportunity. Nevertheless, the results do suggest that there is an unmet demand for more active travel among the students sampled in this study. Whether this demand is related to a desire for a different travel experience, more autonomy for parents, or other factors is not known.

Findings for gender were similar to previous work, as boys were more likely to actively travel than girls (Evenson et al. 2003; Fulton et al. 2005; McMillan et al. 2006; Merom et al. 2006; Yarlagadda and Srinivasan 2008), but the reasons for these differences are not clear. Researchers have pointed to parental fears, as girls are more likely to be the targets of "stranger danger," such as kidnapping or sexual abuse, than boys, but also to social beliefs about what are and are not appropriate activities for boys and girls (Evenson et al. 2003; Fulton et al. 2005; Merom et al. 2006; Yarlagadda and Srinivasan 2008). Furthermore, the differences could relate to the concept of gendered spaces and how environments can

influence boys and girls differently (Clampet-Lundquist et al. 2006).

Implications for Planners, Researchers, and School Boards

The findings from this study have direct implications for planners, public health professionals, and local school boards for increasing rates of active commuting to and from school. Foremost, because of the importance of distance to active travel, school boards should put extra thought into how siting decisions will affect travel modes and the benefits that come from walking, cycling, and other active modes. Furthermore, planners and developers should build and retrofit communities to be more conducive to active forms of travel, with special attention paid to how traffic affects children's travel and with good street environments including street trees.

Rates of active travel were 10 percent higher for the journey home from school, suggesting that there are important differences between the two trips. Almost 60 percent of students reported that the driver of their vehicle was going somewhere else (besides home) after the drop-off, suggesting that there is a strong link between children's school trip mode and parents' commuting patterns. A reasonable explanation for increased walking rates home from school is that parents are still at work and unavailable to pick up children when schools get out during midafternoon. This does not mean that the built and social environment does not come into play in both directions but rather that there is a link between household dynamics and, in particular, between parents' and children's commuting patterns (McDonald 2008; Yarlagadda and Srinivasan 2008).

Limitations and Strengths

Although this research moves beyond the typical ecological study, a few limitations do exist. Researchers could not identify the actual route a child takes to school; rather, the shortest distance between home and school, or probable route, was used. Another potential criticism of this research might be directed at the fact that due to ethics board requirements, home postal codes were used rather than exact addresses. In addition, parental response rates on certain social variables such as income and educational attainment were too low for this study.

This study aims to make advancements within the literature through the use of route-based analysis,

thus improving the modeling of the environmental characteristics to which children are potentially exposed. Using a corridor-based measure to examine environmental characteristics is an important advancement in the knowledge related to school travel and perhaps more relevant than the spatial aggregation used in neighborhood-based studies. Recent work has examined aspects of the shortest path (Schlossberg et al. 2006; Timperio et al. 2006), but this study adds additional dimensions. Schlossberg et al. (2006) used a buffer of 200 meters on either side of the shortest path to measure environmental characteristics. This created a 400-meter-wide corridor between each participant's residence and school in which environmental attributes were examined. The researchers did not discuss how they determined the buffer distance they used along the route. A zone 200 meters wide on each side as used by Schlossberg et al. (2006) is very large and would incorporate environments that would be several blocks away from the actual route. These would be averaged with the characteristics of the immediate environment along the route, decreasing variability in the data and creating aggregation errors. This study used a distance of 50 meters. Although there is not adequate theory to guide the selection of this buffer distance, 50 meters was used to ensure that only one street was examined and increase the variability in the data. In making a decision to walk or not (or in making the decision for their child), people might evaluate their image of the general environment in an area that extends beyond their potential walking route. For example, people might think about their general neighborhood environment rather than visualizing their particular travel route, or they might, in some way, combine different types of assessment. This is an important question of environmental psychology, but how this evaluative process occurs is not known. Therefore, the decision was made to capture the immediate built environment that a pedestrian would be directly exposed to, about half a block on either side of the route. A narrower buffer distance was determined not to capture much of the built environment beyond the street right-of-way itself. A wider buffer often extended to blocks adjacent to the route and would reduce the variability of measured environments among the modeled routes. This study also assessed more aspects of the route environment, aside from intersection density, route directness, and major street crossings. Land use mix, presence of street trees or sidewalks, traffic volume, crime, and the percentage of single detached homes were all examined at the route level.

In conclusion, distance between home and school was the most important determinant, but factors of the built and social environment did play a role. School siting should be an important issue not only for school boards but also for planning and public health professionals. Location of schools plays a vital role in the distances students must travel between home and school, and shorter distances are the best way to encourage active journeys to and from school and promote a form physical activity that is naturally built into their daily lives. The use of active travel to school will not solve the obesity epidemic, but it is one step toward increasing daily levels of physical activity among children.

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Note

1. Students living within 1.6 kilometers of the school can obtain bus privileges if they have to overcome a hazard (such as crossing a major highway). A total of 3.8 percent of all students attending the twenty-one sampled schools were eligible to take the school bus due to a hazard. Children living in a dual-custody relationship might also have two addresses, although only one postal code was given; they might be entitled to take the bus from the other address. Some measurement errors could be due to our use of home postal codes to calculate travel distance to school, rather than precise home addresses; however, the median distance between every residential address in the city and its related postal code is only 80 meters, so this unlikely the cause of many discrepancies. Finally, errors related to the postal code given or mode of travel might explain a few cases as to why children claim to be taking the school bus when living less than 1.6 kilometers from school.

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