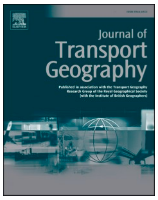
Journal of Transport Geography 114 (2024) 103788

Contents lists available at ScienceDirect

Journal of Transport Geography

journal homepage: www.elsevier.com/locate/jtrangeo



Sociodemographic matters: Analyzing interactions of individuals' characteristics with walkability when modelling walking behavior

Lancelot Rodrigue, Ahmed El-Geneidy *, Kevin Manaugh

McGill University, Canada

ARTICLE INFO

Keywords:
Walkability
Walking
Socio-demographic
Equity
Walk Score©
MAPS-Mini

ABSTRACT

The concept of walkability encompasses a multitude of features of the built and social environments that impact walking behavior, leading to the creation of a wide range of walkability indices. While past studies have compared the research outputs from multiple walkability indices, little research has looked at how relevant each index is across sociodemographic groups and how the relationship between sociodemographic characteristics and behavior vary from one index to another. Using trip data from Montréal, Canada, this paper evaluates two commonly used walkability indices at different scales – Walk Score© (meso-scale) and the MAPS-Mini audit tool (micro-scale) – and their interactions with sociodemographic characteristics. Weighted binary logistic regressions are used to model the probability of adults taking a homebased utilitarian walking trip. A total of ten models are generated, including eight models in which one of four socio-demographic variables – gender, age, household income, and presence of children below 13 years old in the household – is interacted with one of the two walkability indices. Sensitivity analyses are then conducted using the interaction variables' outputs by varying the values of the interacted sociodemographic variable. Results show significant interactions for all variables for both indices except from Walk Score©'s interaction with gender. Opposite effects are observed between the two indices in the sensitivity analysis for household income. The differential results observed between the indices and between sociodemographic groups underscore the need to properly test the equity implication of using certain walkability measures in research.

1. Introduction

The definition of walkability has long been debated by researchers. While no consensus has emerged, walkability can be broadly conceptualized as features of the physical and social environment that can promote walking as a mode of transport (i.e. purposive walking) or as an activity in itself (i.e. discursive walking) (Tobin et al., 2022). The way researchers and policy makers conceive of walkability as a concept reflects different preoccupations and policy goals, leading to a plurality of definitions that can often be incongruent with one another (Forsyth, 2015; Shashank and Schuurman, 2019). A wide variety of walkability indices have been developed to summarize characteristics of the built and social environment relevant to walking behavior, each integrating different set of variables. This variability in indices has been shown to lead to contrasting or even contradictory geographical patterns of "highly walkable" and "poorly walkable" areas (Shashank and Schuurman, 2019). While past studies have tested a multitude of walkability indices to compare how well they reflect walking behavior (Liao et al., 2020a; Manaugh and El-Geneidy, 2011; Shashank and Schuurman, 2019), these analyses have not readily integrated pedestrians' sociodemographic characteristics into the comparison process. Such a step is crucial considering that several studies have shown that the relative importance of factors influencing walking behavior vary with gender (Hidayati et al., 2020), age (Stafford and Baldwin, 2018), income (Manaugh and El-Geneidy, 2011) and multiple other socio-demographic factors. This is attributable to the subjective importance of features of the built and social environments on walking behavior, which is influenced by individuals' positionality within society (Adkins et al., 2019; De Vos et al., 2023). A previous review article has highlighted how the overlook of sociodemographic characteristics when assessing the impact of the built environment on walking behavior might have contributed to inefficient planning interventions aimed at promoting walking (Adkins et al., 2017).

Given this context, we hypothesize that *a walkability index will reflect walking behavior differently for different social groups*. Given the differences between walkability indices observed in past research (Liao et al.,

---

* Corresponding author.
E-mail addresses: lancelot.rodrigue@mail.mcgill.ca (L. Rodrigue), ahmed.elgeneidy@mcgill.ca (A. El-Geneidy), kevin.manaugh@mcgill.ca (K. Manaugh).

https://doi.org/10.1016/j.jtrangeo.2023.103788
Received 24 May 2023; Received in revised form 18 December 2023; Accepted 22 December 2023

2020b; Manaugh and El-Geneidy, 2011; Shashank and Schuurman, 2019), we also hypothesize that *different indices will reflect walking behavior for the same sociodemographic group differently*. This study tests these hypotheses by modelling purposive walking while using two commonly used walkability indices – one at the micro-scale (i.e., street or intersection level) and one at the meso-scale (i.e., small areal level). We then interact the walkability indices with four socio-demographic variables: gender, age, household income and the presence of children below 13 years old in the household to highlight the differential impacts. Through this study, we aim to build upon previous studies that critically compared indices used in walkability research (Liao et al., 2020a; Manaugh and El-Geneidy, 2011; Shashank and Schuurman, 2019) by showing how different walkability indices can reflect walking behavior of sociodemographic groups to a different extent. We also aim to contrast such findings between walkability indices at different scales (i.e., micro-scale and meso-scale). Findings from this study will be of value to researchers in the transport and public health fields as they aim to create and use an umbrella of walkability tools that can reflect the factors influencing the walking behavior of several sociodemographic groups.

2. Literature review

Walkability research has been and continues to be animated by debates surrounding the exact definition of the concept of "walkability", what elements it should consider and what goals it should represent (Forsyth, 2015; Shashank and Schuurman, 2019; Tobin et al., 2022). As a result of these divergent views of what walkability ought to be, a wide variety of indices have been elaborated to synthesize some of the features that influence walking behavior into numerical values. Walkability indices can be for the most part categorized into two categories based on the geographical scale of the features they consider: meso-scale or micro-scale.

Meso-scale walkability indices synthesizes features of the built and social environment at a small areal scale such as postal code areas, census tracks or small neighborhoods (Bivina et al., 2020). By considering an area, these indices can integrate density variables in their calculations (e.g., population density, destination density or intersection density) or other statistics summarized at a specific areal level (e.g., criminality). Other variables that can be incorporated in meso-scale walkability indices include land-use mix or accessibility measures among others (Fonseca et al., 2021). Beside the use of some of these variables directly as proxies for walkable environments, there also exist composite meso-scale indices such as Walk Score©, which incorporates block length, intersection density and gravity-based accessibility to a fix set of destination (Hall and Ram, 2018), or Frank et al. (2010)'s walkability index which combines population density, retail floor area ratio, intersection density and land use mix. Meso-scale walkability indices rely primarily on large-scale, more commonly available data pertaining to the practicality of the built environment for walking (e.g., accessibility by walking, road network connectivity), making them more widely used in research (Fonseca et al., 2021).

On the opposite end, micro-scale walkability indices provide a synthesis of the pedestrian-friendliness of the built environment at the street or intersection level. These indices can include elements pertaining to the sidewalks (e.g., presence, width, buffers, maintenance), crosswalks (e.g., types, ramp at the curb), street amenities (e.g., streetlights and benches), and tree cover among other things (Bivina et al., 2020). They can also, in some cases, report elements pertaining to usage of the built environment (e.g., social interactions, number and characteristics of road users (Boarnet et al., 2011; Cain et al., 2012; Day et al., 2006). Street- and intersection-level factors have shown to impact pedestrian behavior primarily by influencing the quality (e.g., pleasantness, comfort, feeling of safety) of their walking experience (Clifton and Livi, 2005; Jensen et al., 2017; Lee and Dean, 2018). Due to the nature of these features of the built environment, micro-scale indices are collected through audit processes, which can be rather time-consuming. Examples of micro-scale walkability indices include the Irvine Minnesota Inventory (Boarnet et al., 2011; Day et al., 2006) as well as the MAPS audit tool which comes in three different formats: MAPS, MAPS-abbreviated and MAPS-mini (Cain et al., 2017; Cain et al., 2012; Sallis et al., 2015). Among those, the MAPS-Mini audit tool, which consists of 15 items, is the one that has been used the most frequently in research in recent years (Bartzokas-Tsiompras et al., 2021; Bartzokas-Tsiompras et al., 2020; Daley et al., 2022; Rodrigue et al., 2022).

Walkability indices are first and foremost made to synthesize features of the built environment deemed to be important in shaping walking behavior. However, the choice of which features to include and which weight to give to each component is dependent on the ability of the final index to adequately capture walking behavior. While common walkability indices have passed the test of statistical validity, they can still be limited in their ability to capture walking behavior given their limitations to only a subset of relevant features of the built environment (Boarnet et al., 2011; Consoli et al., 2020; Hall and Ram, 2018; Herrmann et al., 2017; Sallis et al., 2015; Shashank and Schuurman, 2019; Tuckel and Milczarski, 2015).

Past research comparing multiple walkability indices have highlighted differential capacities to contribute to the modelling of walking behavior (Manaugh and El-Geneidy, 2011) and variable geographical patterns of high and low walkability (Shashank and Schuurman, 2019) from one index to another. Such findings have highlighted the need to justify the choice of a walkability index more carefully in a research context. Still, these studies have relied mostly on meso-scale indices, meaning that there is currently a gap in the literature regarding comparisons of micro-scale and meso-scale walkability indices. This study will aim to fill part of this gap by contrasting commonly used micro-scale and meso-scale walkability indices.

Another shortcoming of the current literature comparing walkability indices, is that they have not readily integrated pedestrians' socio-demographic characteristics into the comparison process, despite a growing burden of evidence of their importance in shaping individuals' walking behavior (Hidayati et al., 2020; Stafford and Baldwin, 2018). A narrative-based review by Adkins et al. (2017) summarized inequities in the effect of the built environment (mainly characterized through meso-scale walkability indices) on walking behavior along income, ethnicity and education axes. The authors found a weaker effect of the built environment for disadvantaged groups in 13 of the 17 studies reviewed. A few of the studies reviewed showed that people with lower incomes are more likely to walk in areas with low walkability (Manaugh and El-Geneidy, 2011; Steinmetz-Wood and Kestens, 2015). Adkins et al. (2017) highlighted in their review that the current focus of planning practices on deriving built-environment fixes without sociodemographic contextualization might have led to ineffective interventions aimed at increasing the prevalence of walking in a neighborhood.

In terms of gendered differences, past studies have shown contrasting effects when analyzing the effect of walkability, as denoted by different indices, on women's walking behavior (Golan et al., 2019; Kelley et al., 2016; Twardzik et al., 2019). Another study showed a larger increase in the frequency of walking for women than for men following an improvement of the pedestrian-scape of a street (Jensen et al., 2017). These effects have been linked in parts to women being more likely to allocate more importance towards perceived safety – both in term of crime and traffic – in their decision to walk or not (Clifton and Livi, 2005; Hidayati et al., 2020). Persistent gendered distribution of mobilities of care have also been highlighted as limiting factors to women's mobility options, impacting primarily their ability to use active transport (Craig and van Tienoven, 2019; Grant-Smith et al., 2017; Ravensbergen et al., 2022).

Age is another a crucial sociodemographic factor that has been shown to influence walking behavior (Stafford and Baldwin, 2018). For instance, older adults have been shown to be less likely to walk than adults of other age groups (Curl and Mason, 2019; Stafford and Baldwin, 2018; Wasfi et al., 2017), with differential impacts of the built environment being observed between age groups (Liao et al., 2020b; Stafford and Baldwin, 2018). Fear of falling (Curl et al., 2020), avoidance of risky or uncomfortable environments (Dean et al., 2020) as well as extreme urban density and land-use mix (Cheng et al., 2020) have all been negatively linked with older adults' walking behaviors while micro-scale features such as tree cover and sidewalk conditions have been positively associated to walking behavior for this demographic (Lee and Dean, 2018). On the other spectrum of age, several studies have shown that the primary limiting factors that dictate active transport behavior in children and subsequently other household members, are parents' fears and concerns, not walkability (Carver et al., 2013; Chillón et al., 2014; Curtis et al., 2015; Foster et al., 2014; Lang et al., 2011; McMillan, 2007; Ye et al., 2018).

These differentiated walking behaviors have been sparsely integrated into walkability measures through participatory processes to generate sociodemographic-sensitive walkability tools (Golan et al., 2019; Moura et al., 2017). However, such tools remain underused compared to more typical, objective walkability indices, likely due to their high resource intensity which can hinder their rapid transferability to a large range of sociodemographic groups and across varied geographical contexts. As such, it is crucial to not solely elaborate new sociodemographic-sensitive walkability tools from scratch, but to also better understand how currently used measures explain walking behavior for different sociodemographic groups. While past studies have assessed the capacity of a specific feature or index of the built environment to influence the decision to walk or not for a given sociodemographic group, to our knowledge, no past studies have simultaneously considered multiple sociodemographic characteristics and contrasted their interaction with walkability measures at different scales. Understanding the underlying sociodemographic assumptions behind widely use walkability index could facilitate the change towards more sociodemographic-sensitive walkability by allowing for modifications of such tools rather than their complete replacement.

3. Methodology

3.1. Data

Data for this study were collected in Montréal, Canada. Two commonly used walkability measures, Walk Score© and the MAPS-Mini audit tool, were used to represent objectively measured meso- and micro-scale walkability respectively. Walk Score©, which is a composite index reflecting block length, intersection density and gravity-based accessibility to a fix set of destination (Hall and Ram, 2018) is one of the most commonly used meso-scale walkability index in the academic literature thus justifying its choice. The MAPS-Mini Audit tool is a validated street level audit tool commonly used by public health professionals – which describes features that pedestrians directly interact with while walking (Daley et al., 2022; Sallis et al., 2015). The MAPS-Mini audit tool therefore presents the opportunity, in theory, to be able to reflect factors influencing both purposive and discursive walking behavior but primarily in term of walking experience. MAPS-Mini data were collected as part of a built environment audit conducted by the authors within a 1 km service area around 25 new light-rail train (LRT) stations in Montreal, Canada (Fig. 1). Service areas were used to represent a realistic 'walkshed' (i.e., the area around a location within which people are expected to be able to walk to the location) around each station. In total, 2497 street segments were audited using an adapted version of the MAPS-mini audit tool. Data collection took place between May 25th to July 1st, 2021, and May 5th and June 10th, 2022 and required a total of 650 h from 18 auditors who were all trained prior to the audit on the collection of the objective data.

Trip level data from the 2018 Montréal Origin-Destination (O—D) survey were used in the analysis. The O—D survey, which is conducted every five years by the regional public-transit planning agency in the Montréal Metropolitan Region collects a travel diary record covering all household members' trips on the previous day for a random sample of 5% of the households in the region. Expansion factors – which are weights assigned to each observation in a dataset to allow to expand the sample at the population level – are then derived for each trip, person, and household to allow for representative analyses.

Trips from the O—D survey ($n = 393, 826$) were first filtered to get to the comparable regional sample ($n = 141{,}102$). First, trips that had missing origins or destinations or that had either of those located outside of the Montréal Census Metropolitain Area (CMA) were removed ($n = 104{,}206$). Then all those conducted by modes other than walking, cycling, public transit, or car (i.e., school bus, inter-regional buses, other) ($n = 16{,}910$) were removed since accurate travel times could not be calculated (Birkenfeld et al., 2023). Additionally, trips made by

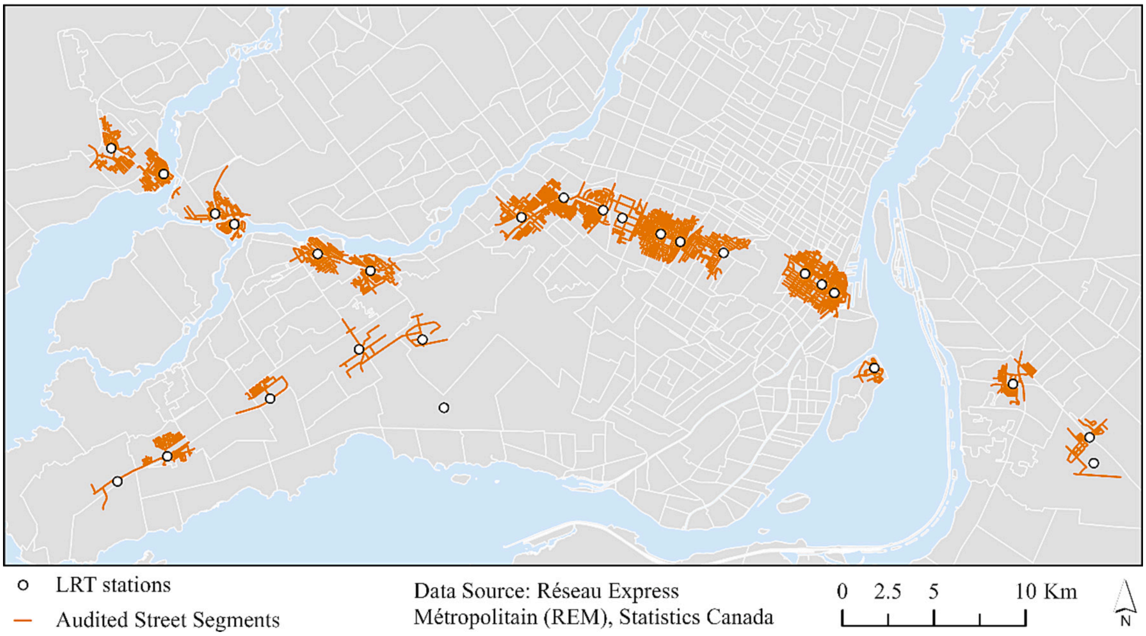


Fig. 1. Street segments audited around new LRT stations in Montréal, Canada, using the MAPS-Mini audit tool.

children below 18 years old (n = 32,776) were removed as factors influencing their propensity to walk have been shown to differ from adults (Chillón et al., 2014; McMillan, 2007), which could affect the relationship between age and the built environment. At this point, a trip chaining dummy variable was derived based on whether the trip in question was part of a succession of trips starting each from the end location of the previous one. After that, only home-based trips were kept leading to a region-wide sample of 141,102 trips with which regional-level descriptive statistics were calculated.

To obtain the sample for analysis, we kept only trips from households falling within the 1-km service areas around the REM stations (Fig. 1) and that had reported a usable answer for all variables of interest (n = 2964). Lastly, one trip was randomly selected for each person to avoid having them appear more than once in the sample as this would have required a multi-level modelling approach which would have masked the effects of individual-level characteristics (Manaugh and El-Geneidy, 2011). This choice is supported by the fact that 77.9% of respondents in the final sample reported only one homebased trip. The final sample is composed of 2352 actual trips realized by 2352 different individuals from 1430 different households.

Using the final sample of trips, a weighted average of the MAPS-Mini score was calculated using all audited street segments reachable in a 400-m network distance from the home location. It was assumed that the audited streets were representative of the neighboring built environment. The MAPS-Mini audit score – a score between 0 and 21 – was then weighted based on the total length of each street segments relative to the total street network within the 400-m service area around a household and averaged. Values were subsequently normalized using the maximum value in the sample to correct the right-sided skewness of the data (Fig. 2). For Walk Score©, values at the household location were collected through an online API. Contrarily to the MAPS-Mini score, the distribution of the Walk Score© values was closer to a normal distribution. Both MAPS-Mini and Walk Score© values were converted to be on a scale from 1 to 10 to allow meaningful comparison. Other built-environment characteristics such as job and population density were left out of the model due to being highly correlated with Walk Score©.

Walking travel times were calculated along the street network, obtained from open street maps, using the routing package r5r (Pereira et al., 2021) in R with a walking speed of 4.5 km/h (Silva et al., 2014). These travel times were calculated for all O—D pairs, no matter what mode was actually used for the trip, meaning that this variable represents how long it would have taken if the trip had been done by walking, whether it was actually done by walking or not. Trip purpose data from the O—D survey were aggregated as being either work, school, shopping or other. Household level characteristics considered included household size, the number of cars, as well as the presence of children in the household. Household income which was reported in $30,000 increments in the O—D survey was also used, but for the purpose of the statistical models, it was combined into five classes. Lastly, while age and walking travel times are reported in years and minutes respectively in Table 1, they were both divided by 10 in the statistical models resulting in coefficient reported being for marginal increases of 10 years in age and 10 min in walking travel times. Complete descriptive statistics of the sample are displayed in Table 1 (continuous variables) and Table 2 (non-continuous variables).

It should be noted that the O—D survey has been recording sex, not gender, since it first inception in the 1970s. However, the primary pathways explored to explain the observed difference between women and men in travel behaviors are mostly structured around the social construct of gender and not biological sex differences (Clifton and Livi, 2005; Hidayati et al., 2020; Ravensbergen et al., 2022; Shirgaokar, 2019). As such, while the available data only records sex, since 99.67% of the Canadian population identifies as cis-gendered (Statistics Canada, 2022), we assumed gender to be concordant to self-declared sex for this analysis. Furthermore, some variables relevant to walking behavior such as ethnicity, disability status, educational attainment, attitudinal characteristics towards travel, stated perceptions of the built environment as well as weather at the time of the trip were not collected in the 2018 Montréal Origin-Destination survey. While some of these variables are omissions from the survey (i.e., ethnicity, disability status, educational attainment), most of them are rarely collected in large-scale Origin-Destination surveys. Lastly, aside from the partial closure of a few streets between 2018 and 2021 due to the construction of the LRT around which the MAPS-Mini data was collected, we can reasonably assume that the street-level built-environment is consistent between 2018 (when the O-D-survey was collected) and 2021–2022 (when the MAPS-Mini data was collected). This assumption is supported by past research within the study area looking at planning policy changes that showed limited implementation of policy changes between 2016 (when the LRT project was announced) and 2022 (Soliz et al., 2023).

Table 1
Mean values of continuous model variables.

Variables	Sample (n = 2352)	Region (n = 141,102)
Trip-level characteristics		
Walking travel time (Minutes)	90.9	98.9
Person-level characteristics		
Age (Years)	49.0	46.0
Household-level characteristics		
Household size (Count)	2.7	2.4
Household cars (Count)	1.4	1.4
Walkability indices		
Walk Score (Normalized)	5.8	–
MAPS Mini Score (Normalized)	5.3	–

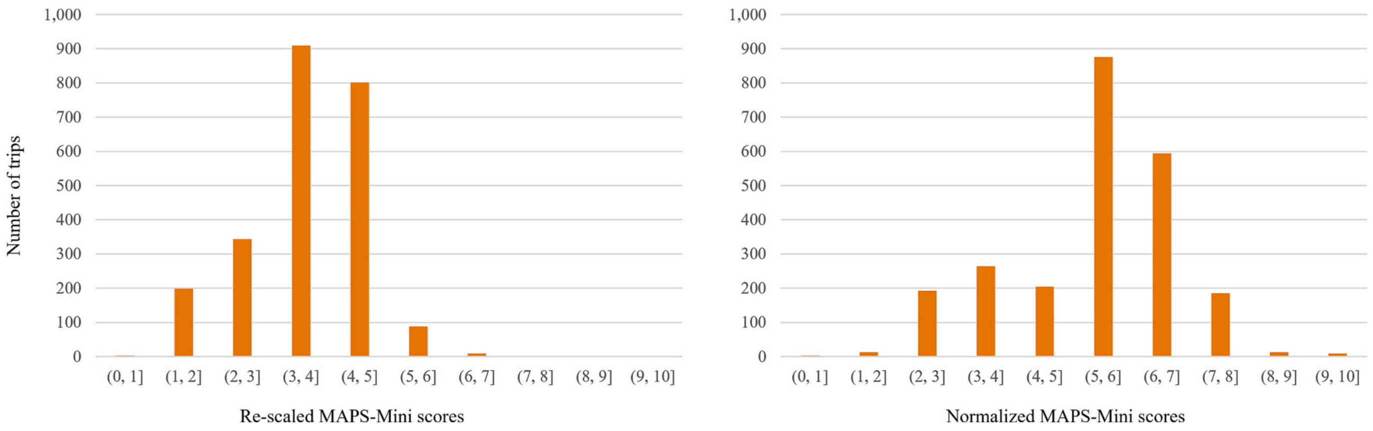


Fig. 2. Distribution of the re-scaled MAPS-Mini scores (left) and normalized Maps mini score relative to the maximal value in the sample (right) for the 2352 trips retained.

Table 2
Descriptive statistics of categorical model variables.

Variables	Sample (n = 2352)	Region (n = 141,102)
Dependent variable	%	%
Trip done by walking	14.2	8.7
Independent variables		
Trip-level characteristics		
Trip Purpose		
Work	49.2	42.8
School	9.9	7.5
Shopping	12.0	15.5
Other	28.9	34.2
Trip chaining (Binary)	19.5	21.5
Person-level characteristics		
Gender (Women)	50.3	51.5
Has a Transit pass	31.9	27.8
Household-level characteristics		
Presence of children under 13 (Binary)	20.7	22.7
Household Income		
$0 - $30,000	12.5	17.0
$30,000–$60,000	21.3	27.2
$60,000–$90,000	18.7	21.5
$90,000–$150,000	24.4	23.6
$150,000 +	23.2	10.7

3.2. Analysis

Expansion factors derived from socio-demographic and travel flow data are used in travel behavior surveys to weight the sample to the broader population and ensure its representativeness. Using the trip-level expansion factors from the O—D survey, weighted binary logit models were computed in R with the glm function to model the probabilities of having taken a home-based trip by walking. It was decided to use a single-level model given the goal of the analysis to assess the influence of individual, household and built environment characteristics on the choice of walking for a trip and given the structure of the data (i.e., It should be noted that the 2018 O—D survey only recorded walking as a mode when it was the only mode use in a trip. As such walking to another mode is not included in the dependent variable.

The validity of the inclusion of each variable in the models was tested by computing the Variation Inflation Factor (VIF). In order to evaluate the differential effect of local accessibility and the micro-scale built environment across person and household level characteristics, interactions variables were modelled between the characteristics of interest and the walkability indices used – Walk Score© and the MAPS-Mini audit tool. Each interaction was inputted into a separate model using the same set of control variables present in the original models. For all 10 models generated, Tjur R^2 is reported in addition to the log likelihood to assess the fit of the models (Tjur, 2009). For each interaction variables, a sensitivity analysis was generated by varying the value of the interacted socio-demographic variable (e.g., different ages, household income levels). All other independent variables were fixed at their mean except for walking travel time which was fixed at 15 min to reflect a realistic walking time. Probabilities to walk were then calculated and graphed for each interaction variables.

4. Results

Descriptive statistics of the continuous and categorical and variables included in the models are presented in Table 1 and Table 2 respectively. Walking trip were more frequent in the sample used (14.2%) than region-wide (8.7%). The main independent variables that differed notably between the sample and the region relate to the household income. The sample used for the analysis has an overrepresentation of higher income individuals and an underrepresentation of lower-income groups which is coherent with the demographic in the study area as highlighted in previous research (Daley et al., 2022). Other independent variables that showed notable differences with the regional values are the share of working trips (6.4% higher in the sample), the share of trips for other purposes (5.3% lower in the sample) and transit pass ownership (4.1% higher in the sample). The implication of these variations from the regional context will be discussed further in the discussion.

Results from the base linear logit model (Table 3) reveal that all predictors – aside from a trip being for shopping in both models and for school in the Walk Score model – had a statistically significant effect at the 5% level on the probability of taking a homebased trip by walking. The directionality of these significant effects was the same between both models regardless of the walkability index used. Walk Score© allowed for a slightly better fitted model (Tjur $R^2 = 0.488$, log likelihood = −13,763) than the MAPS-Mini audit tool (Tjur $R^2 = 0.475$; log likelihood = −13,923). Similar observations in terms of the models' goodness of fit hold for each other pair of models.

In terms of trip characteristics, the odds of taking a trip by walking were 49% higher for work trips than for other utilitarian trips in the Walk Score© model and 61% higher in the MAPS-Mini model, ceteris paribus. School trips had 11% lower odds of being done by walking for the MAPS-Mini model, holding other variables constant, while no significant effect was observed for the Walk Score© model. Every increase of 10 min in the time it would take to make the reported trip by walking led to 56% lower odds of walking in the Walk Score© model and 57% lower in the MAPS-Mini model, holding other variables constant at their mean. Lastly, odds of a trip being conducted by walking were 51% lower for the Walk Score© model and 53% lower in the MAPS-Mini model if the trip was part of a trip chain compared to if it was not, ceteris paribus.

For person level characteristics, women had 20% lower odds of walking r than men in the Walk Score© model while these odds were 21% lower in the MAPS-Mini model. Odds of taking a trip by walking were also lowered by 22% for the Walk Score© model and 25% for the MAPS-Mini model for every increase of 10 years in age. Individuals holding a monthly transit pass had odds of walking 61% lower than those that do not have one in the Walk Score© model and 65% lower for the MAPS Mini model.

For household characteristics, every added person led to a reduction in odds of walking of 5% in the Walk Score© model and 12% in the MAPS-Mini model. Every added car accessible in a household led to a reduction in odds of walking by 50% in the Walk Score© model and 53% in the MAPS-Mini model, ceteris paribus. The presence of children aged below 13 years old led to a reduction in odds of walking of 39% in the Walk Score© model and 41% in the MAPS-Mini model, holding other things constant. In term of household income, all groups were more likely to walk for a homebased trip than those in the lowest income groups by 26% to 64% in the Walk Score© model and by 27% to 84% in the MAPS-Mini model.

Finally, improvements of 1 in normalized Walk Score© values at home location led to an increase of 19% in the probabilities of taking a homebased trip by walking (OR = 1.19, 95% CI [1.17–1.21]) while an improvement in 1 of the normalized MAPS-Mini score led to an increase of 11% (OR = 1.11, 95% CI [1.08–1.14]), holding other things constant.

4.1. Gender

The interaction between Walk Score© and gender (OR = 0.98, 95% CI [0.95–1.01]) was not statistically significant ($p = 0.170$) meaning that Walk Score© has a statistically similar effect on women and men in our model. Still, visual observations (Fig. 3) hints towards Walk Score© potentially having a larger effect on men's odds of walking (marginal increase rate of 20%) than women's (marginal increase rate of 18%). On the contrary, the interaction between the MAPS Mini score and gender (OR = 1.22, 95% CI [1.15–1.28]) was statistically significant ($p < 0.01$) meaning that a differential effect of MAPS Mini score was observed between women and men. With every increase of 1 point in the normalized MAPS-Mini score, women's odds of walking increased 22% more compared to men's. The sensitivity analysis shows a minimal

Table 3
Odds ratios from binary logit models predicting the probability of taking a trip by walking.

	Base models		Gender Interaction		Age interactions		Income interactions		Children interactions	
Predictors	*Walk Score*	*MAPS-Mini*	*Walk Score*	*MAPS-Mini*	*Walk Score*	*MAPS-Mini*	*Walk Score*	*MAPS-Mini*	*Walk Score*	*MAPS-Mini*
(Intercept)	8.61**	25.74**	7.96**	46.72**	25.06**	172.69**	12.72**	14.17**	7.19**	20.37**
Trip-level characteristics										
Trip Purpose [Reference: Other]										
Work	1.49**	1.61**	1.48**	1.60**	1.48**	1.58**	1.51**	1.69**	1.49**	1.61**
School	0.94	0.89*	0.94	0.88*	0.91	0.92	0.90	0.86**	0.95	0.88*
Shopping	0.91	0.92	0.91	0.90*	0.92	0.90*	0.90*	0.92*	0.92	0.92
Walking travel time	0.44**	0.43**	0.44**	0.43**	0.44**	0.43**	0.44**	0.43**	0.44**	0.43**
Trip chaining	0.49**	0.47**	0.49**	0.46**	0.48**	0.46**	0.49**	0.47**	0.48**	0.47**
Person-level characteristics										
Gender (Woman)	0.80**	0.79**	0.94	0.25**	0.81**	0.78**	0.80**	0.78**	0.81**	0.81**
Age	0.78**	0.75**	0.78**	0.75**	0.62**	0.50**	0.78**	0.76**	0.78**	0.79**
Transit Pass	0.39**	0.35**	0.38**	0.35**	0.38**	0.35**	0.38**	0.34**	0.39**	
Household-level characteristics										
Household size	0.95**	0.88**	0.95**	0.88**	0.94**	0.88**	0.95**	0.88**	0.95*	0.89**
Household cars	0.50**	0.47**	0.50**	0.48**	0.50**	0.47**	0.52**	0.48**	0.51**	0.47**
Presence of children under 13	0.61**	0.59**	0.61**	0.58**	0.60**	0.59**	0.63**	0.60**	1.07	0.35**
Household income [Continuous]							0.94	1.30**		
Household income [Reference: -$30,000]										
$30,000–$60,000	1.26**	1.27**	1.25**	1.26**	1.25**	1.29**			1.25**	1.26**
$60,000–$90,000	1.19**	1.27**	1.19**	1.26**	1.19**	1.27**			1.18**	1.26**
$90,000–$150,000	1.64**	1.84**	1.64**	1.84**	1.61**	1.79**			1.64**	1.80**
$150,000 +	1.38**	1.53**	1.38**	1.51**	1.34**	1.51**			1.37**	1.49**
Walk Score©	1.19**		1.20**		1.04		1.14**		1.21**	
MAPS Mini Score		1.11**		1.01		0.81**		1.23**		1.15**
Interactions										
Gender * Walk Score©			0.98							
Gender * MAPS-Mini Score				1.22**						
Age * Walk Score©					1.03**					
Age * MAPS-Mini-Score						1.07**				
Income * Walk Score©							1.02**			
Income * MAPS-Mini Score								0.97**		
Presence of children * Walk Score©									0.92**	
Presence of children * MAPS-Mini Score										0.87**
N	2352	2352	2352	2352	2352	2352	2352	2352	2352	2352
Tjur R^2	0.488	0.475	0.488	0.476	0.494	0.480	0.487	0.473	0.489	0.476
Log Likelihood	−13,763	−13,923	−13,762	−13,898	−13,741	−13,884	−13,790	−13,955	−13,755	−13,914

Note: **$p < 0.01$; * $p < 0.05$.

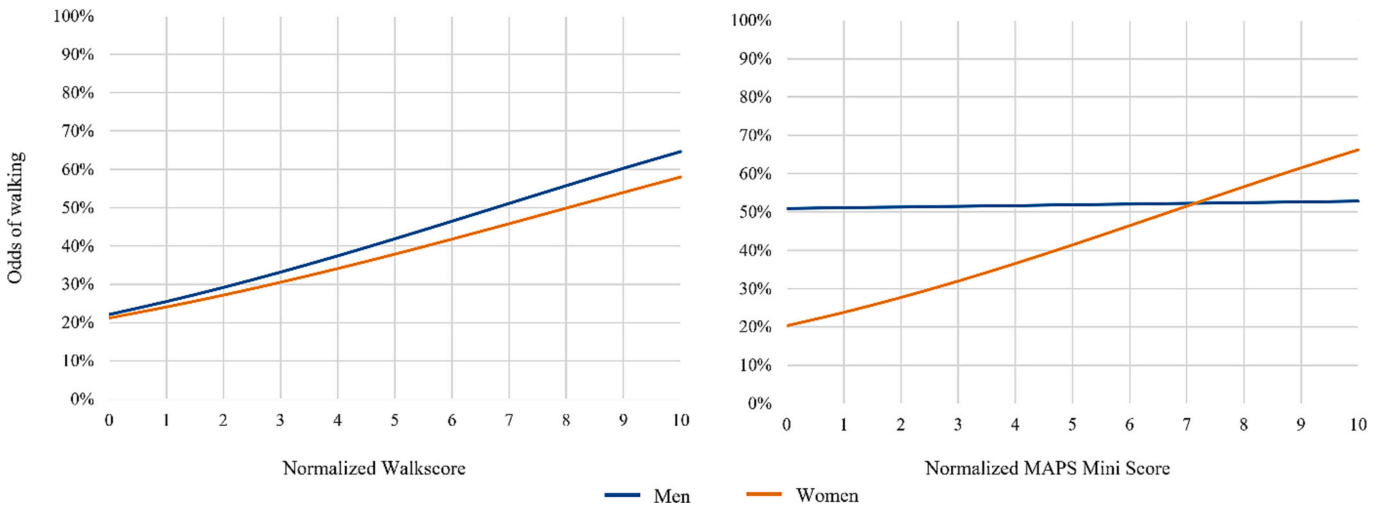


Fig. 3. Odds of walking from interactions between gender and walkability indices.

increase in men's odds of walking as the MAPS-Mini score value increases (1% marginal increase rate) while women's odds of walking increase significantly (23% marginal increase rate), eventually catching up and surpassing men's.

4.2. Age

The interaction between age and Walk Score© (OR = 1.03, 95% CI [1.02–1.04]) was statistically significant ($p < 0.01$) meaning that for every increase of 10 years in age, an improvement of 1 point in normalized Walk Score© would lead to an increase in odds of walking by 3%, ceteris paribus. Similarly, the interaction between age and MAPS-mini (OR = 1.07, 95% CI [1.06–1.09]) was statistically significant ($p < 0.01$) meaning that for every increase of 10 years in age, an improvement of 1 in normalized MAPS Mini would lead to an increase in the probability of walking 7% larger than for someone 10 years younger, holding other variables at their mean. The positive and statistically significant odd ratios of these interactions therefore imply that both features considered in both indices (i.e., local accessibility for Walk Score and the micro-scale-built environment for the MAPS Mini) gain importance in promoting walking as adults age. It should be noted that for the MAPS-Mini model, the probability of walking is predicted to decrease for someone aged 20 years old as walkability increases. This could point towards a non-linear relationship between age and the MAPS Mini score. On the contrary, odds of walking increase for all ages in the Walk Score© model, albeit at different rates.

4.3. Household income

The interaction between household income and Walk Score© was positive (OR = 1.02, 95% CI [1.01–1.02]) and statistically significant ($p < 0.01$) meaning that every increase of $30,000 in household income led to an increase in odds of walking 2% larger for an improvement of 1 in normalized Walk Score©, all else equal. Higher income groups, which are the least likely to walk in areas with poorer local accessibility, end up being the most likely to walk in higher walking accessibility areas (Fig. 5). Nonetheless, the odds of walking are predicted to increase for all income brackets, albeit at different rates. For MAPS-Mini, the interaction with household income was negative (OR = 0.97, 95% CI [0.96–0.98]) and statistically significant ($p < 0.01$) meaning that every increase of $30,000 in household income will lead to an incremental change in the odds of walking 3% smaller for an increase of 1 in the normalized MAPS Mini score. The negative significant odds ratio of this interaction implies that micro-scale walkability, as summarized by the MAPS Mini audit tool here, promote walking more the lower one's household income is leading to the convergence of the odds of walking across income groups (Fig. 4). It also suggests that people living in households with incomes $180 K and above will see their odds of walking decrease as walkability increases. Similar to the decrease in odds of walking observed for younger age groups (Section 4.2), the observed declines in odds of walking for higher income group in the MAPS-Mini model could indicate a non-linear relationship.

4.4. Presence of children in the household

The interactions between the presence of children aged below 13 years old in a household with Walk Score© (OR = 0.92, 95% CI [0.88–0.96]) and with the normalized MAPS-Mini score (OR = 0.87, 95% CI [0.82–0.93]) were both statistically significant ($p < 0.01$). This meant that with every increase of 1 in the normalized walkability index, adults living in households with children below 13 years old saw lower incremental increase in their odds of walking (8% lower for the Walk Score© model and 13% lower for the MAPS Mini model) than adults in household without young children. Individual living in a household with and without children below 13 years old are expected to see significant increases in their odds of walking as Walk Score increases, albeit at differential rates (Fig. 6). On the contrary, increase in the MAPS Mini Score seemingly have no effect on individuals living in households with children below 13 years old.

5. Discussion

Our analysis underscores different interactions between two walkability indices at different scale (i.e., Walk Score© at the meso-scale and the MAPS-Mini audit tool at the micro-scale) and four socio-demographic variables (i.e., gender, age, household income and presence of children below 13 years old in the household) when modelling adults' odds of walking for utilitarian trips. These findings corroborate the two hypotheses posited in the introduction. First, for both Walk Score© and MAPS-Mini separately, significant variations in the statistical importance of the index were observed between individuals of different age, household income and family composition while gendered differences in the effects of the MAPS-Mini were also observed. As such, it can be stated that for a given walkability index, its relevancy in explaining walking behavior varies between socio-demographic groups as hypothesized. Secondly, Walk Score© and MAPS-Mini showed contrasting interactions with gender and household income while more nuanced variations were observed for the interactions with age and the presence of children in a household. This corroborates our second hypothesis, as different walkability indices reflect walking behavior differently for a given sociodemographic group.

In terms of gender interactions, the lack of statistically significant differences between men and women for Walk Score© aligns with past research looking at the correlation between this measure and physical activity (Twardzik et al., 2019) but it goes against findings on the differential correlation of local accessibility with active transport between South Asian American women and men (Kelley et al., 2016). These

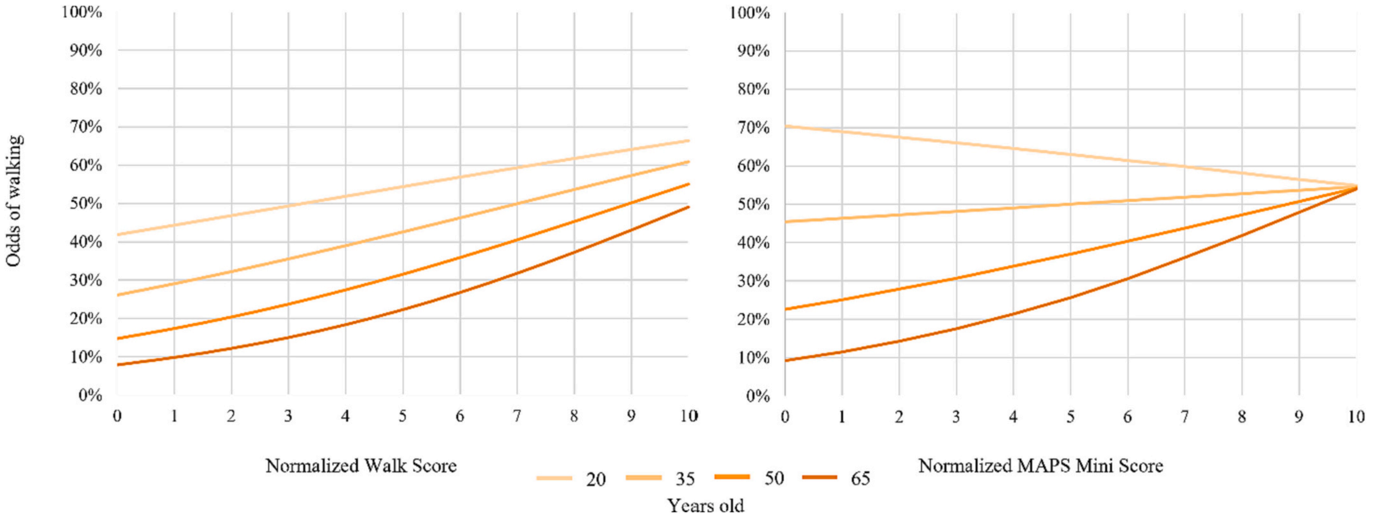


Fig. 4. Odds of walking from interactions between age and walkability indices.

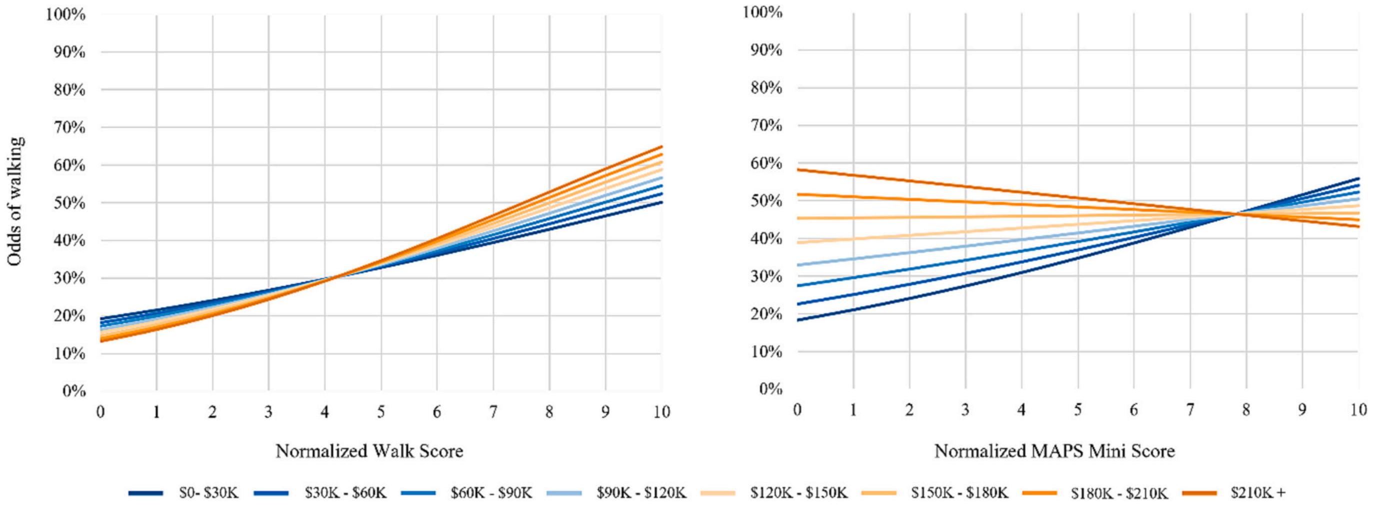


Fig. 5. Odds of walking from interactions between household income and walkability indices.

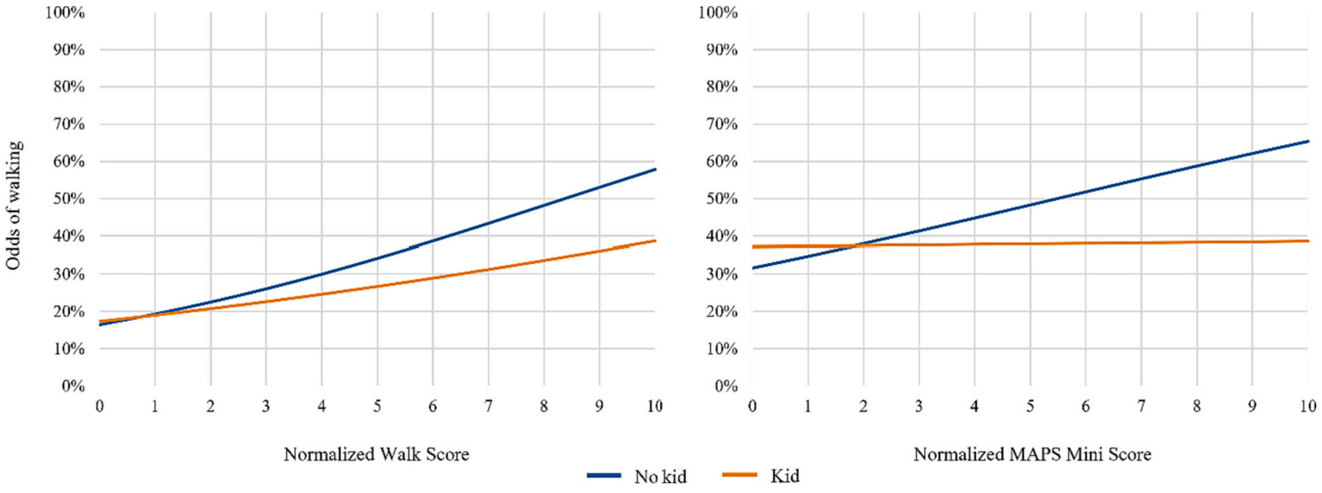


Fig. 6. Odds of walking from interactions between the presence of children below 13 years old in the household and walkability indices.

differences could point towards potential intersectionality between sociodemographic characteristics in relation to the relevancy of features of the built environment for walking. Conversely, the findings for MAPS-mini corroborate findings from a previous study that women's odds of walking increase significantly more following street-level interventions than men (Jensen et al., 2017). This can be explained by the heightened considerations of safety – both in term of crime and traffic – that have been observed among women compared to men (Clifton and Livi, 2005; Hidayati et al., 2020). This has been partially attributed to the fact that women tend to be socially conditioned to be more risk-averse than men (Shirgaokar, 2019), often leading to higher levels of avoidance in environment with low perceived safety. Interventions such as proper street lighting or safe walking infrastructures – which are both considered in the MAPS-Mini audit tool – have been mentioned as potential interventions to help tackle this issue (Clifton and Livi, 2005).

In terms of age, the decrease in propensity to walk with increase in age and the positive interactions between walkability and age observed for both indices are coherent with past research which indicated that the implication of walkability varied across age groups (Liao et al., 2020b; Moura et al., 2017; Stafford and Baldwin, 2018). Given that older adults have been consistently associated with higher risk of fatality in car-pedestrian collisions due to their increased vulnerability (Buehler and Pucher, 2017), it makes sense that their walking behavior would be predominantly shaped by the quality of the street environment they interact with and how safe it makes them feel (Curl et al., 2020; Dean et al., 2020). Similarly, having access to relevant destinations by walking can enable older adults to conduct their daily trip, provided that local-accessibility is not too high to act as a deterrent due to high pedestrian volumes (Cheng et al., 2020). The lower observed effect of walkability as measured by both indices on young adults' walking behavior is coherent with previous research (Lam et al., 2022). The observed decrease in predicted odds of walking for younger adults when interacting age with the MAPS-Mini score could indicate that this relationship is non-linear.

For household income, the increased effect of Walk Score© with increases in household income is coherent with past research that found a weaker effect of local accessibility, and several other meso-scale walkability indices, on lower income groups (Adkins et al., 2017; Manaugh and El-Geneidy, 2011; Steinmetz-Wood and Kestens, 2015). Conversely, the observed reversed effect of the MAPS-Mini audit tool on the probability of doing a trip by walking across income groups and the predicted decrease in walking rates for higher income bracket do not align with the literature. As shown in past studies with other walkability indices, it would have been assumed that lower income individuals would walk more in areas with poor micro-scale environments due to a lack of accessible travel alternatives both financially and geographically (Adkins et al., 2017; Manaugh and El-Geneidy, 2011). The contradictory nature of the interaction between income and the micro-scale built environment with the current literature could be attributed to a lack of research analyzing the interaction between micro-scale walkability and socio-economic status when analyzing the choice of walking or not for a trip. Indeed, while low micro-scale walkability in the study area mostly aligns with car-centric suburban settings, which tend to be higher income (Daley et al., 2022), past research has also shown that people in low-income areas are reporting poorer micro-scale environments in term of esthetics, perceived safety or walking infrastructure (Sallis et al., 2011). These seemingly contradicting realities point towards a need for disaggregation of micro-scale characteristics forming the MAPS-Mini audit tool to evaluate their spatial distribution and individual contribution to walking behaviors. The overrepresentation of high-income individuals and of higher-income areas in the study sample could also have had an impact on this relationship. Additional research – both quantitative and qualitative – is needed to further explore the relevancy of micro-scale walkability features on walking behavior across socio-economic groups.

When looking at the presence of children in the household, the negative effects observed of additional children on adult's walking rates are coherent with past that highlighted parental perceptions of safety both in term of criminality and traffic as more important factors in children's mobility, and therefore their own, then walkability in itself (Chillón et al., 2014; Curtis et al., 2015; Foster et al., 2014; Lang et al., 2011; McLaren, 2018; McMillan, 2007). To that aspect, both Walk Score© and the MAPS-Mini audit tool reflect the expected differences in walking rates expected between the people living with young children and those that do not. Still, both measures are limited in orienting interventions to better promote walking in parents with young children. While broader interventions such as the securitization of neighborhoods – both objectively and subjectively – and educational campaigns on safe walking habits have been mentioned in the literature as potential pathways of action (Carver et al., 2013; Lang et al., 2011; McMillan, 2007), further research specifically on children walking behavior would be need to evaluate their effect and how they might modify the interaction between walkability and walking for young children and their families. It is also important to note that the decline in walking rates observed for adults living in households with two or more children in the sensitivity analysis conducted with MAPS-Mini might be once again indicative of a potentially non-linear relationship or a limitation in the ability of this index to capture utilitarian walking given the incongruent nature of this finding with the literature.

As stated in the methodology section, some sociodemographic variables of interest (e.g., ethnicity, disability status and educational attainment) could not be tested due to their absence in the 2018 Montréal O—D Survey. Similarly, the constrained study area due to the time-consuming process of collecting the MAPS-Mini audit tool, prevented to have a sample large enough to adequately explore the intersectionality of sociodemographic characteristics. Furthermore, the study area does not represent all type of built environments present in the region, meaning that some of the findings might be intrinsically linked to the area of study. Future iterations of the analysis conducted in this paper should explore other walkability indices that can be easily collected at a large-scale to explore these interactions at a regional level. A larger sample size will help further inquiring into potential intersectional effects of individual's sociodemographic characteristics on their relationship with the features summarize by walkability indices. Lastly, it is important to acknowledge that our findings are from a higher-income country perspective, and that further research in other contexts should be conducted to allow for potential generalizability.

Notwithstanding these limitations, our study contributes to the walkability literature by building upon past studies that contrasted research findings using a multitude of indices (Liao et al., 2020b; Manaugh and El-Geneidy, 2011; Shashank and Schuurman, 2019), highlighting that different walkability indices summarize elements of the built and social environment that have differential levels of importance in the decision to walk or not between sociodemographic groups. We show that walkability indices' relevancy when studying walking behavior varies along sociodemographic axes as well as from one walkability index to another. Our study particularly draw attention to the differences and similarities between meso-scale and micro-scale walkability indices. Through these findings, we provide key methodological insights for researchers aiming to employ walkability indices to better understand walking behavior or the distribution of walkable areas in an equitable way.

6. Conclusion

In this paper we highlight the importance of assessing the differential relevancy of walkability indices in shaping walking behavior across sociodemographic groups. People of different sociodemographic and socioeconomic groups have differential needs regarding the built and social environment to support their walking behavior. Such differences are not captured in the same way by micro-scale and meso-scale walkability indices and are likely to vary between walkability indices of the same scale as well. As such, we posit that the inherent assumptions that come with the choice of walkability indices should be expanded to include the sociodemographic characteristics of the researchers' targeted population. To render such assumptions clearer, sensitivity analyses, like the ones conducted in this study, should be conducted for each component of composite walkability indices to identify their relevancy across sociodemographic groups. Such approaches should be conducted on large enough samples to enable the assessment of intersectional effects of sociodemographic characteristics on walkability assessment. This method could complement already existing participatory approaches (i.e., Golan et al., 2019; Moura et al., 2017) by rapidly revealing key adjustments to be made to existing walkability indices to make them more relevant to different sociodemographic groups across different geographical contexts. The sociodemographic sensitivity analyses conducted in this paper further supports the growing literature that centers walkability around individual perceptions rather than solely objective evaluations of the built environment. Lastly, we believe, as has been suggested in previous research (Forsyth, 2015; Shashank and Schuurman, 2019), that the usability of any walkability index, whether already existing or new, should be more closely justified to make sure that they are being employed for usage that are coherent with the elements of walkability they capture.

CRediT authorship contribution statement

Lancelot Rodrigue: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. **Ahmed El-Geneidy:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Kevin Manaugh:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

Data availability

Data will be made available on request.

Acknowledgements

We would like to thank the 18 auditors who collected the audit built environment data as well as Daniel Bergeron and Pegha Nouri from Autorité Régionale de Transport Métropolitain (ARTM) for providing access to the OD Surveys. This paper draws on research supported by The Canadian Institutes of Health Research (CIHR) and The Natural Sciences and Engineering Research Council of Canada (NSERC)

Collaborative Health Research Projects (CHRP) Program (CIHR CPG-170602 and CPG-170602 X-253156, NSERC CHRPJ 549576-20) as well as the Social Sciences and Humanities Research Council of Canada (SSHRC) Canada Graduate Scholarship Master's Program (CGS-M).

References

Adkins, A., Makarewicz, C., Scanze, M., Ingram, M., Luhr, G., 2017. Contextualizing walkability: do relationships between built environments and walking vary by socioeconomic context? J. Am. Plan. Assoc. 83 (3), 296–314. https://doi.org/10.1080/01944363.2017.1322527.

Adkins, A., Barillas-Longoria, G., Martinez, D.N., Ingram, M., 2019. Differences in social and physical dimensions of perceived walkability in Mexican American and non-hispanic white walking environments in Tucson, Arizona. J. Transp. Health 14. https://doi.org/10.1016/j.jth.2019.100585. Article 100585.

Bartzokas-Tsiompras, A., Tampouraki, E., Photis, Y., 2020. Is walkability equally distributed among downtowners? Evaluating the pedestrian streetscapes of eight European capitals using a micro-scale audit approach. Int. J. Transp. Dev. Integr. 4 (1), 75–92.

Bartzokas-Tsiompras, A., Photis, Y., Tsagkis, P., Panagiotopoulos, G., 2021. Microscale walkability indicators for fifty-nine European central urban areas: an open-access tabular dataset and a geospatial web-based platform. Data Brief 36, 107048. https://doi.org/10.1016/j.dib.2021.107048.

Bivina, G., Gupta, A., Parida, M., 2020. Walk accessibility to metro stations: an analysis based on meso- or micro-scale built environment factors. Sustain. Cities Soc. 55 https://doi.org/10.1016/j.scs.2020.102047.

Boarnet, M., Forsyth, A., Day, K., Oakes, J., 2011. The street level built environment and physical activity and walking: results of a predictive validity study for the Irvine Minnesota inventory. Environ. Behav. 43 (6), 735–775. https://doi.org/10.1177/0013916510379760.

Buehler, R., Pucher, J., 2017. Trends in walking and cycling safety: recent evidence from high-income countries, with a focus on the United States and Germany. Am. J. Public Health 107 (2), 281–287.

Cain, K., Millstein, R., Sallis, J., Conway, T., Geremia, C., Frank, L., Saelens, B., King, A., 2012. Validity of the microscale audit of pedestrian streetscapes (MAPS). J. Sci. Med. Sport 15 (Supplement 1), S30. https://doi.org/10.1016/j.jsams.2012.11.072.

Cain, K., Gavand, K., Conway, T., Geremia, C., Millstein, R., Frank, L., Saelens, B., Adams, M., Glanz, K., King, A., 2017. Developing and validating an abbreviated version of the microscale audit for pedestrian streetscapes (MAPS-abbreviated). J. Transp. Health 5, 84–96.

Carver, A., Timperio, A., Crawford, D., 2013. Parental chauffeurs: what drives their transport choice? J. Transp. Geogr. 26, 72–77. https://doi.org/10.1016/j.jtrangeo.2012.08.017.

Cheng, L., De Vos, J., Zhao, P., Yang, M., Witlox, F., 2020. Examining non-linear built environment effects on elderly's walking: a random forest approach. Transp. Res. Part D: Transp. Environ. 88, 102552 https://doi.org/10.1016/j.trd.2020.102552.

Chillón, P., Hales, D., Vaughn, A., Gizlice, Z., Ni, A., Ward, D., 2014. A cross-sectional study of demographic, environmental and parental barriers to active school travel among children in the United States. Int. J. Behav. Nutr. Phys. Act. 11 (1), 61. https://doi.org/10.1186/1479-5868-11-61.

Clifton, K., Livi, A., 2005. Gender differences in walking behavior, attitudes about walking, and perceptions of the environment in three Maryland communities. Res. Women's Issues Transp. 2, 79–88.

Consoli, A., Nettel-Aguirre, A., Spence, J.C., McHugh, T.L., Mummery, K., McCormack, G.R., 2020. Associations between objectively-measured and self-reported neighbourhood walkability on adherence and steps during an internet-delivered pedometer intervention. PLoS One 15 (12). https://doi.org/10.1371/journal.pone.0242999. Article e0242999.

Craig, L., van Tienoven, T., 2019. Gender, mobility and parental shares of daily travel with and for children: a cross-national time use comparison. J. Transp. Geogr. 76, 93–102. https://doi.org/10.1016/j.jtrangeo.2019.03.006.

Curl, A., Mason, P., 2019. Neighbourhood perceptions and older adults' wellbeing: does walking explain the relationship in deprived urban communities? Transp. Res. A Policy Pract. 123, 119–129. https://doi.org/10.1016/j.tra.2018.11.008.

Curl, A., Fitt, H., Tomintz, M., 2020. Experiences of the built environment, falls and fear of falling outdoors among older adults: an exploratory study and future directions. Int. J. Environ. Res. Public Health 17 (4), 1224.

Curtis, C., Babb, C., Olaru, D., 2015. Built environment and children's travel to school. Transp. Policy 42, 21–33. https://doi.org/10.1016/j.tranpol.2015.04.003.

Daley, J., Rodrigue, L., Ravensbergen, L., DeWeese, J., Butler, G., Kestens, Y., El-Geneidy, A., 2022. Foot-based microscale audit of light rail network in Montreal Canada. J. Transp. Health 24, 101317.

Day, K., Boarnet, M., Alfonzo, M., Forsyth, A., 2006. The Irvine–Minnesota Inventory to measure built environments: development. Am. J. Prev. Med. 30 (2), 144–152. https://doi.org/10.1016/j.amepre.2005.09.017.

De Vos, J., Lättman, K., van der Vlugt, A., Welsch, J., Otsuka, N., 2023. Determinants and effects of perceived walkability: a literature review, conceptual model and research agenda [article]. Transp. Rev. https://doi.org/10.1080/01441647.2022.2101072.

Dean, J., Biglieri, S., Drescher, M., Garnett, A., Glover, T., Casello, J., 2020. Thinking relationally about built environments and walkability: a study of adult walking behavior in Waterloo, Ontario. Health Place 64, 102352. https://doi.org/10.1016/j.healthplace.2020.102352.

Fonseca, F., Ribeiro, P., Conticelli, E., Jabbari, M., Papageorgiou, G., Tondelli, S., Ramos, R., 2021. Built environment attributes and their influence on walkability [review; early access]. Int. J. Sustain. Transp. 20 https://doi.org/10.1080/15568318.2021.1914793.

Forsyth, A., 2015. What is a walkable place? The walkability debate in urban design. Urban Des. Int. 20 (4), 274–292.

Foster, S., Villanueva, K., Wood, L., Christian, H., Giles-Corti, B., 2014. The impact of parents' fear of strangers and perceptions of informal social control on children's independent mobility. Health Place 26, 60–68. https://doi.org/10.1016/j.healthplace.2013.11.006.

Frank, L., Sallis, J., Saelens, B., Leary, L., Cain, K., Conway, T., Hess, P., 2010. The development of a walkability index: application to the neighborhood quality of life study. Br. J. Sports Med. 44 (13), 924–933.

Golan, Y., Henderson, J., Wilkinson, N., Weverka, A., 2019. Gendered walkability: building a daytime walkability index for women. J. Transp. Land Use 12 (1), 501–526.

Grant-Smith, D., Osborne, N., Johnson, L., 2017. Managing the challenges of combining mobilities of care and commuting: an Australian perspective. Community Work Fam. 20 (2), 201–210.

Hall, M., Ram, Y., 2018. Walk score® and its potential contribution to the study of active transport and walkability: a critical and systematic review. Transp. Res. Part D: Transp. Environ. 61, 310–324.

Herrmann, T., Boisjoly, G., Ross, N., El-Geneidy, A., 2017. The missing middle filling the gap between walkability and observed walking behavior [article]. Transp. Res. Rec. 2661, 103–110. https://doi.org/10.3141/2661-12.

Hidayati, I., Tan, W., Yamu, C., 2020. How gender differences and perceptions of safety shape urban mobility in Southeast Asia. Transport. Res. F: Traffic Psychol. Behav. 73, 155–173. https://doi.org/10.1016/j.trf.2020.06.014.

Jensen, W., Stump, T., Brown, B., Werner, C., Smith, K., 2017. Walkability, complete streets, and gender: who benefits most? Health Place 48, 80–89.

Kelley, E., Kandula, N., Kanaya, A., Yen, I., 2016. Neighborhood walkability and walking for transport among south Asians in the masala study. J. Phys. Act. Health 13 (5), 514–519.

Lam, T., Wang, Z., Vaartjes, I., Karssenberg, D., Ettema, D., Helbich, M., Timmermans, E., Frank, L., den Braver, N., Wagtendonk, A., Beulens, J.W., Lakerveld, J., 2022. Development of an objectively measured walkability index for the Netherlands [article]. Int. J. Behav. Nutr. Phys. Act. 19 (1) https://doi.org/10.1186/s12966-022-01270-8. Article 50.

Lang, D., Collins, D., Kearns, R., 2011. Understanding modal choice for the trip to school. J. Transp. Geogr. 19 (4), 509–514. https://doi.org/10.1016/j.jtrangeo.2010.05.005.

Lee, E., Dean, J., 2018. Perceptions of walkability and determinants of walking behaviour among urban seniors in Toronto, Canada. J. Transp. Health 9, 309–320.

Liao, B., van den Berg, P., van Wesemael, P., Arentze, T., 2020a. Empirical analysis of walkability using data from the Netherlands. Transp. Res. Part D: Transp. Environ. 85, 102390 https://doi.org/10.1016/j.trd.2020.102390.

Liao, B., van den Berg, P., van Wesemael, P., Arentze, A., T., 2020b. How does walkability change behavior? A comparison between different age groups in the Netherlands. Int. J. Environ. Res. Public Health 17 (2), 540.

Manaugh, K., El-Geneidy, A., 2011. Validating walkability indices: how do different households respond to the walkability of their neighbourhood? Transp. Res. Part D: Transp. Environ. 16 (4), 309–315.

McLaren, A., 2018. Parent–child mobility practices: revealing 'cracks' in the automobility system. Mobilities 13 (6), 844–860. https://doi.org/10.1080/17450101.2018.1500103.

McMillan, T., 2007. The relative influence of urban form on a child's travel mode to school. Transp. Res. A Policy Pract. 41 (1), 69–79. https://doi.org/10.1016/j.tra.2006.05.011.

Moura, F., Cambra, P., Gonçalves, A., 2017. Measuring walkability for distinct pedestrian groups with a participatory assessment method: a case study in Lisbon. Landsc. Urban Plan. 157, 282–296. https://doi.org/10.1016/j.landurbplan.2016.07.002.

Pereira, R., Saraiva, M., Herszenhut, D., Braga, C., Conway, M., 2021. r5r: rapid realistic routing on multimodal transport networks with R5 in R. Findings 21262. https://doi.org/10.32866/001c.21262.

Ravensbergen, L., Fournier, J., El-Geneidy, A., 2022. Exploratory analysis of mobility of Care in Montreal, Canada. Transp. Res. Rec. 03611981221105070.

Rodrigue, L., Daley, J., Ravensbergen, L., Manaugh, K., Wasfi, R., Butler, G., El-Geneidy, A., 2022. Factors influencing subjective walkability: results from built environment audit data. J. Transp. Land Use 15 (1), 1–21.

Sallis, J., Slymen, D., Conway, T., Frank, L., Saelens, B., Cain, K., Chapman, J., 2011. Income disparities in perceived neighborhood built and social environment attributes. Health Place 17 (6), 1274–1283. https://doi.org/10.1016/j.healthplace.2011.02.006.

Sallis, J., Cain, K., Conway, T., Gavand, K., Millstein, R., Geremia, C., Frank, L., Saelens, B., Glanz, K., King, A., 2015. Is your neighborhood designed to support physical activity? A brief streetscape audit tool. Prev. Chronic Dis. 12 https://doi.org/10.5888/pcd12.150098.

Shashank, A., Schuurman, N., 2019. Unpacking walkability indices and their inherent assumptions. Health Place 55, 145–154. https://doi.org/10.1016/j.healthplace.2018.12.005.

Shirgaokar, M., 2019. Operationalizing gendered transportation preferences: a psychological framework incorporating time constraints and risk aversion. Transp. Policy 75, 10–18. https://doi.org/10.1016/j.tranpol.2018.12.010.

Silva, A., da Cunha, J., da Silva, J., 2014. Estimation of pedestrian walking speeds on footways. In: Proceedings of the institution of civil engineers-municipal engineer.

Soliz, A., Rodrigue, L., Peaker, C., Bernard, I., El-Geneidy, A., 2023. Zoning in on transit-oriented development: understanding bylaw reform as critical policy groundwork [article]. J. Am. Plan. Assoc. https://doi.org/10.1080/01944363.2023.2239771.

Stafford, L., Baldwin, C., 2018. Planning walkable neighborhoods: are we overlooking diversity in abilities and ages? J. Plan. Lit. 33 (1), 17–30.

Statistics Canada, 2022. Canada is the first country to provide census data on transgender and non-binary people. https://www150.statcan.gc.ca/n1/daily-quotidien/220427/dq220427b-eng.htm.

Steinmetz-Wood, M., Kestens, Y., 2015. Does the effect of walkable built environments vary by neighborhood socioeconomic status? Prev. Med. 81, 262–267. https://doi.org/10.1016/j.ypmed.2015.09.008.

Tjur, T., 2009. Coefficients of determination in logistic regression models—a new proposal: the coefficient of discrimination. Am. Stat. 63 (4), 366–372.

Tobin, M., Hajna, S., Orychock, K., Ross, N., DeVries, M., Villeneuve, P., Frank, L., McCormack, G., Wasfi, R., Steinmetz-Wood, M., Gilliland, J., Booth, G., Winters, M., Kestens, Y., Manaugh, K., Rainham, D., Gauvin, L., Widener, M., Muhajarine, N., Fuller, D., 2022. Rethinking walkability and developing a conceptual definition of active living environments to guide research and practice. BMC Public Health 22 (1), 450. https://doi.org/10.1186/s12889-022-12747-3.

Tuckel, P., Milczarski, W., 2015. Walk score (TM), perceived neighborhood walkability, and walking in the US. Am. J. Health Behav. 39 (2), 241–255. https://doi.org/10.5993/ajhb.39.2.11.

Twardzik, E., Judd, S., Bennett, A., Hooker, S., Howard, V., Hutto, B., Clarke, P., Colabianchi, N., 2019. Walk score and objectively measured physical activity within a national cohort. Epidemiol. Commun. Health 73 (6), 549–556.

Wasfi, R., Steinmetz-Wood, M., Kestens, Y., 2017. Place matters: a longitudinal analysis measuring the association between neighbourhood walkability and walking by age group and population center size in Canada. PLoS One 12 (12), e0189472.

Ye, N., Gao, L., Juan, Z., Ni, A., 2018. Are people from households with children more likely to travel by car? An empirical investigation of individual travel mode choices in Shanghai, China. Sustainability 10 (12), 4573.