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BRIEF REPORT

Individual- and Area-Level Disparities in Access to the Road Network, Subway System and a Public Bicycle Share Program on the Island of Montreal, Canada

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Abstract
Background Few studies have examined potential disparities in access to transportation infrastructures, an important determinant of population health.
Purpose To examine individual- and area-level disparities in access to the road network, public transportation system, and a public bicycle share program in Montreal, Canada.
Methods Examining associations between sociodemographic variables and access to the road network, public transportation system, and a public bicycle share program, 6,495 adult respondents (mean age, 48.7 years; 59.0 % female) nested in 33 areas were included in a multilevel analysis.
Results Individuals with lower incomes lived significantly closer to public transportation and the bicycle share program. At the area level, the interaction between low-education and low-income neighborhoods showed that these areas were significantly closer to public transportation and the bicycle share program controlling for individual and urbanicity variables.
Conclusions More deprived areas of the Island of Montreal have better access to transportation infrastructure than less-deprived areas.

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Access is defined as people's ability to reach goods, services, and activities, which is the primary objective of a majority of transportation activities [1]. Behavioral medicine researchers have shown that access, typically operationalized as proximity, to physical activity facilities [2–4] and healthy food stores [5, 6] is correlated with health behaviors. However, these results have recently been questioned by reviews and longitudinal studies [7, 8]. Proximity to physical activity facilities and healthy food options is socially and spatially stratified with deprived individuals residing in deprived areas typically located at a greater distance from potential health-enhancing facilities [9, 10]. To reduce inequities in access, interventions have attempted to increase the number of physical activity facilities and of healthy food stores in deprived areas [11].

The concept of access is broader than individual or area proximity to physical activity opportunities and healthy food stores. Because access implies the mobility and spatial distribution of people, goods and services, transportation infrastructures play a key role in reducing inequities in access [12]. Access extends beyond residential area proximity and represents people's ability to reach goods, services, and activities that are spatially distributed. Thus, interventions designed to increase the number of physical activity facilities and healthy food stores in deprived areas do not completely address the problem of inequities in access.

If access to multiple services is limited in deprived areas, a complementary intervention to increasing access would increase availability of transportation systems including road networks, public transportation, and walking/cycling. Increasing access to transportation systems could reduce health inequities by allowing individuals to reach services that cannot easily be relocated, for example, health services and jobs.

A small body of research has examined the interaction between access to transportation systems and the primary mode of transportation in predicting health outcomes [13–16]. Inagami et al. [14] examined interactions between fast food/restaurant density (a measure of access) and automobile ownership in predicting body mass index in a sample of 2,156 respondents residing in deprived areas of Los Angeles, CA, USA. The results controlling for immigration status, race, sex, education, employment, marital status, and age showed that respondents not owning an automobile, who had greater access to fast food outlets, weighed 12 lbs more than those residing in low access areas, but also weighed 2.7 lbs more than those residing in high-access areas and owning an automobile. Respondents with lower access and owning automobiles weighed the least. Lamb et al. [16] showed that in Scotland, individuals living in affluent neighborhoods had poorer walking, bicycling, and bus access to facilities for moderate and vigorous physical activity, while the same neighborhoods had better automobile access to the physical activity facilities. A recent review suggests that deprived areas are disproportionally exposed to major roadways and motor vehicles [17], which improve access for automobile owners. However, materially deprived persons are less likely to own a motor vehicle. Simultaneously, greater exposure to the road network produces health risks due to exposure to air pollution [18] and increased risk of injury due to collisions [19].

Behavioral medicine researchers are beginning to examine inequities in access to transportation systems. If inequities in transportation systems exist, people residing in deprived areas may not be able to reach necessary goods, services, and activities, including those that support physical activity and healthy eating. As well, use of public transportation and walking/cycling both contribute directly to the accumulation of recommended daily physical activity. The current study contributes to this area of research by examining individual and neighborhood access to the road network, public transportation, and a public bicycle share program in Montreal, Canada.

Methods

A repeated cross-sectional survey design was used. Individual level data from three population-based samples of adults recruited via telephone survey were pooled. Surveys were part of a larger study aimed at evaluating the impact of a public bicycle share program [20] and conducted between 4 May–10 June 2009, 8 October–12 December 2009, and 8 November–12 December 2010. Response rates for the surveys were 36.9, 34.6, and 35.7 %, respectively, and the sample fraction was 0.002. The sampling frame for each survey was individuals residing on the Island of Montreal with a landline telephone. Within contacted households, the available individual to next celebrate a birthday and aged over 18 years was targeted to respond. To recruit sufficient numbers of respondents reporting cycling, the sampling frame was stratified according to the presence or absence of public bicycle share program docking stations in the neighborhood of residence. In the first stratum, random digit dialing to landlines was used to contact those residing on the Island of Montreal. In the second stratum, oversampling was conducted by randomly selecting landlines with Montreal postal codes in those neighborhoods and recruiting 25 % more respondents than would be expected based on population data from the 2006 Canadian Census [21] in areas where the public bicycle share program was available. Complete methodological details and survey timelines have been published [20].

Neighborhoods defined by the city of Montreal as well as the contours of municipalities on the Island of Montreal were used to define 33 areas. These areas are larger than census tracts with an average population of 56,151 residents. Neighborhood level data were obtained from the 2006 Canadian census [21] and the City of Montreal.

Procedures

Ethical approval was obtained from the ethics committee of *Centre de Recherche du Centre Hospitalier de l'Université de Montréal*. Respondents were recruited via a polling firm who obtained verbal informed consent prior to participation. Respondents could complete the survey in French or English. Researchers trained telephone interviewers and performed ongoing quality surveillance to ensure the survey was being conducted in accordance with researcher training.

Measures

The outcome variables of interest were individual level access to the road network, public transportation, and a public bicycle share program. Road network access was operationalized using a kernel density estimation of the Montreal road network and computing the density value for each participant based on home postal code. The kernel density variable ranged from 0 to 9. Higher values represent greater density of the road network. Public transportation and public bicycle program access were operationalized using the road network distance in meters from the participants' home postal code to the nearest subway or public bicycle share docking station.

Individual level variables including age, sex, education, household income, employment status, being born in Canada, and having a driver's license were measured using standard questions from the Canadian census [21]. Area level deprivation variables were operationalized as a dichotomous education variable (≥25 % of the population without a high school education vs. <25 % of the population without a high school education), a binary income variable (≥25 % of the population having low income vs. <25 % of the population having low income) and their interaction. Urban form control variables were density of destinations, street connectivity, and population density [22].

Data Analysis

Data analysis consisted of three separate multilevel regressions examining the relationship between the three outcomes (i.e., road network, subway, and public bicycle program access) and individual and neighborhood level variables. The road network variable was normally distributed and analyzed using multilevel linear regression. The subway and bicycle share program variables were skewed and analyzed using multilevel negative binomial regression. All analyses control for survey period.

Results

The analysis sample consisted of 6,495 respondents (92.8 % of the 7,012 total respondents) nested in 33 areas. The 507 excluded respondents had missing postal code or sociodemographic data. The analysis sample had a mean age of 48.7 (SD=17.1) years and 59.0 % was female. Table 1 shows individual and neighborhood level descriptive statistics.

Figure 1 shows the geographic distribution of the road network density, the subway system, and the public bicycle share program stations on the Island of Montreal. Table 2 outlines results from three separate multilevel regression models predicting road network, subway, and public bicycle program access of individuals as a function of individual- and area-level variables. Results for access to the road network showed that students (β=−0.14, 95 % CI: −0.22, −0.07) lived in areas where road network density was lower compared to people employed full time. There were no area level differences between road network density when comparing high- and low-income and education neighborhoods.

For access to the subway system, people with less than a high school education lived significantly further (coefficient= 0.06, 95 % CI: 0.03, 0.09). Compared to households earning $100,000 or more, those earning $50,000–99,999, $49,999–20,000, and less than $20,000 lived significantly closer to the subway. People living in areas with a higher percentage of low education (coefficient=0.56, 95 % CI: 0.45, 0.67) or low-income (coefficient=0.89; 95 % CI: 0.68, 1.09) resident's were further from public transportation. The interaction between low income and low education showed that these areas

Table 1 Sociodemographic characteristics of 6,495 residents of 33 areas of the Island of Montreal, Canada surveyed in spring 2009, fall 2009, and fall 2010

	Percent (*n*)
Individual level (*n*=6,860)	
Age (average (SD))	48.7 (17.1)
Foreign born	
Yes	24 % (1,542)
No	76 % (4,953)
Drivers license	
Yes	75 % (4,893)
No	25 % (1,602)
Employment	
Full time	45 % (2,924)
Part time	7 % (467)
Student	9 % (595)
Retired	22 % (1,509)
Leave	17 % (1,073)
Education	
High school or less	27 % (1,775)
Trade school	7 % (452)
College	13 % (856)
University	53 % (3,412)
Household income	
Less than $20,000	13 % (867)
$20,000–49,999	30 % (1,936)
$50,000–99,999	24 % (1,565)
More than $100,000	13 % (798)
Missing	20 % (1,329)
Sex	
Male	41 % (2,665)
Female	59 % (3,830)
Road network density (average (SD))	5.7 (1.0)
Distance to subway (average (SD))	2.9 km (4.2 km)
Distance to bicycle share (average (SD))	3.7 km (5.7 km)
Area level (*n*=33)	
No diploma	
More than 25 % with no high school	30 % (10)
Less than 25 % with no high school	70 % (23)
Low income	
More than 25 % low income	28 % (9)
Less than 25 % low income	72 % (24)
Street connectivity (average (SD))	1,341.5 (526.1.3)
Density of destinations (average (SD))	212.3 (116.3)

SD standard deviation

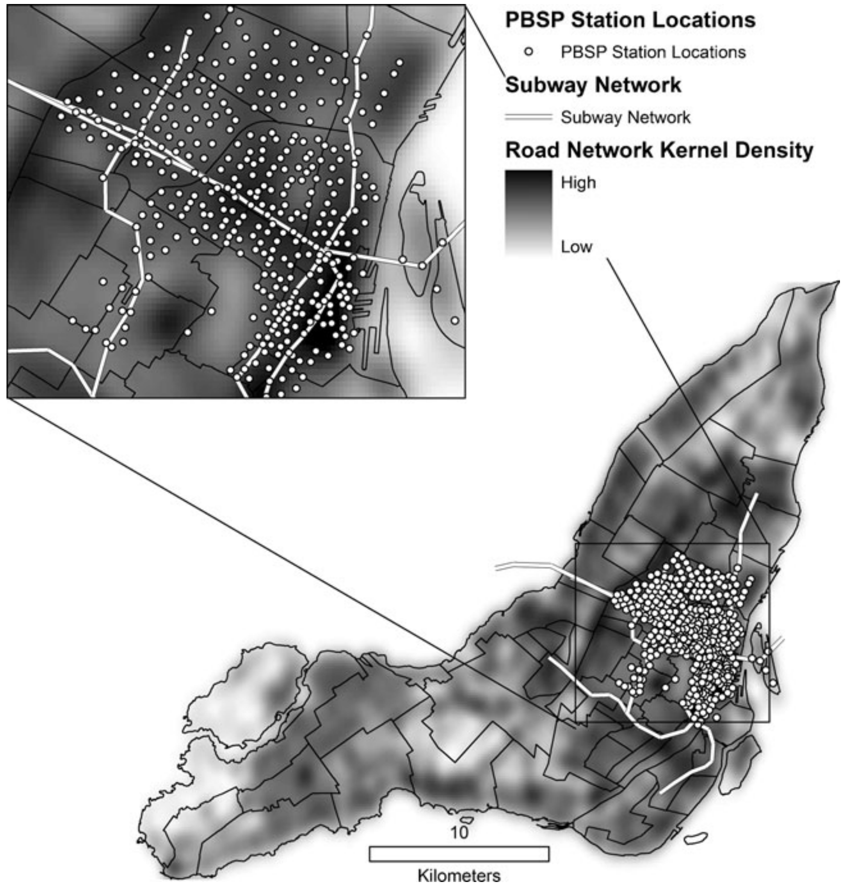

Fig. 1 Geographic distribution of road network density, subway system access, and public bicycle share program (PBSP) access on the Island of Montreal, Canada

were significantly closer to public transportation (coefficient=−1.59, 95 % CI: −1.88, −1.30).

For access to the bicycle share program, people with less than a high school education lived significantly further (coefficient=0.04, 95 % CI: 0.02, 0.07) than those with a university education. Compared to households earning $100,000 or more, those earning $50,000–99,999, $49,999–20,000, and less than $20,000 lived significantly closer to bicycle share. Areas with a higher percentage of low-education resident's (coefficient=−0.50, 95 % CI: −0.60, −0.40) were closer to the bicycle share. Areas with a higher percentage of low-income resident's (coefficient=2.11, 95 % CI: 1.93, 2.28) were further from the bicycle share. The interaction between area level income and education showed that low-income, low-education areas were significantly closer to the bicycle share program (coefficient=−3.18, 95 % CI: −3.44, −2.28).

Discussion

This study examined access to the road network, the subway system, and the public bicycle share program in Montreal, Canada. Results suggest that in Montreal areas with a higher percentage of low-income and low-education residents have greater access to the subway system, and the bicycle share program. The interaction term showed that those residing in areas with a high proportion of both low-income and low-education residents had the best access to the subway system and to the bicycle share program. Greater access to the subway system and cycling as forms of transportation can contribute positively to health by increasing physical activity which produces a number of positive health outcomes including lowering body mass index [23]. There were no area level differences in access to the road network. This finding differs from a recent review [17]. We analyzed the entire road network rather than major roadways, which may explain the divergent results. The road network is ubiquitous in major cities, which may explain the null finding at the area level.

At the individual level, having less than a high school education was associated with living further from public transportation and the bicycle share program compared to those with a university education. Having a yearly household income greater than $100,000 was associated with living further from public transportation and the bicycle share. Being a student was the only socioeconomic variable significantly associated with access to the road network.

Overall, the results suggest that there are relatively few disparities in access to transportation in Montreal. This finding differs from most North American cities where

Table 2 Associations between individual- and area-level socio-demographic variables and access to the road network, public transportation, and a public bicycle share program among 6,495 residents of 33 areas on the Island of Montreal surveyed during spring 2009, fall 2009, and fall 2010

	Road network access coefficient (95 % CI)	Public transportation access coefficient (95 % CI)	Bicycle share program access coefficient (95 % CI)
Intercept	4.27 (3.74, 4.80)*	2.73 (2.55, 2.91)*	2.04 (1.86, 2.21)*
Individual level			
Age	0.00 (−0.00, 0.00)	0.00 (0.00, 0.00)*	0.00 (−0.00, 0.00)
Foreign born	−0.01 (−0.07, 0.04)	0.01 (−0.02, 0.03)	−0.01 (−0.03, 0.02)
Drivers license	−0.01 (−0.05, 0.04)	0.03 (0.01, 0.06)*	0.03 (−0.00, 0.05)
Employment			
Part time	−0.05 (−0.10, 0.00)	0.01 (−0.02, 0.04)	0.00 (−0.03, 0.03)
Student	−0.14 (−0.22, −0.07)*	−0.01 (−0.06, 0.03)	−0.02 (−0.06, 0.03)
Retired	−0.03 (−0.11, 0.04)	0.03 (−0.02, 0.07)	0.02 (−0.02, 0.06)
Leave	−0.03 (−0.10, 0.5)	−0.03 (−0.07, 0.01)	−0.00 (−0.04, 0.03)
Education			
High school or less	0.01 (−0.06, 0.08)	0.06 (0.03, 0.09)*	0.04 (0.02, 0.07)*
Trade school	0.05 (−0.02, 0.12)	−0.01 (−0.06, 0.04)	−0.02 (−0.06, 0.03)
College	0.03 (−0.03, 0.09)	0.02 (−0.02, 0.05)	0.02 (−0.02, 0.05)
Household income			
<$20,000	0.07 (−0.02, 0.16)	−0.06 (−0.94, −0.02)*	−0.06 (−0.09, −0.04)*
$20,000–49,999	0.06 (−0.03, 0.16)	−0.09 (−0.12, −0.04)*	−0.08 (−0.11, −0.04)*
$50,000–99,999	0.07 (−0.04, 0.18)	−0.10 (−0.15, −0.05)*	−0.09 (−0.14, −0.05)*
Sex	0.00 (−0.04, 0.04)	0.02 (−0.01, 0.04)	−0.00 (−0.02, 0.02)
Area level			
No diploma	−0.24 (−0.68, 0.21)	0.56 (0.45, 0.67)*	−0.50 (−0.60, −0.40)*
Low income	0.81 (0.92, 2.54)	0.89 (0.68, 1.09)*	2.11 (1.93, 2.28)*
Low income×no diploma	−0.12 (−1.92, 1.66)	−1.59 (−1.88, −1.30)*	−3.18 (−3.44, −2.93)*
Street connectivity	0.00 (−0.00, 0.00)	−0.00 (−0.00, −0.00)*	0.00 (0.00, 0.00)*
Density of destinations	0.00 (−0.00, 0.00)	−0.00 (−0.00, −0.00)*	−0.02 (−0.02, −0.02)*

Models control for survey period and population density within the neighborhoods. Reference categories are: foreign born=no, driver's license=no, sex=male, employment=full time, education=university education, household income=>$100,000, no diploma=<25 % no diploma, low income cutoff=<25 % low income. *CI* confidence interval

*$p<0.05$

neighborhoods with a high proportion of low-income residents are systematically underserved by public transportation and may not be able to mobilize when major road building projects are proposed in these neighborhoods [24, 25]. The results may be specific to Montreal because of policies that discourage the concentration of low-income housing [26]. These policies limit clustering of low-income housing and ensure that the implementation of public transportation and the bicycle share program serve a large proportion of the population while also providing equitable access.

The present study suggests that in Montreal transportation systems and land use policies have been used as an important intervention for reducing social and spatial inequities in access to services. Whether better access to transportation systems results in meaningful improvements in health outcomes, has yet to be examined.

Future research should consider the role of access and use of transportation systems as explanatory mechanisms for health behaviors. Transportation systems may have direct effects on behavior such as physical activity or may interact with other environmental variables to explain behavior. Studies examining the impacts of access and use of transportation systems on health between large North American cities could address limitations of the present study.

Limitations

Residential self-selection could bias the results of the study. For example, individuals with higher incomes may choose areas with limited public transportation because they prefer to use their personal motor vehicle. The operationalization of access to public transportation did not take into account the bus and commuter train network in Montreal. Not considering these networks underestimates total access to public transportation and may over- or underestimate the effect of public transportation access. Access is not limited to space. Monetary, time, and other costs were not considered in the definition of access. Measuring access to the transportation system alone does not account for what types of services are accessible via the transportation system. The random digit dialing sample may not be representative of the population and likely over represents women and older adults.

Conclusion

In Montreal, people living in low-income and low-education areas have greater access to the public transportation system and a public bicycle share program compared to people living in high-income and high-education areas. The results differ from similar studies in North American. Land use policies that limit the clustering of low-income housing in Montreal may explain the findings and suggests that transportation systems and land use policies are an important intervention for reducing social and spatial inequities in access to services.

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Conflict of Interest Statement The authors have no conflict of interest to disclose

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