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Walkable and Safe Route to Transit for Pedestrians in Greater Montreal : An Environmental Justice Approach

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ABSTRACT

The experience of walking to transit stops plays a critical role in the use of public transportation. Having a safe and walkable environment for this part of the trip is even more important for vulnerable population groups, who depend more heavily on public transportation. The aim of this paper was to evaluate first-mile/last-mile walkability and road risks in the Montreal metropolitan area using an environmental justice approach. Using a spatially sound method, we determined that areas in which a greater number of people identify as visible minorities are disadvantaged in terms of walking-to-transit routes and that areas with low-income populations and people ages 65 and over have more walkable environments but also have to deal with more road risk.

Keywords: First-mile/last-mile, spatial analysis, environmental justice, walkability, pedestrian safety

INTRODUCTION

At one point or another along their journey, all transit users become pedestrians. Walking is critical to the use of public transportation and the first-mile/last-mile experience. The literature on the first-mile/last-mile experience addresses the access or egress to and from public transportation. Some authors use the term "last-mile problem" when it comes to highlighting challenges and barriers transit users face in accessing transit stops (1–3). Built environment and trip attributes can enhance the use of walking as access or egress modes to transit stations (4). In fact, the out-of-vehicle environment has a bigger impact on transit users' satisfaction than in-vehicle and system-related factors (2).

Assessing the first-mile/last-mile

The literature on the first-mile/last-mile experience primarily uses surveys to assess which particular elements are important for transit users (2,5–7). This method is suitable for evaluating the satisfaction of transit users and their public transport experience. Studies on walkability, however, use a variety of tools to determine the extent to which an environment is pedestrian friendly. Walkability methods are more appropriate if the issue being studied addresses the suitability of the environment rather than a person's individual experience.

Walkability in the first-mile/last-mile

Walkability refers to the extent to which the built environment motivates people to walk and, to a certain degree, how welcoming the built environment is to those individuals (8). The pioneering study of Cervero and Kockelman (9) established the 3Ds (density, diversity and design) as crucial features of built environments that must be assessed in order to improve walkability. Since then, many more features of the physical environment have been considered to have an impact on walking behaviors: presence of a sidewalk, cleanliness, street connectivity, land-use mix, green spaces, car traffic volume, aesthetic of places, etc. Depending on the data available, or the scope of the research, these factors are grouped into broader categories, much like the 3Ds, in order to facilitate analysis and adapt the data to the context. These categories or dimensions—which include efficiency and comfort, safety/security and pleasantness can all be used as walkability indices (8,10–15).

Walkability studies apply three main types of research methods—audits, qualitative methods and GIS-based tools—to measure the extent of a particular environment's walkability (11). These methods must be embedded in the local context, taking into consideration the latter's spatial, social and population characteristics (16).

The first of these methods—walkability audits—allows researchers to collect observations from a list of elements recognized as being important for pedestrians in a given context (e.g.: urban, rural) and the targeted population (e.g.: children, seniors) (17,18). Qualitative methods such as walk-along interviews or focus groups, for their part, aim to gather perceptions of an environment from the pedestrian's point of view (19,20). The third method—GIS-based walkability assessment—allows spatial data to be superimposed onto a road network to evaluate the walkability of each road segment based on the specific features found within them. This method is widely used, especially when studying larger territories, since the first two methods are not suitable in such cases (21).

While certain studies on the first-mile/last-mile concept have integrated some walkability concepts and methods, walkability is surprisingly not systematically part of such research despite how critical it is for transit users. For example, regarding the access to and egress from a transit station, Kathuria and al. (22) found that walkway quality can increase the use of a specific transit stop. Similarly, elements such as sidewalk connectivity and street furniture were identified as elements that enhance the walking experience of transit users (1,2). Roadway narrowing, street lightning and protected bike lanes were also found to affect the overall experience and the specific route chosen to access public transit since these elements influence users' perception of safety (2,23).

Mobility inequalities

Research on mobility and transit use found that some populations are more dependent on transit and are therefore more impacted by walkability in the first-mile/last-mile zone. There are generally four sub-groups of the population affected by these mobility inequalities: seniors, low-income populations, visible minorities and youth. Seniors, who are more often unmotorized and faced with economical constraints, rely upon public transportation to stay socially active (24), to gain the autonomy they need to enhance social interactions (25) and to access services (26). Low-income population groups in the Montreal metropolitan area tend to use public transportation more often and have less access to vehicle use (27). This dependency on public transportation due to low automobility has also been demonstrated across the United States by Giuliano (28). It is also worth mentioning that access to transit can lessen the extent to which low-income populations are negatively affected by spatial mismatch, which is defined as a mismatch between where jobs are located and where job seekers live (29). Moreover, Thomas (30) reported that youth and young adults are committed to using public transit rather than cars due to its affordability and that, even when they are old enough, youth and young adult population groups in Quebec have less automobile access than other groups (31). Amar and Teelucksingh (32) study also reveals that immigrants in Toronto rely on public transportation due to structural barriers such as a lack of affordable housing, the location of employment and the lack of opportunity to obtain a driver's license.

In parallel with this literature, several studies have shown that socioeconomic factors are associated with different pedestrian amenities, including traffic-calming measures (33–38). Similarly, many risk factors related to pedestrian safety are overrepresented among certain socioeconomic groups or neighborhoods. For example, there is a higher rate of pedestrian-motor vehicle collisions among lower-income populations (39–41), minority groups (39,40,42,43), children and youth (44,45), and the elderly (46–49). This combination of social and transportation-related disadvantages can lead to what is referred to as transport poverty (50). Transport poverty, in turn, leads to a lack of access to essential goods and services, inadequate planning and decision-making processes and social exclusion that can result in even more social and transportation inequalities.

Environmental justice

Environmental justice is a concept that emerged in the United States in the 1980s to demonstrate that Afro-American populations were more exposed to risk due to their residential proximity to pollution or health hazards (51). Since then, the literature on environmental justice in centered around the three following approaches: (1) environmental equity is interested in the spatial distribution of risks and amenities relative to socioeconomic group (which includes the distribution of environmental benefits and resources across different socioeconomic groups) (52–54); (2) recognition justice arises from the lack of consideration that the authorities (and their policies) demonstrate towards certain groups; (3) procedural justice emerges from a lack of representation or power dynamics in decision-making processes related to environmental implementation.

A safe and walkable environment is critical for transit users—especially vulnerable population groups. As such, it is clear that further research is needed in order to assess the first-mile/last-mile experience, specifically where the notion of mobility inequality is concerned. This paper specifically examines walkability and road risk within the first-mile/last-mile near transit stops in the Montreal metropolitan area using an environmental equity approach.

METHODS

Study area and population groups

The study area is the Montreal metropolitan area, which has a population of 4.05 million inhabitants and spans 4,370 km². This area is serviced by 22,029 transit stops (bus, metro, train: See Table 1), half of which are located on the Island of Montreal (42%), a third (30%) on the Greater South Shore, including the city of Longueuil (16%), 15% on the Greater North Shore and 13% in Laval, which is the second most populated city in the area, 3rd in the province. Data on the transit stops was obtained from the transit authorities servicing the study area (*Société de transport de Montréal*, *Société de transport de Laval*, *Réseau de transport de Longueuil* and *Exo*).

TABLE 1 : Number of stops, by transportation mode

Type of vehicle	# of stops*
Bus	21,763
Metro	275
Train	62

*Some stops include more than one type of vehicle

To study the walkable surroundings, we created a catchment area around each of these stops, based on road network distance: 500 meters in Montreal and 800 meters for other areas. The distance of the catchment area is greater outside of Montreal due to lower population density, which influences the distance that people walk to access transit, as demonstrated in studies by van Soest and al. (55). Figure 1 illustrates an example of a catchment area around a transit stop in Montreal and another on the North Shore (La Plaine). A catchment area was created for each of the transit stops (n=22029).

Figure 1: examples of catchment areas a) in Montreal and b) in La Plaine

As mentioned earlier, this study focuses on four population groups known to be prone to environmental injustice insofar as transport is concerned: (1) low-income populations (2) individuals who identify as visible minorities, (3) young people between the ages of 15 and 24 and (4) people over 65 years of age. We recognized the literature of the vulnerability of people with disabilities when accessing transit, but this population group couldn't be included in this study due to the data unavailability on our territorial scale.

Data on these populations was taken from the 2021 Statistics Canada Population Census, at the dissemination-area level (DA) (56). We identified participants who were considered part of low-income populations using Statistics Canada's Low-income Cut-offs, Before Tax (LICO-BT) measure, which represents income thresholds at which individuals spend 20% or more of their income before tax than the average family on food, shelter and clothing. Visible minorities, for their part, were identified in accordance with Statistics Canada's definition of visible minorities—namely, "persons, other than Aboriginal peoples, who are non-Caucasian in race or non-white in color." Lastly, we used the Statistics Canada Population Census data as is for individuals between the ages of 15 and 24 and for people over 65 years of age.

In order to disaggregate these socio-demographic variables from dissemination areas to transit stop catchment areas, we used a population-based weighting technique proposed by Pham and al. (57) which uses dissemination (city) blocks, considered to be more precise:

$$ti = ta\,\frac{Ti}{Ta}$$

In this formula, ti represents the estimated population of a given group (e.g.: people over 65 years of age) in a city block, ta is this group's population in a dissemination area, Ti is the total population in a city block and Ta is the total population in a dissemination area. City blocks intersecting with transit stop catchment areas were first selected in order to calculate the proportion of each of these groups using the equation provided above. The sum of all these proportions by transit stop catchment area is the final attribute for analysis. Table 2 presents the resulting descriptive statistics for the four population groups we studied.

TABLE 2 : Descriptive statistics of population groups studied in transit stop catchment areas (n=22,029)

	Mean	**SD**	**Median**	**Min**	**Max**
Ages 15 to 24 (%)	10.93	3.02	10.8	0	40.33
Ages 65 years and over (%)	18.37	7.32	17.59	0	68.69
Visible minorities (%)	26.45	16.53	24.03	0	88.57
Low-income populations (%)	6.42	5.31	4.87	0	38.15

Safe and walkable route-to-transit index

To compare the route to access transit as a pedestrian for each population group, we calculated a "safe and walkable route" index with the avalaibled data at the Montreal metropolitan area's scale based on two indicators: a road-risk indicator and a walkability indicator (Figure 2). Table 3 presents the variables included as part of each indicator and their sources. Three variables were chosen for their effect on road safety (8,58,59): road density, presence of major roads and past collisions. Four variables were chosen for their influence on walkability (10,12,13,15): destinations (e.g.: retail stores, services), canopy, intersection density and population density. Before calculating these indices, their variables were weighted using an Analytic Hierarchy Process (AHP). AHP method is one of the Multiple Criteria Decision-Making (MCDM) methods, which are methods used to best meet a variety of criteria (quantitative or qualitative) resulting in an unique objective value. MCDM methods in transportation research offers many benefits : it leads to justifiable and transparent decisions of conflicting or contradictory variables, it organizes and simplify a vast amount of data and, finally, it can be controlled in order to be adapted to the research subject (60). The reviews of literature of Mardani and al. (61) and Yannis and al. (60) reveal that AHP is one of the most utilized MCDM method in transportation research, notably due to his adaptability to diverse subjects, therefore beign the best choice for this project. The AHP was used by pairwise comparison using Saaty's scale (62) (1 = equally important, 3 = moderately more important, 5 = strongly more important, 7= very strongly more important, 9 = extremely more important). The comparison matrix was completed by 3 graduate students and a professor, all of whom are members of *Laboratoire piétons et espaces urbains* at *Institut national de la recherche scientifique.* Input for the weighting process, provided by experts in this field of study, was extracted from the literature (63). Finally, to calculate these indicators using the z-scores of the variables, we subtracted the road-risk indicators (negative) from the walkability indicator (positive):

$$Transit\ Access\ Index = (Walkability\ indicator * 0.46) - (Road\text{-}Risk\ indicator * 0.54)$$

TABLE 3: Indicator's variables, weighting and sources

Indicator's weight	**Indicator**	**Variable's weight**	**Variable**	**Definition**	**Data source**
0.54	Road risks	0.04	Road density	# of km of road in a transit catchment area	DMTI spatial
		0.47	Major Road	Proportion of major road (Primary Highways, Secondary Highways and Major Roads) on the road network per area	DMTI spatial
		0.49	Collisions	Proportion of road collisions involving a vehicle on kilometers of a road (2011–2020)	*Société de l'assurance automobile du Québec* (SAAQ)
0,46	Walkability	0.33	Destinations	Number of Destinations per area	*Adresses Québec*
		0.11	Canopy	Proportion of the transit catchment area that is covered by a canopy higher or equal to 2 meters (2021)	*Communauté métropolitaine de Montréal*
		0.40	Intersections	Proportion of intersections of two or more streets per km²	*DMTI spatial*
		0.16	Population density	Density of population per km^2	Statistics Canada

Analysis

Our methods are inspired by the Carrier and al. (64) study in which several statistical tests were conducted using the same four population groups. First, we used a *t* test to compare the extreme quintiles (Q1 and Q5) of each population in order to evaluate the association of each group to the safe and walkable route-to-transit stop index and its two underlying indicators (each separately). Second, to address the spatial dependency of our data, we used two spatial regressions based on the results of the Lagrange Multiplier test: spatial lag and spatial error models (65). The dependent variables in these three regression models (safe and walkable route-to-transit index, road-risk indicator and walkability indicator) were normalized using the *bestNormalize* package in R (66). This package performs multiple normalizing transformations and selects the best one based on a Pearson *P* test divided by its degree of freedom for normality. For each dependent variable, the Ordered Quantile normalization was the most effective (67). The proportions of the four sub-groups were used as independent variables to determine if there were any significant associations between the dependent variable and these population groups once we controlled for the three other groups. The *t* tests were computed in R using the doBy library (68) and the spatial regressions were computed in R using the spatialreg library (69).

RESULTS

Analysis and mapping of the safe and walkable route-to-transit index

The safe and walkable route-to-transit index in transit stops catchment areas ranges from -2.16 to 7.09 (least advantageous access to most advantageous access), the road-risk indicator ranges from -1.07 to 4.77 (least road risk to most road risk) and the walkability indicator ranges from -0.99 to 16.87 (least walkable to most walkable). As shown in Figure 2, the least favourable safe and walkable access routes to transit are located near major roads. The transit stops that are located closer to Montreal's central neighborhoods have an increased walkability indicator, so do road risks. Outside of Montreal, many major roads—such as the transit stops on service roads alongside Highway 10 in Longueuil and on the South Shore, and alongside Highway 25 and Highway 15 in Laval and on the North Shore—have both low walkability and high road risks.

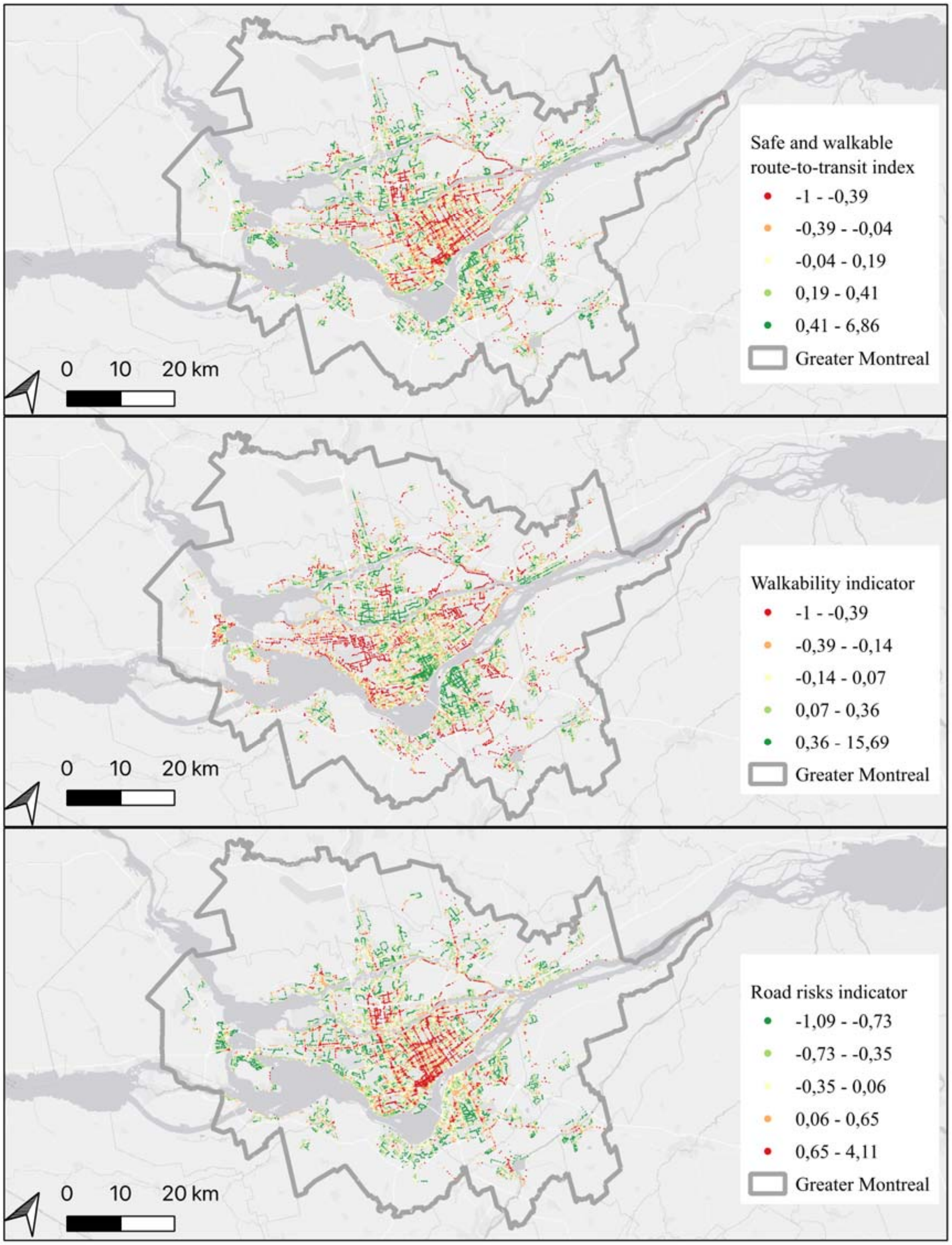

Figure 2: Indices for safe and walkable route to transit (top) walkability (middle) and road risks (bottom)

Comparison of extreme quantiles for each population group

The results comparing transit to the most disadvantaged populations (Q1) as well as to the least disadvantaged populations (Q5) are shown in Table 4. Where the safe and walkable route-to-transit index is concerned, we can observe that the means decrease for visible minorities and low-income populations (highest decrease). This indicates that transit stops with a higher proportion of these two population groups have a worse route-to-transit index score compared to transit stops with a lower proportion. The opposite is true for the population between the ages of 15 and 24 and over 65 years old, since the difference between Q1 and Q5 is positive: there is a better route-to-transit index score for the transit stops in the quintiles with the highest proportion of this population.

TABLE 4 : Comparison of the first and last quintiles of the studied groups for safe and walkable route to transit

	Safe and walkable route-to-transit index			
	Mean		**Difference**	
Population Groups	**Q1**	**Q5**	**Difference**	**p value**
Ages 15-24	-0.020	-0.089	0.069	0.000
Ages 65 and over	0.034	0.039	0.005	0.000
Visible minorities	-0.215	0.106	-0.321	0.000
Low-income populations	-0.272	0.126	-0.398	0.000
	Road-risk indicator			
	Mean		**Difference**	
	Q1	**Q5**	**Difference**	**p value**
Ages 15-24	0.053	0.095	-0.042	0.000
Ages 65 and over	0.118	-0.057	0.175	0.000
Visible minorities	0.367	-0.260	0.627	0.000
Low-income populations	0.637	-0.403	1.040	0.000
	Walkability indicator			
	Mean		**Difference**	
	Q1	**Q5**	**Difference**	**p value**
Ages 15-24	0.018	-0.082	0.100	0.000
Ages 65 and over	0.065	-0.152	0.217	0.000
Visible minorities	-0.037	-0.074	0.037	0.892
Low-income populations	0.156	-0.199	0.355	0.000

Spatial regressions of the population groups

In order to test for spatial dependence in our data, we used Ordinary Least Squares (OLS) regression and calculated the Moran's I of the residuals. As shown in Table 5, all dependent variable residuals are significantly spatially autocorrelated. We therefore used a Lagrange Multiplier test and a Robust Lagrange Multiplier test to assess which spatial regression fit the data (65). Since all of these tests were statistically significant, we then computed spatial lag and spatial error regression. Following this, the spatial regression which best minimized Akaike's Information Criterion (AIC) was chosen.

TABLE 5 : Ordinary Least Squares Regression and Lagrange Multiplier Test Statistics

	Safe and walkable route-to-transit index	Road-risk indicator	Walkability indicator
R2	0.1712***	0.2848***	0.1412***
adjusted R2	0.1711	0.2846	0.1410
F statistic	1137 on 22004 DF	2190 on 22004 DF	0.9259 on 22004 DF
AIC	58327.89	55042.00	59078.29
Moran's I (error)	0.746***	0.727***	0.775***
LM (lag)	68573.36***	59450.27***	73816.90***
LM (error)	70909.30***	64095.67***	3107.55***
RLM (lag)	18.30***	162.28***	320.56***
RLM (error)	2354.24***	4807.68***	3107.55***

Note: p is obtained with a randomization procedure (999 permutations). OLS = Ordinary Least Squares; AIC = Akaike's Information Criterion; LM = Lagrange Multiplier; RLM = Robust Lagrange Multiplier. Moran's I is calculated using a row standardized distance band matrix of 500 meters. 18 observations have been removed due to isolation in the spatial weight matrix (n=22016).
* p < 0.05
** p < 0.01
*** p < 0.001

The results of the spatial lag and spatial error regression indicate that visible minorities and low-income populations are disadvantaged when it comes to the safe and walkable route-to-transit index, those between the ages of 15 and 24 are at an advantage, and those ages 65 and over have no significant advantage (Table 6). The *z values* indicate that the conditions of low-income populations make them less likely to have access to safe and walkable route-to-transit stops. Where the road-risk indicator is concerned, visible minorities, low-income populations and people ages 65 and over are overexposed to risk. Once again, low-income populations are the ones who experience the most road safety hazards along their walking routes to transit stops. The walkability indicator increases for those ages 15-24 as well as for those ages 65 and over and for low-income population groups but decreases for those who identify as visible minorities. Finally, we observed that the spatial lag and spatial error regression improved our models by decreasing the AIC and the spatial autocorrelation of the residuals.

TABLE 6: Spatial lag and spatial error regression

	Safe and walkable route-to-transit index	**Road risks**	**Walkability**
Intercept	-0.060 (-1,148)	-0.173 *** (-3,421)	-0.154 ***(-11,500)
Ages 15-24	0.052 *** (15,616)	-0.043 *** (-13,504)	0.009 *** (9,037)
Ages 65 and over	-0.002 (-1,441)	0.003 ** (3,137)	0.002 *** (6,404)
Visible minorities	-0.008 *** (-8,184)	0.006 *** (6,183)	-0.001*** (-4,652)
Low-income populations	-0.043 *** (-13,194)	0.048 *** (15,563)	0.003 *** (4,916)
Lambda (error)	0.932***	0.934 ***	
Rho (lag model)			0.928 ***
AIC	28029	25883	26190
AIC (difference with OLS model)	-30299	-29159	-32888
Moran's I (error)	0.080	0.075	0.050

Note: Coefficients are written with z values in parentheses. p is obtained with a randomization procedure (999 permutations). OLS = Ordinary Least Squares; AIC = Akaike's Information Criterion.
Moran's I is calculated with a row standardized distance band matrix of 500 meters. 18 observations have been removed due to isolation in the spatial weight matrix (n=22016).
* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$

DISCUSSION

This paper examines the walkability and road risk within the first-mile/last-mile area near transit stops through the creation of a route-to-transit index measuring safe and walkable routes. Using an environmental equity approach, we found that individuals who identify as visible minorities have a less walkable route to transit, but low-income population, people between the ages of 15 and 24 and people ages 65 and over lived in areas with a better walkability score for accessing transit stops. These surprising results for the three latter populations are in line with the studies conducted by Bereitschaft (70) in the 106 most populous United States Metropolitan statistical areas (MSA), where he found a positive association between socially vulnerable urban populations and neighborhood walkability. However, Bereitschaft (70) reported a significant inter-metropolitan variation in access to walkable space which suggests that, in some American metropolitan areas, populations that were highly socially vulnerable were less likely to live in a walkable neighborhood. On the other hand, Doiron and al. (71) found that, when applying both the material and social deprivation index, high walkability was more common in the least deprived areas. That said, it is important to keep in mind that, in comparison with our research, this study does not address an entire metropoliltan area, but rather addresses the city of Montreal only. It also does not specifically address the route to transit stops. Finally, our results also show that three out of four of our studied population groups faced more road risks on their walking route to transit stops. Similarly, Roll and McNeil (39) reported that, in Oregon, race and income were positively correlated with pedestrian injuries even after controlling for traffic exposure and built environmental factors. The literature review of Stoker and al. (44) highlights the overexposure of elderly and low-income population.

Our results also indicate that most walkable transit stops also have higher road risk. This is consistent with the literature, since higher walkability scores are associated with more accidents involving pedestrians (72,73). Moreover, the study conducted by Miranda-Moreno, Morency and El-Geneidy (74) in Montreal demonstrates that having built environments that increase walkability is also associated with more pedestrian activity, which often translates to increased exposure to risk and potentially more collisions involving a pedestrian. These authors suggest that safety strategies and actions are needed to mitigate this effect and, as the literature has shown, these strategies are now lacking in disadvantaged areas (33,34,38).

Research limitations

To the best of our knowledge, our article innovates by combining walkability and road risk in an index to capture what is happening near transit stops, specifically in the first-mile/last-mile zones. There are still, however, certain limitations to our results. First, although it is common among studies using a walkability index to proceed with z-standardized variables due to different metrics (75), this can also be viewed as a limitation. It should also be noted that we normalized the dependent variables in the spatial regression models. Another limitation can be observed in the analysis of extreme quantiles. As noted by Carrier and al. (64), who also used this statistical test, the first and the last quintiles are arbitrary thresholds that do not necessarily reflect the largest concentration of vulnerable populations. We chose this test due to its widespread use in the literature but could instead have opted for spatial segregation indices to identify the extreme concentration of vulnerable population groups surrounding transit stops. Further research is needed to examine walking routes to transit, particularly in spatially segregated neighborhoods.

CONCLUSION

The experience of walking to transit stops plays a critical role in the use of public transportation. Having a safe and walkable environment for this part of the trip is even more important for vulnerable population groups, who depend more heavily on public transportation. The aim of this paper was to evaluate first-mile/last-mile walkability and road risks in the Montreal metropolitan area using an environmental justice approach. Using a spatially sound method, we determined that areas in which a greater number of people identify as visible minorities are disadvantaged in terms of walking-to-transit routes and that areas with low-income populations and people ages 65 and over have more walkable environments but also have to deal with more road risk.

Moving forward, it would be relevant to use other walkability methods, such as walkabout interviews or on-site walkability audits, to address these issues. This would enable the gathering of complementary knowledge of the walking trip to access transit stops, from subjective experiences to the mapping of microscale walkability features. Our work helps reach a better understanding of pedestrian issues within the first-mile/last-mile zone, which is important for ensuring better mobility equity as well as a shift towards more sustainable transport modes such as walking and public transportation.

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AUTHOR CONTRIBUTIONS

The authors confirm contribution to the paper as follows: study conception and design: M.-S. Cloutier and P. Brodeur-Ouimet; analysis and interpretation of results: P. Brodeur-Ouimet; draft manuscript preparation: P. Brodeur-Ouimet and M.-S. Cloutier. All authors reviewed the results and approved the final version of the manuscript.

DECLARATION OF CONFLINCTING INTERESTS

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