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The role of perceived and objective accessibility in shaping walking behavior: Insights from mid-sized Spanish cities☆

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ABSTRACT

Understanding the relationship between perceived and objective accessibility is critical for promoting urban mobility. This study explores the relationship between perceived and objective accessibility in shaping pedestrian behavior within mid-sized Spanish cities characterized by high activity density. Using perceived proximity as a proxy for accessibility, the study evaluates how these two measures influence travel mode choices across various trip purposes. The results suggest that perceived accessibility mediates the relationship between objective accessibility and walking decisions particularly for activities like restaurants and entertainment. Moreover, the alignment between perceived and objective accessibility varies by activity type, with stronger correlations observed in high-accessibility contexts. These findings underscore the importance of integrating subjective perceptions with objective measures when designing interventions aimed at promoting active transportation, such as walking. By addressing psychological and experiential dimensions of accessibility alongside conventional spatial metrics, this study provides valuable guidance for urban planners and policymakers to enhance sustainable transportation systems.

1. Introduction

The nexus between accessibility and the perception of proximity as determinants of pedestrian choices has attracted considerable scholarly attention in recent years (Blandin et al., 2023; Boakye-Dankwa et al., 2018; Lättman et al., 2018; Lättman, 2020; Lättman et al., 2020; Pot et al., 2021). The concept of universal accessibility has been deemed crucial in assessing urban policy and transportation systems, given its significant impact on combating social exclusion and improving the health and overall quality of life for city residents (Barton et al., 2012; Ekkel and de Vries, 2017; Geurs and Ritsema van Eck, 2001; Handy, 2020). Given the multiple benefits associated with reduced car dependency, including reduced traffic congestion, improved air quality, and enhanced physical well-being, developing strategies that promote a shift from automobile use to active transportation modes is a current priority.

Objective accessibility metrics are designed to quantify the ease with which individuals can access various destinations, such as schools, workplaces, grocery stores, and recreational facilities (Handy, 2020). While the tradition of optimizing spatial metrics to assess real-world accessibility levels toward basic needs is historically extensive (Barton et al., 2012; Curtis and Scheurer, 2010; Levine, 2020; Marquet et al., 2017; Tsou et al., 2005), in recent years there has been a renewed interest in using chronourbanistic principles to assess citizens access within the theoretical framework of the 15-minute city (Deboosere et al., 2018; Poorthuis and Zook, 2023; Vale

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and Lopes, 2023). Recent studies such as Staricco et al., (2022), Hosford, (2022), and Ferrer-Ortiz et al., (2022) have developed data-driven methodologies to estimate spatial access even including time-of-day variability (Willberg et al., 2023), tailoring estimations to the needs and mobility capabilities of different population groups (Ulloa-Leon et al., 2023), and specific modes of transport (Knap et al., 2023; McNeil, 2011). Overall, these metrics shed light on the physical distribution of resources, helping public institutions to identify spatial imbalances and improve spatial resource allocation.

Despite the increasing use of objective accessibility metrics to predict travel behavior through the analysis of modal choice and car usage patterns, the effectiveness of these metrics is constrained by the discrepancy between objective and perceived accessibility conditions. Studies indicate a significant gap between calculated accessibility and how it is perceived by individuals, with research like that of Pot et al. (2021) and Van Der Vlugt et al. (2019) underscoring the complex nature of human accessibility perception. This divergence is primarily attributed to traditional objective measures' reliance on absolute assessments of time, distance, travel costs, and other spatial data, which fail to account for the nuanced differences influenced by individual preferences, demographic characteristics, and the broader socio-cultural and economic contexts (Jamei et al., 2022). The influences of the built environment on travel behavior, among other human actions, are significantly shaped by individuals' perceptions of their surroundings, including their views on transport infrastructure (Chan et al., 2021; Ma and Cao, 2019; Næss et al., 2021). These perceptions, however, are not mere collections of isolated images of spatial elements; rather, they form an integrated sense of the street that encompasses aspects such as comfort, convenience, and diversity.

This situation has led to a paradox. On the one hand, public administrators are increasingly relying on sophisticated, data-driven objective metrics of accessibility as a cornerstone for strategic urban transformations aimed at encouraging shifts towards more sustainable transport modes. On the other hand, it has been established that travel decisions and behaviors are influenced not by the objective accessibility conditions but by individuals' perceptions of these conditions. This dichotomy may hinder efforts to leverage changes in the built environment effectively to foster sustainable travel behaviors.

Improving our understanding of the intricate relationship between objective and perceived accessibility and how they influence travel choices is essential for designing interventions that accurately target and influence the factors driving individuals' transportation decisions. In this article, proximity perception is used as a measure of perceived accessibility, focusing on individuals' subjective evaluation of the closeness of destinations. Therefore, this research is dedicated to exploring the relationship between mode choice behavior and the perception of proximity to general activities in the context of compact and dense Spanish cities. These cities offer ideal conditions to understand the role of perceived accessibility on modal choice as they tend to have high concentrations of destinations alongside lower-access suburbs. By using cities of different sizes in the same country we attempt to avoid falling into big-city dynamics while comparing travel behaviors within the same mobility cultures (Haustein and Nielsen, 2016). Specifically, we aim to address two key questions within this context: (1) How do proximity perception and walking accessibility relate to each other? (2) What role does proximity perception play in influencing mode choice for different types of trip purposes?

2. Background

Recent studies have shown that perceived accessibility, which reflects an individual's subjective assessment of transport options, significantly influences walking choices (Chor et al., 2016; Solbraa et al., 2018; Suarez-Balcazar et al., 2020). This contrasts with the traditional focus of urban planners, who predominantly consider objective accessibility measures (Lättman et al., 2018). Relying solely on objective data risks overlooking how people actually experience their environments, as individual perceptions can deviate significantly from objectively calculated measures (Gebel et al., 2011; Lättman et al., 2024). This gap between perceived and objective accessibility highlights the need for frameworks that account for psychological and cognitive factors in accessibility evaluations.

To bridge this gap, researchers increasingly call for integrating socio-cognitive theories, such as the Theory of Planned Behavior (TPB) and the Social Cognitive Theory (SCT), into urban mobility studies. TPB focuses on how attitudes, subjective norms, and perceived control predict intentional behavior, including travel mode choices (Ajzen, 1991). SCT emphasizes the interplay between personal cognition, environmental factors, and behavior, making it useful for understanding how perceptions of accessibility influence travel decisions (Bandura, 1986). For instance, Mandal et al. (2023) explored walking behavior using TPB, demonstrating that attitudes toward walking and perceived control over the built environment significantly affect walking choices. Similarly, Chen et al. (2019) applies TPB to examine urban residents' pro-environment travel behavior, showing how service quality in public transport impacts travel decisions. Van Der Vlugt et al. (2022) further show that perceived walking accessibility, shaped by travel attitudes, significantly influences walking behavior. These findings help explain why high objective accessibility levels do not always lead to higher rates of active travel, such as walking or cycling.

Further expanding on the integration of psychological factors, Nordfjærn et al. (2019) applied SCT to investigate how social cognitive factors, such as attitudes and environmental norms, shape transport mode choices in urban environments. Their research demonstrates how personal and environmental factors interact to influence individuals' travel decisions, emphasizing the importance of both internal cognition and external context. This aligns with growing evidence that individuals' perceptions, shaped by psychological and cognitive factors, often have a stronger impact on travel behavior than objectively measured accessibility.

Empirical studies support the notion that perceived accessibility often holds greater influence over travel behavior than objective metrics. Van Acker et al. (2010) found that subjective perceptions of neighborhood characteristics, such as safety and convenience, play a critical role in determining travel behavior, even when objective data suggest good accessibility. Pot et al. (2021) demonstrated that mismatches between objective and perceived accessibility can stem from individual awareness or cognitive biases about the transport environment, often shaping travel choices more effectively than calculated indicators. Lättman (2020) also examined the effects of restricted car use on perceived accessibility and found that when individuals were limited in their car usage, their perceived accessibility significantly decreased, especially in areas lacking robust public transport options. Similarly, in their review, De Vos et al. (2023) highlight that perceived walkability often has a stronger influence on walking behavior and travel satisfaction than objective metrics, noting the individuals' perceptions of ease, safety, and environmental quality are key determinants of walking decisions. This review underscores the need for urban planners to prioritize perceived accessibility to promote active travel effectively and improve overall transport outcomes.

As cities move toward accessibility-based planning, integrating both subjective and objective measures is crucial to accurately reflect how residents experience their environments. In high-accessibility areas, perceived and objective accessibility tend to align, diminishing the role of subjective factors in mode choice decisions. However, much of the existing research has focused on low-accessibility areas, with limited exploration of medium- and high-accessibility areas (Levine, 2020; Martens et al., 2022). Despite their high levels of accessibility, these regions still experience significant emissions and car usage. Further improvements in accessibility within these well-serviced areas may reveal shifts in travel behavior, but this remains largely unexplored.

Moreover, the spatial mismatch hypothesis (Singer et al., 2022) posits that a disconnection between where people live and where jobs are located exacerbates accessibility issues, particularly in urban areas where job suburbanization is common. However, this dynamic may differ in Europe's polycentric cities, where higher population densities and access to opportunities provide a comparative benefit to low-income groups without access to cars (Vale and Lopes, 2023). For these groups, residing in dense urban centers offers greater accessibility benefits, as spatial proximity to essential services functions as a social safety net.

Wellbeing and caregiving also add crucial dimensions to accessibility research. Historically, accessibility studies have focused predominantly on job access (Cheng and Bertolini, 2013; Cui and Levinson, 2020), but a growing discourse highlights the importance of extending this understanding to include health, caregiving, and self-fulfillment (Allen and Farber, 2020). Perceived accessibility plays a critical role in this broader perspective, particularly for women and caregivers, whose travel needs often involve destinations other than employment. Accessibility policies should account for this diversity, ensuring that urban planning supports the caregiving responsibilities that disproportionately affect women, as well as broader concerns related to wellbeing (Ferrer-Ortiz et al., 2022; Song et al., 2022; Zhang et al., 2023). In doing so, policies can better reflect how caregiving shapes perceptions of accessibility and address the needs of vulnerable groups.

In terms of transport justice, studies have found that gender- and age-based disparities often exist in perceived accessibility, particularly for women and younger individuals, who tend to rely on public transport (Lättman et al., 2024). These disparities suggest that urban mobility solutions must address the social justice implications of perceived accessibility to promote equitable access for all. The need for new standards in accessibility metrics, as suggested by Ryan and Martens (2023), is becoming increasingly evident, given the complex and dynamic nature of accessibility in modern urban environments.

This study specifically explores how calculated accessibility influences mode choice decisions indirectly through perceived proximity, which serves as a mediator, in cities with high concentrations of destinations. In higher accessibility settings, perceptions and objective measures tend to align more closely, diminishing the role of subjective factors in decision-making. This research aims to clarify the interplay between subjective and objective factors in shaping urban travel behavior, offering insights that could refine urban planning and policymaking.

3. Data

Data regarding travel behavior is based on self-reported answers to a travel behavior questionnaire conducted within the "La transición ecológica en la movilidad y el transporte" (ECOMOV) and "Social Transport Equity by Planning for Proximity" (STEPP) projects (GEMOTT, 2023). Funded by the Ministry of Science and Innovation and RecerCaixa by Caixabank, these projects aim to understand the role of proximity conditions and proximity-based accessibility on travel behavior and environmental and social outcomes in Spanish cities.

Questionnaires were completed using a Computer-Assisted Telephone Interview (CATI) technique by 1,200 adults residing in the municipalities of Valencia, Granada, and Palma de Mallorca, Spain. A total of 400 surveys were conducted in each city. Participants were randomly sampled from areas classified as having high or low accessibility, although a formal sampling frame was not explicitly provided by the data collection company. Accessibility was defined at the census area level and based on objective walking time to 27 key daily destinations. High accessibility areas corresponded to the 90th percentile (with shorter walking times), while low accessibility areas represented the 10th percentile (with longer walking times). Despite these relative differences in accessibility, all sampled areas shared characteristics typical of high-density urban development characteristic of Spanish cities.

While the external organization responsible for data collection did not provide detailed information on response rates, random sampling methods were employed to ensure broad representation. Although the lack of response rate is a limitation, previous research shown that rigorously applied random sampling can yield reliable and representative findings, even without detailed response metrics (MacInnis et al., 2018). When implemented effectively across diverse environments, random sampling has been demonstrated to provide robust results with high external validity, allowing conclusions to be generalized to broader populations (Barabas and Jerit, 2010). This underscores the importance of careful survey design in maintaining validity, even in the presence of incomplete response data.

We acknowledge the possibility of response bias, as those who chose to respond may differ in ways that could influence the results. However, given the broad distribution of the sample across urban areas and accessibility categories suggests that the data provides meaningful insights. Furthermore, studies have demonstrated that random sampling techniques, even in the absence of detailed response rates, can mitigate the effects of non-response bias and yield valid, generalizable results (Lynn et al., 2001). This highlights the robustness of the approach in ensuring reliable data, even when response tracking is limited.

Our city selection includes compact and historical cities of intermediate size, providing insight into a mid-scale perspective not as widely studied as major cities. The questionnaire included items regarding general travel preferences for various travel purposes or activities, assessment of neighborhood conditions, social cohesion, and satisfaction, together with opinions towards proximity environments. Additionally, we measured mode choice by asking respondents about their primary travel mode, offering alternatives such as car, motorcycle, various types of public transportation, bicycle, walking, and others. To provide a clearer understanding of transportation modes, we categorized the responses into two main groups: 'motorized' (including car, motorcycle, and public transportation) and 'walking' (which encompasses both walking and cycling). We combined cycling into the walking category because it accounted for less than 0.5 % of the total responses. This approach allows us to contrast motorized versus non-motorized modes in the analysis, providing a clearer understanding of travel behavior.

The perception of accessibility was assessed using the following question: "What is your general opinion about the proximity to [specific activity]?" The activities considered in this research included daily shopping, non-daily shopping, restaurants, and entertainment. Respondents were given five response options: "very far," "far," "neither far nor close," "close," and "very close." For analysis purposes, we merged "very far" and "far" into the category of "far" and "very close" with "close" into a single category of "close," to simplify interpretation and enhance clarity.

Although our response categories are not explicitly structured as a traditional Likert scale, they follow the same principle of ordered responses, capturing a clear range of perceptions from "very far" to "very close." This approach offers a similarly robust framework for analysis while reducing ambiguity. By asking directly about the perceived proximity of destinations, we ensure that all respondents are interpreting and answering the question in a consistent, straightforward way, focused solely on how near or far they feel the destinations are. This clarity allows us to treat the responses as ordinal data, allowing for an effective assessment of perceptions across different levels of proximity.

To establish a baseline of objective accessibility for comparison with perceived accessibility, we employed a pedestrian accessibility indicator, calculated using a 100-meter cell grid. This enabled us to calculate the number of everyday destinations reachable within a

Table 1
Sample distribution for 4 activities.

	Daily shopping	Non daily shopping	Restaurants	Entertainment
Sample	1182	1147	995	1005
Education				
College/University	47 %	47 %	49 %	50 %
High School	35 %	36 %	36 %	36 %
Incomplete High School	18 %	17 %	15 %	14 %
Age				
18 to 29	13 %	13 %	14 %	14 %
30 to 44	23 %	23 %	24 %	25 %
45 to 64	37 %	37 %	36 %	38 %
65 plus	27 %	27 %	26 %	23 %
Gender				
Men	44 %	44 %	44 %	45 %
Women	56 %	56 %	56 %	55 %
Objective Accessibility				
Max	1316	1316	650	226
Min	1	1	0	4
Median	277	279	140	87
Mean	370	370	180	91
City				
Granada	34 %	34 %	34 %	33 %
Palma	33 %	33 %	36 %	35 %
Valencia	33 %	33 %	30 %	33 %
Perception				
Close	94 %	78 %	85 %	71 %
Neither Close nor Far	3 %	11 %	7 %	18 %
Far	3 %	11 %	8 %	11 %
Modal share				
Walking	86 %	58 %	72 %	52 %
Motorized	14 %	42 %	19 %	48 %

15-minute walk, represented by isochrones. These destinations included care services, education, provisioning, entertainment, and transit infrastructure.

We selected the 15-minute threshold based on its extensive use in urban planning literature, particularly through the widely recognized ‘15-minute city’ concept. This approach advocates for urban areas designed so that residents can access essential services within a 15-minute walk or bike ride, making it an optimal measure for evaluating accessibility in mid-sized Spanish cities. The threshold reflects a growing consensus on sustainable urban design, particularly in promoting walkability and active travel.

For analysis, we focused on two categories: walking accessibility to shopping provisions—such as grocery stores, convenience stores, hardware stores, and restaurants—and walking accessibility to entertainment/recreational destinations, which included sports facilities, parks, libraries, and theaters.

Table 1 displays the survey statistics. Although the original sample consisted of 1200 individuals, not everyone responded all questions. Consequently, the sample size varies depending on the specific purpose of travel. Despite this reduction, the overall sociodemographic composition of the survey remains relatively stable in most cases. Regarding objective local accessibility measures, the values highlight the excellent accessibility of Spanish cities. For example, over half of the sample reported access to 277 shopping destinations or 87 entertainment venues within a 15-minute radius. Finally, in terms of perception, the majority of the respondents believe that destinations for the different activities are close.

4. Methods

First, we explore the intricate relationship between perceived accessibility and objective accessibility, recognizing the potential interplay between these two dimensions. To investigate this link, we employ ordinal logistic regression models to analyze the relationship between perceived proximity levels (“close”, “neither close nor far”, and “far”) and calculated local accessibility. Ordinal logistic regression, often referred to as the ordered logit model, is a statistical method that extends traditional regression techniques to analyze data with ordered categorical outcomes. Unlike standard linear regression, which is suited for continuous variables, ordinal logistic regression is tailored for situations where the outcome variable is ordered but unequally spaced.

We acknowledge the skewness in the perceived accessibility data for activities like daily shopping, where only 3 % of respondents report destinations as “far.” This distribution likely reflects the real-world proximity of essential services, especially in mid-sized Spanish cities, where most amenities are within walking distance, making the “far” category naturally rare. Ordinal Logistic Regression (OLR) is well-suited for this type of data, as it models ordinal dependent variables effectively, even when categories are imbalanced. Research by Salas-Eljatib et al. (2018) supports the argument that adjusting for balance may alter statistical properties and distort meaningful insights, particularly in cases like this where imbalances reflect real-world distributions. Additionally, OLR has been shown to remain robust in handling imbalanced data (Fullerton, 2009), making it an appropriate choice for analyzing skewed data without sacrificing interpretability.

The calculated accessibility or provision density refers to the number of destinations within a 15-minute walking isochrone from the residence, with specific provision categories tailored to each activity (e.g., local stores for daily shopping activities). This analysis is further refined by segmenting the data according to four specific travel activities: daily shopping, non-daily shopping, restaurants, and entertainment.

The results of our model are graphically presented showing the perception probability versus the local accessibility. Local accessibility is presented as percentage of the maximum accessibility in the sample. As seen in Table 1, the 100 % represents the maximum value for each activity. By mapping local accessibility on the x-axis against the probabilities of walking by categories on the y-axis, we offer a clear depiction of how perception and objective accessibility influence travel behavior across different levels. This visual approach allows for a practical exploration of individuals’ responses to transportation options in various accessibility contexts, enriching our comprehension of factors driving travel decision-making.

Secondly, we examine how variations in perceived and objective accessibility affect modal choice. To achieve this, we investigate walking and vehicle travel modal choices by utilizing proximity perception as perceived accessibility, and local accessibility as objective accessibility for the same four activities. Our analysis employs binary logit models to analyze both modes’ choices and their dependency on perceived and local accessibility, as well as sociodemographic characteristics. Sociodemographic characteristics, as depicted in Table 1, encompass four age groups (18–29, 30–44, 45–64, 65 +), three education levels (incomplete high school, complete high school, and university/college studies), and two genders (men and women). Additionally, the models include a dummy variable for the city where the sample is collected (Granada, Valencia, Palma).

We acknowledge that other individual variables such as family situation, income, mobility resources, or transport-related attitudes could offer further insights into modal choice. However, introducing a greater number of variables would increase the complexity of model estimation and interpretation without significantly enhancing the model’s explanatory power. Based on the pseudo R^2 values, adding more variables would likely result in only marginal improvements, as the primary drivers of modal choice in our models are the accessibility variables themselves. Our goal in this study is to evaluate the relative influence of perceived and objective accessibility on travel behavior, and the inclusion of the current sociodemographic controls provides a balance between model complexity and interpretability. If the focus of the analysis were to shift towards greater predictive accuracy, incorporating additional variables would be warranted.

By including both local objective accessibility and perceived accessibility as independent variables, we conduct a comprehensive examination of the factors influencing travel choices. To evaluate the significance of each accessibility element, we vary model specifications to include only objective accessibility, only perceived accessibility, and both variables together. Each model is assigned a number, as indicated in Table 2.

We then compare the goodness of fit among these models using McFadden's pseudo R^2 values, which measure how well the model fits the data. Pseudo R^2 in logistic regression is commonly estimated by comparing the likelihood of the fitted model to that of a constant model, which simply replicates the modal share. The likelihood function represents the probability of observing the given data based on the model parameters. In this context, it quantifies how well the model predicts the observed outcomes. By comparing the likelihood of the fitted model to that of the constant model, pseudo R^2 provides a measure of how much better the fitted model performs in predicting the outcomes compared to a model that assumes no relationship between the predictors and the outcome (i.e., for every case, the probability of using a certain mode is the same as the aggregated modal share of the sample data). Pseudo R^2 values range from 0 to 1, with values closer to 1 indicating a better fit of the model to the data. By comparing pseudo R^2 values, we can determine which factors better predict travel mode choice. For example, if the model with local accessibility alone outperforms the perception-based model, it suggests that objective accessibility may be more relevant than individual perception. Conversely, if both models yield similar pseudo R^2 values, with the combined model showing a marked improvement, it indicates that both factors are of comparable importance.

Next, we conduct an analysis of average marginal effects (AME) to gain deeper insights into the impact of independent variables on the probability of walking. AME analysis allows us to quantify the change in the probability of walking associated with incremental changes in objective accessibility or shifts in perception categories. Specifically, we assess how the probability of walking varies when objective accessibility increases by one unit or when perception transitions from "close" to "neither close nor far", or from "close" to "far". By estimating these average marginal effects, we can discern the magnitude of influence that perception and calculated local accessibility exert on walking behavior across different activity purposes. This granular analysis enables us to evaluate both individual and relative effects of perception and accessibility in influencing walking behavior. Such detailed insights contribute to a comprehensive understanding of the dynamics shaping travel behavior and inform targeted interventions to promote sustainable transportation choices.

5. Results

5.1. Perceived accessibility model

The perception of distance is closely tied to the actual accessibility of destinations. When individuals are in close proximity to many destinations, they are less likely to perceive those destinations as far away. To explore how objective accessibility affects perceived accessibility, we employ an ordered logit model with perception as the dependent variable, as explained previously. By incorporating local accessibility measures as independent variables, we can statistically analyze how the presence of destinations within walking distance influences individuals' perceptions of proximity. Modeling results are presented in Appendix 1.

In Fig. 1, we represent the probability of destinations being perceived as either ("close", "neither close nor far", and "far") based on the objective accessibility levels (expressed as a percentage). Objective accessibility is expressed as percentages, with 100 % representing the maximum accessibility across the entire sample, as shown in Table 1 (i.e., the maximum number of destinations accessible within a 15-minute walk). The y-axis of the figure delineates the probability of a destination being perceived as belonging to one of the proximity classes, while the x-axis corresponds to the provision percentage. This visual representation offers a clear and intuitive way to understand how increases in the objective accessibility of destinations can potentially shift perceptions.

In general, there is a clear increase in the probability of perceiving a destination as close with the increase in objective accessibility. However, a high density of destinations within a 15-minute walk radius is not a requisite for destinations to be perceived as close. This could be reflective of the high accessibility standards characteristic of Spanish cities, where the urban norm ensures some degree of provision within a 15-minute walk for all survey participants. The other activities exhibit different behaviors but show a steep slope in the increase in the probability of being perceived as close with the increase in provision.

Restaurants and non-daily shopping activities share similar curves in their probability of being "close", although both show increased sensitivity to objective accessibility at the lower end of the accessibility spectrum. The slope of the probability curve is quite steep initially, indicating that even a small increase in objective accessibility substantially enhances the likelihood of these destinations being perceived as close. However, entertainment destinations, display a different trend. The probability of them being perceived as 'close' grows more consistently and linearly across the entire range of objective accessibility. This suggests a more direct relationship between the number of entertainment destinations within a walkable distance and the perception of their proximity, without the initial sensitivity or subsequent plateau observed in the restaurant and non-daily shopping curves.

5.2. Mode choice model

In order to rank the relative importance of (1) objective accessibility, (2) perceived accessibility, and (3) the combined effect of

Table 2
Model number identificator.

Model No. (Walking Probability)	Independent variables
1	Objective accessibility + Sociodemographics
2	Perceived accessibility + Sociodemographics
3	Objective accessibility + Perceived accessibility + Sociodemographics

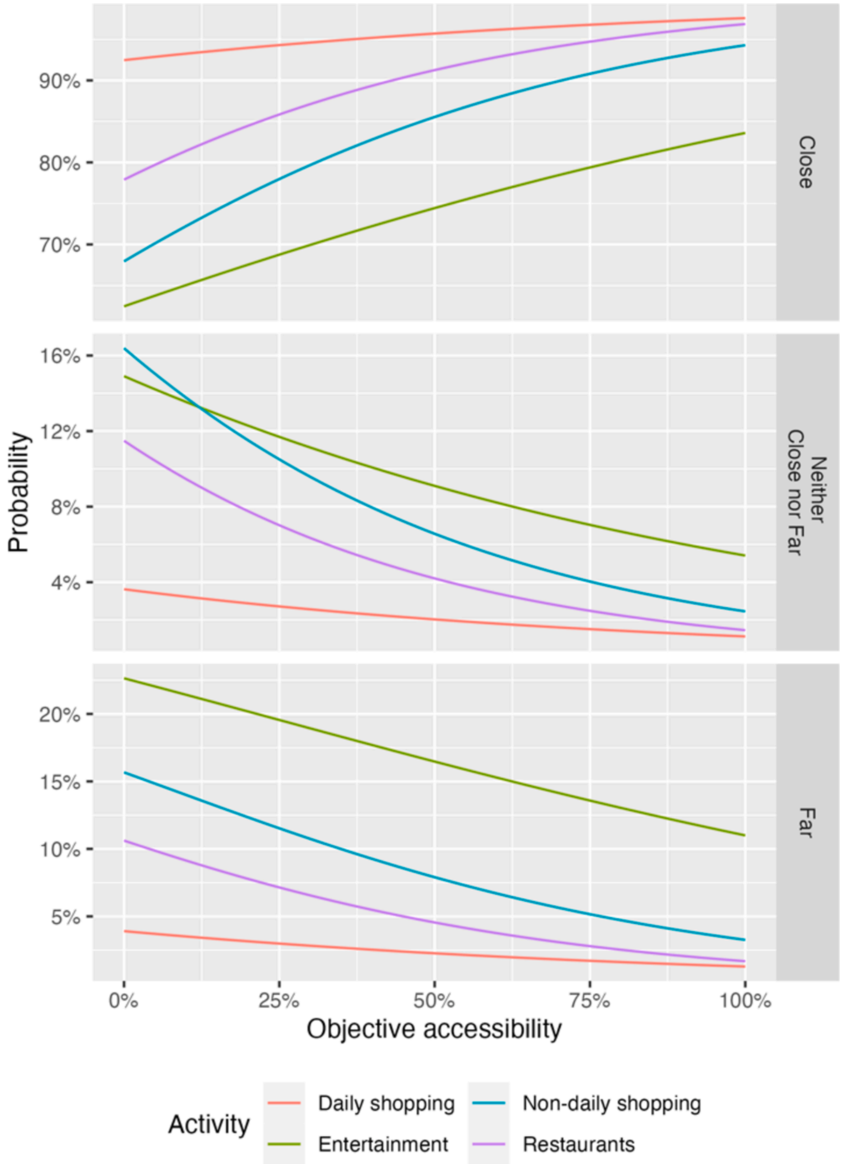

Fig. 1. Ordered logits for proximity perception as a function of objective accessibility.

perceived and objective accessibility on the probability of choosing to walk to various destinations, we analyzed four distinct models for each type of destination (daily shopping, entertainment, non-daily shopping, restaurants). The results of the estimations are presented in Appendix 2. Figure 2 illustrates the comparative goodness of fit for each model by showcasing the pseudo R^2 values, which are derived from the likelihood measures, for each activity. These values are indicators of how well each model explains the observed behavior, relative to a constant model, with higher values suggesting a superior model fit.

The analysis reveals that model 3 incorporating both perceived and objective accessibility consistently yields a better fit, suggesting that the interplay between these two factors is crucial in predicting walking behavior. However, there are variations in the specific contributions of each variable to the analysis. For daily shopping, objective accessibility has a more pronounced effect on walking behavior, as indicated by model 1 (which includes only objective accessibility), which has a superior fit compared to model 2 (perceived accessibility only). This trend is further pronounced in the case of non-daily shopping, where the fit of model 1 closely approaches model 3.

Regarding entertainment, there appears to be a more balanced effect of each attribute, with slightly better fit observed in model 1 compared to model 2. However, in the case of restaurants, the model based on perception demonstrates a superior pseudo R^2 compared to the model based solely on objective measures. This scenario is the sole instance among the examined activities where perceived accessibility proves to be a more significant predictor than objective accessibility.

When evaluating the influence of various factors on walking probabilities, it is best to consider not only the fit of the model but also

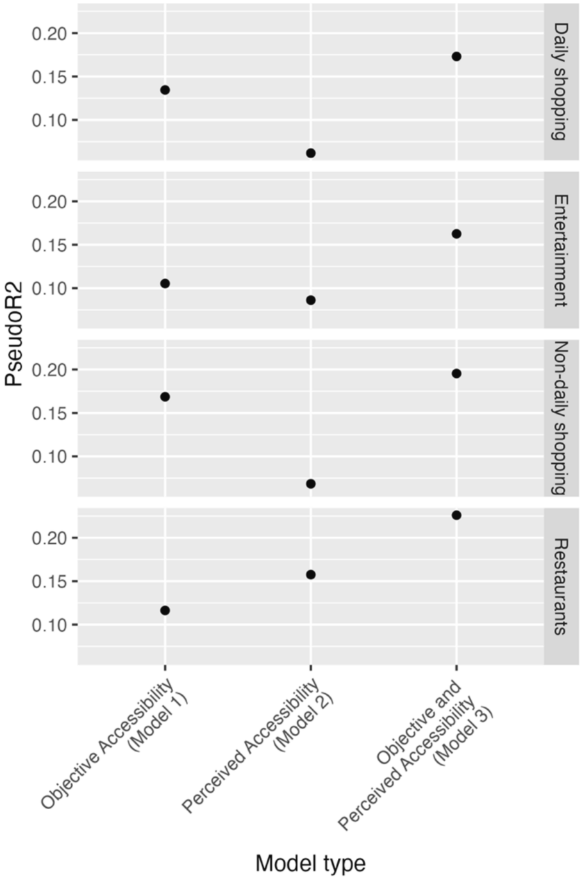

Fig. 2. Pseudo-R^2 for binary logits.

the magnitude of the effect that each variable exerts on the likelihood of choosing to walk. This effect size, quantified as the Average Marginal Effect (AME), represents the expected change in the probability of walking in response to a one-unit increase in objective provision or a shift in the level of perceived proximity.

Fig. 3 shows the results of our AME analysis by plotting the different activities on the x-axis of the panel, and the specific estimated walking probability changes on the y-axis. Each row in the panel displays the attribute under analysis, and each column in the panel indicates the type of model. There are three empty panels since in the objective accessibility model does not include perception, and the perception model does not include objective accessibility.

The graph illustrates how changes in accessibility and perception influence people's choice between walking and driving for various activities. For daily shopping, an increase of 100 more shopping destinations results in a 5 % higher likelihood of walking, as observed in model 1. This increase in shopping destinations represents less than 10 % of the maximum number of shops in these cities. Conversely, if individuals' perceptions change from 'close' to 'far,' there is a 35 % lower likelihood of walking, as demonstrated in model 2. In model 3, which includes both objective and perceived accessibility, a similar 5 % increase in walking likelihood is anticipated for every 100 new shopping destinations. However, the shift in perception from 'close' to 'far' is only associated with a 25 % decrease in walking likelihood, significantly less compared to the perception-only model.

Similarly, in the scenarios of non-daily shopping and restaurants, the results closely resemble those observed in the context of daily shopping, with a slight increase in the impact of objective accessibility on walking probability. Contrastingly, the effect of objective accessibility on walking probability for entertainment-related activities is more significant, with each additional destination within the 15-minute walk radius increasing the likelihood of walking by 0.3 %. This substantial effect suggests that the availability of entertainment venues is a stronger determinant of walking behavior compared to other types of destinations. Moreover, comparisons between models combining both objective and perceived accessibility versus those considering only objective accessibility indicate a notable level of similarity. This similarity suggests that the density of destinations as a measure of objective accessibility has an independent and notable influence on walking behavior, regardless of how closely it aligns with individuals' perceptions.

In the realm of non-daily shopping, the impact of perception on the probability of walking is more gradual than in other activities. This suggests that individuals' walking decisions for non-daily shopping are less influenced by perceived distance than for other activities.

The restaurant model within the two attributes approach shows a pronounced sensitivity to changes in perception. There is a

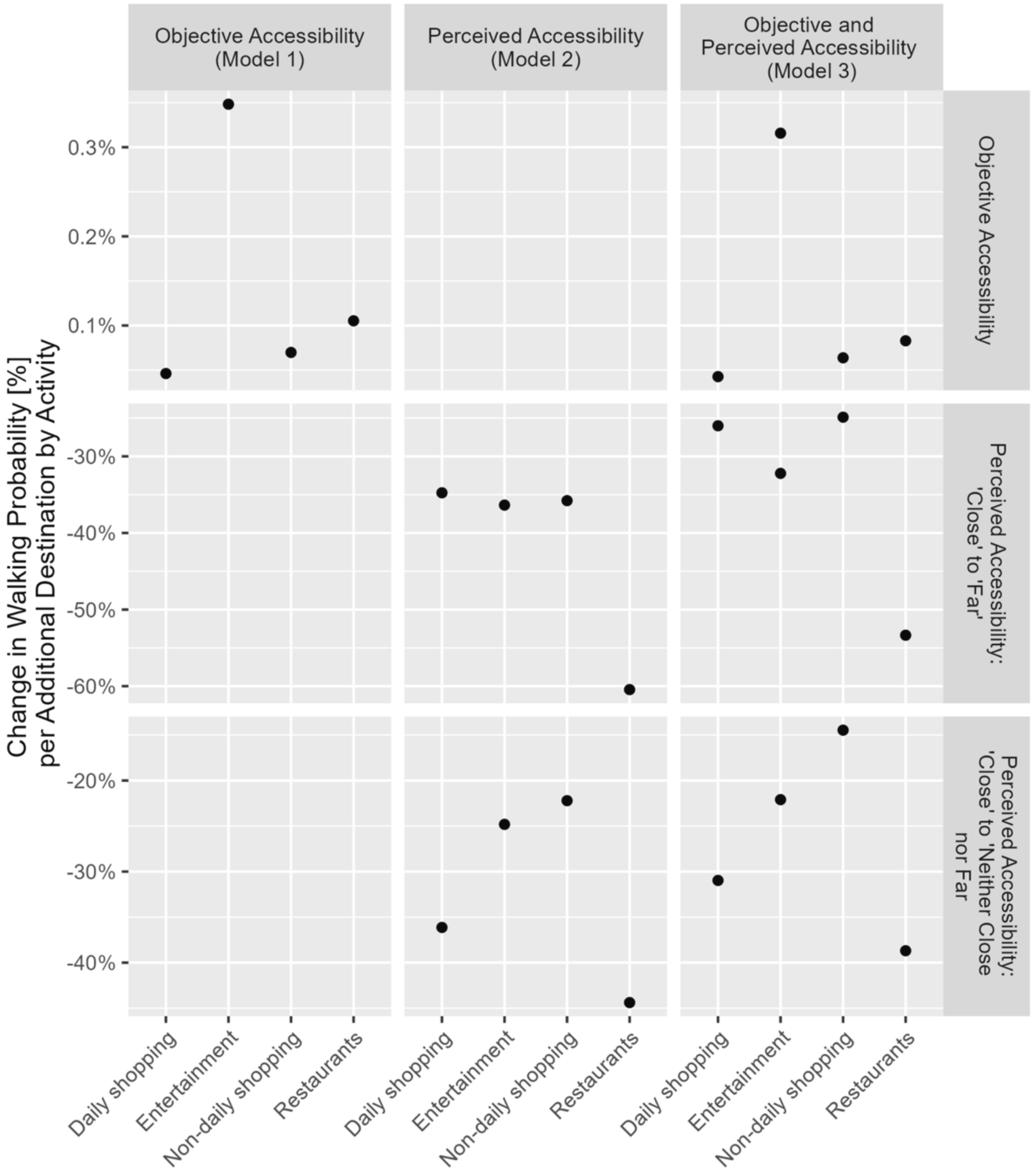

Fig. 3. Average marginal effects for perceived and objective accessibility.

substantial 40 % decrease in the likelihood of walking when an individuals' perception of a restaurant shifts from "close" to "neither close nor far", and a 55 % decrease when the perception shifts to "far". Entertainment shows a transition that is more gradual than daily shopping but not as gradual as non-daily shopping. The walking probability decreases by 32 % when a destination's perceived proximity shifts from 'close' to 'far', and by 22 % when the shift is from 'close' to 'neither close nor far'.

In models that consider only perception, as opposed to those considering objective accessibility, the magnitudes of the effects tend to increase, suggesting an overestimation of the effect of perception change when local accessibility measures are not included. For example, when transitioning from "close" to "far", the reduction in walking probability for shopping and entertainment in models considering both attributes is between 25 and 32 %, while it exceeds 35 % in models considering only perception. Similarly, for restaurants, the reduction in walking probability is approximately 55 % in models considering both attributes, while it reaches 60 % in models considering only perception.

6. Discussion and conclusion

Our study explored how perceived and objective accessibility influence mode choice, particularly walking behavior. We found that perceived accessibility is strongly tied to objective accessibility, but their effects vary by activity type. These insights highlight the complexity of the relationship between actual accessibility, perception, and travel behavior, underscoring the importance of considering both factors when promoting walking as a sustainable mode of transport.

Our analysis reveals a close relationship between perceived and objective accessibility in mid-size Spanish cities. Individuals who live near a high number of destinations tend to perceive those locations as closer. This finding aligns with other studies (Ma and Cao, 2019; Næss et al., 2021) but contrasts with research that suggesting that perceived accessibility can sometimes deviate from objective measures (Tuckel and Milczarski, 2015; Van Der Vlugt et al., 2019).

The relationship between objective accessibility and perception varies by destination type. For example, objective accessibility to entertainment destinations has a more linear impact on perceived accessibility, while daily shopping trips, though also linear, exhibit less sensitivity to changes in objective accessibility.

For restaurants, we hypothesize that perceived accessibility may align more closely with specific objective measures, such as proximity to high-end or fast-food options, rather than broad restaurant categories. This is because the general accessibility indicator may not fully capture the individual preferences and specific characteristics of dining options, which play a significant role in decision-making. The wide variety of restaurants makes perceived accessibility more relevant, as individuals are likely to consider personal preferences and the nature of the destination. Consequently, these factors make perceived accessibility more important than objective accessibility in this case, as personal factors like the type of restaurant weigh more heavily in determining whether individuals choose to walk.

Daily shopping trips exhibit minimal sensitivity to changes in local accessibility across all destination density ranges. Marginal increases in accessibility have little impact on perceived accessibility, likely due to the regularity of these trips. In this case, perception seems to be idriven more by habitual behavior than by objective factors.

Non-daily shopping destinations, such as clothing or music stores, tend to be more dispersed, which may make perceived accessibility less relevant for the walking choice. Travel choices for these destinations are likely influenced by specific accessibility information, as individuals may plan these trips more carefully and have better knowledge of their options and objective accessibility. We hypothesize that in areas with lower commercial activity, objective accessibility might play a more significant role in influencing walking behavior. In contrast, in areas with higher commercial presence, As the alignment between objective and perceived accessibility improves, objective accessibility may serve as a more reliable predictor of walking behavior.

Entertainment objective measures demonstrate a more linear effect on perceived accessibility, with stronger responses to increases in local accessibility. Travel choices for entertainment are more sensitive to changes in destination density, suggesting that individuals' decisions to walk for entertainment are more strongly influenced by marginal increases in accessibility compared to other activities.

Our findings support the Theory of Planned Behavior (TPB), which posits that perceptions influence intentional behaviors like walking. Perceived accessibility appears to mediate the link between environmental factors and walking behavior. In the case of restaurants, for example, perceived accessibility has a stronger influence on walking behavior than objective measures alone. This potential mediating role also applies to other activities, though the balance between perception and objective accessibility varies by type of activity.

Additionally, evidence from previous research (Van Der Vlugt et al., 2022; Ma and Cao, 2019) suggests that the relationship between walking and perceived accessibility may be bidirectional. Frequent walking may reshape individuals' perceptions of accessibility as they become more familiar with their environment. This feedback loop reinforces the likelihood of walking, suggesting that repeated walking behavior makes destinations feel closer over time. Understanding this dynamic is essential for advancing future research on the interaction between accessibility and travel behavior.

Our study provides valuable insights for urban planners seeking to promote walking and sustainable transport modes. We hypothesize that in high-accessibility areas, further increases in objective accessibility may lead to diminishing returns in terms of perceived accessibility, especially for restaurants and non-daily shopping destinations. As such, planners should consider the potential mediating role of perceived accessibility and recognize the importance of psychological and social factors, including familiarity and attachment to place, when designing interventions to encourage walking. Addressing these factors—beyond improving physical infrastructure—may result in more impactful strategies to reduce car dependency and enhance walkability.

For instance, enhancing the diversity and quality of local destinations, as well as improving walkable environments, may increase perceived accessibility and encourage walking. In contrast, relying solely on objective accessibility measures, such as proximity to destinations, may not always be sufficient to influence behavior. This hypothesis should inform future policies aimed at improving walkability and sustainable urban mobility.

6.1. Limitations

This study acknowledges a few limitations that should be taken into account when interpreting the results, though they do not notably detract from the overall findings. First, the reliance on self-reported survey data introduces the potential for response or non-response bias. Although detailed response rates were not available, the use of random sampling techniques helps mitigate these concerns and improve the representativeness of the sample.

Second, while perceived accessibility as a key variable may incorporate an element of subjectivity, this reflects the influence of psychological factors—such as safety, comfort, and environmental quality—which are important in shaping individuals' travel behavior. Although a traditional Likert scale was not employed, the use of ordinal categories is a suitable approach for capturing perceptions, and any potential limitations in comparability with other studies are minimal.

Moreover, the study focused on a limited set of sociodemographic variables to maintain model simplicity. While factors such as income, family structure, and transport-related attitudes were not included, this was a deliberate methodological choice to keep the analysis focused. Future studies could extend the model to incorporate these additional variables for a more nuanced understanding, but their absence does not notably diminish the validity of the current findings.

Finally, the selection of a 15-minute threshold for objective accessibility was informed by its prominence in urban planning literature. While exploring alternative thresholds, such as 10 or 20 minutes, could yield further insights, the chosen threshold remains highly relevant and appropriate for the scope of this study. Future research could benefit from examining the effects of different thresholds to further enrich the understanding of accessibility's role in influencing walking behavior.

CRediT authorship contribution statement

Jaime Orrego-Oñate: Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. **Oriol Marquet:** Writing – review & editing, Writing – original draft, Funding acquisition, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

1. Perception ordered logits

Term	Estimate	std. error	p. value	coef. type	Type
Objective Accessibility: Shopping destinations	−0.001	0.000	0.034	coefficient	Daily shopping
Close|Far	2.508	0.182		scale	Daily shopping
Far|Neither Far nor Close	3.280	0.221		scale	Daily shopping
Objective Accessibility: Shopping destinations	−0.002	0.000	0.000	coefficient	Non-daily shopping
Close|Far	0.751	0.104		scale	Non-daily shopping
Far|Neither Far nor Close	1.630	0.120		scale	Non-daily shopping
Objective Accessibility: Restaurants	−0.003	0.001	0.000	coefficient	Restaurants
Close|Far	1.260	0.128		scale	Restaurants
Far|Neither Far nor Close	2.042	0.151		scale	Restaurants
Objective Accessibility: Entertainment	−0.004	0.001	0.002	coefficient	Entertainment
Close|Far	0.509	0.144		scale	Entertainment
Far|Neither Far nor Close	1.742	0.160		scale	Entertainment

2. Binary logits

Term	Estimate	P-value	Model	Type
Intercept	0.815	0.01	Model 1	Daily shopping
30–44 years old	−0.603	0.05	Model 1	Daily shopping
45–64 years old	−0.407	0.17	Model 1	Daily shopping
65 + years old	−0.109	0.74	Model 1	Daily shopping
Education: Complete High School	0.129	0.50	Model 1	Daily shopping
Education: Incomplete High School	0.509	0.05	Model 1	Daily shopping
Women	0.168	0.34	Model 1	Daily shopping

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Term	Estimate	P-value	Model	Type
Objective Accessibility: Shopping destinations	0.004	0.00	Model 1	Daily shopping
Intercept	2.093	0.00	Model 2	Daily shopping
30–44 years old	−0.557	0.06	Model 2	Daily shopping
45–64 years old	−0.371	0.20	Model 2	Daily shopping
65 + years old	0.339	0.30	Model 2	Daily shopping
Education: Complete High School	−0.069	0.72	Model 2	Daily shopping
Education: Incomplete High School	0.005	0.98	Model 2	Daily shopping
Women	0.136	0.43	Model 2	Daily shopping
Perception: Far	−1.867	0.00	Model 2	Daily shopping
Perception: Neither Far nor Close	−1.924	0.00	Model 2	Daily shopping
Intercept	0.945	0.00	Model 3	Daily shopping
30–44 years old	−0.533	0.09	Model 3	Daily shopping
45–64 years old	−0.325	0.28	Model 3	Daily shopping
65 + years old	0.137	0.69	Model 3	Daily shopping
Education: Complete High School	0.069	0.73	Model 3	Daily shopping
Education: Incomplete High School	0.394	0.14	Model 3	Daily shopping
Women	0.156	0.39	Model 3	Daily shopping
Objective Accessibility: Shopping destinations	0.004	0.00	Model 3	Daily shopping
Perception: Far	−1.733	0.00	Model 3	Daily shopping
Perception: Neither Far nor Close	−2.001	0.00	Model 3	Daily shopping
Intercept	−1.213	0.00	Model 1	Non-daily shopping
30–44 years old	0.057	0.80	Model 1	Non-daily shopping
45–64 years old	0.451	0.04	Model 1	Non-daily shopping
65 + years old	0.549	0.02	Model 1	Non-daily shopping
Education: Complete High School	−0.117	0.44	Model 1	Non-daily shopping
Education: Incomplete High School	−0.350	0.07	Model 1	Non-daily shopping
Women	0.173	0.20	Model 1	Non-daily shopping
Objective Accessibility: Shopping destinations	0.004	0.00	Model 1	Non-daily shopping
Intercept	0.421	0.03	Model 2	Non-daily shopping
30–44 years old	−0.071	0.74	Model 2	Non-daily shopping
45–64 years old	0.305	0.13	Model 2	Non-daily shopping
65 + years old	0.711	0.00	Model 2	Non-daily shopping
Education: Complete High School	−0.256	0.07	Model 2	Non-daily shopping
Education: Incomplete High School	−0.718	0.00	Model 2	Non-daily shopping
Women	0.157	0.21	Model 2	Non-daily shopping
Perception: Far	−1.556	0.00	Model 2	Non-daily shopping
Perception: Neither Far nor Close	−0.937	0.00	Model 2	Non-daily shopping
Intercept	−0.924	0.00	Model 3	Non-daily shopping
30–44 years old	0.026	0.91	Model 3	Non-daily shopping
45–64 years old	0.465	0.03	Model 3	Non-daily shopping
65 + years old	0.590	0.01	Model 3	Non-daily shopping
Education: Complete High School	−0.133	0.39	Model 3	Non-daily shopping
Education: Incomplete High School	−0.356	0.07	Model 3	Non-daily shopping
Women	0.157	0.26	Model 3	Non-daily shopping
Objective Accessibility: Shopping destinations	0.003	0.00	Model 3	Non-daily shopping
Perception: Far	−1.295	0.00	Model 3	Non-daily shopping
Perception: Neither Far nor Close	−0.740	0.00	Model 3	Non-daily shopping
Intercept	−0.249	0.30	Model 1	Restaurants
30–44 years old	0.362	0.13	Model 1	Restaurants
45–64 years old	0.820	0.00	Model 1	Restaurants
65 + years old	0.698	0.01	Model 1	Restaurants
Education: Complete High School	−0.258	0.12	Model 1	Restaurants
Education: Incomplete High School	−0.556	0.01	Model 1	Restaurants
Women	−0.162	0.29	Model 1	Restaurants
Objective Accessibility: Restaurants	0.006	0.00	Model 1	Restaurants
Intercept	1.106	0.00	Model 2	Restaurants
30–44 years old	0.248	0.31	Model 2	Restaurants
45–64 years old	0.778	0.00	Model 2	Restaurants
65 + years old	0.904	0.00	Model 2	Restaurants
Education: Complete High School	−0.468	0.01	Model 2	Restaurants
Education: Incomplete High School	−0.861	0.00	Model 2	Restaurants
Women	−0.025	0.88	Model 2	Restaurants
Perception: Far	−2.917	0.00	Model 2	Restaurants
Perception: Neither Far nor Close	−2.042	0.00	Model 2	Restaurants
Intercept	0.202	0.44	Model 3	Restaurants
30–44 years old	0.306	0.24	Model 3	Restaurants
45–64 years old	0.899	0.00	Model 3	Restaurants
65 + years old	0.745	0.01	Model 3	Restaurants
Education: Complete High School	−0.373	0.04	Model 3	Restaurants
Education: Incomplete High School	−0.660	0.01	Model 3	Restaurants

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Term	Estimate	P-value	Model	Type
Women	−0.076	0.65	Model 3	Restaurants
Objective Accessibility: Restaurants	0.006	0.00	Model 3	Restaurants
Perception: Far	−2.820	0.00	Model 3	Restaurants
Perception: Neither Far nor Close	−1.999	0.00	Model 3	Restaurants
Intercept	−1.250	0.00	Model 1	Entertainment
30–44 years old	−0.026	0.91	Model 1	Entertainment
45–64 years old	0.189	0.37	Model 1	Entertainment
65 + years old	0.324	0.16	Model 1	Entertainment
Education: Complete High School	−0.452	0.00	Model 1	Entertainment
Education: Incomplete High School	−0.445	0.04	Model 1	Entertainment
Women	−0.088	0.52	Model 1	Entertainment
Objective Accessibility: Entertainment	0.016	0.00	Model 1	Entertainment
Intercept	0.602	0.00	Model 2	Entertainment
30–44 years old	−0.229	0.30	Model 2	Entertainment
45–64 years old	0.118	0.57	Model 2	Entertainment
65 + years old	0.632	0.01	Model 2	Entertainment
Education: Complete High School	−0.490	0.00	Model 2	Entertainment
Education: Incomplete High School	−0.681	0.00	Model 2	Entertainment
Women	−0.027	0.84	Model 2	Entertainment
Perception: Far	−1.620	0.00	Model 2	Entertainment
Perception: Neither Far nor Close	−1.049	0.00	Model 2	Entertainment
Intercept	−0.894	0.00	Model 3	Entertainment
30–44 years old	−0.116	0.62	Model 3	Entertainment
45–64 years old	0.224	0.31	Model 3	Entertainment
65 + years old	0.457	0.06	Model 3	Entertainment
Education: Complete High School	−0.423	0.01	Model 3	Entertainment
Education: Incomplete High School	−0.423	0.06	Model 3	Entertainment
Women	−0.066	0.65	Model 3	Entertainment
Objective Accessibility: Entertainment	0.016	0.00	Model 3	Entertainment
Perception: Far	−1.582	0.00	Model 3	Entertainment
Perception: Neither Far nor Close	−1.045	0.00	Model 3	Entertainment

References

Ajzen, I., 1991. The theory of planned behavior. Organ. Behav. Hum. Decis. Process. 50, 179–211. https://doi.org/10.1016/0749-5978(91)90020-T.

Allen, J., Farber, S., 2020. Planning transport for social inclusion: An accessibility-activity participation approach. Transp. Res. Part D: Transp. Environ. 78, 102212. https://doi.org/10.1016/j.trd.2019.102212.

Bandura, A., 1986. Social foundations of thought and action: a social cognitive theory, Prentice-Hall series in social learning theory. Prentice-Hall, Englewood Cliffs, N.J.

Barabas, J., Jerit, J., 2010. Are Survey Experiments Externally Valid? Am Polit Sci Rev 104, 226–242. https://doi.org/10.1017/S0003055410000092.

Barton, H., Horswell, M., Millar, P., 2012. Neighbourhood Accessibility and Active Travel. Plan. Pract. Res. 27, 177–201. https://doi.org/10.1080/02697459.2012.661636.

Blandin, L., Vecchio, G., Hurtubia, R., Aitken, I.T., 2023. Car dependency in the urban margins: the influence of perceived accessibility on mode choice (preprint). Open Science Framework. https://doi.org/10.31219/osf.io/dk2mb.

Boakye-Dankwa, E., Nathan, A., Barnett, A., Busija, L., Lee, R.S.Y., Pachana, N., Turrell, G., Cerin, E., 2018. Walking behaviour and patterns of perceived access to neighbourhood destinations in older adults from a low-density (Brisbane, Australia) and an ultra-dense city (Hong Kong, China). Cities 84, 23–33. https://doi.org/10.1016/j.cities.2018.07.002.

Chan, E.T.H., Schwanen, T., Banister, D., 2021. The role of perceived environment, neighbourhood characteristics, and attitudes in walking behaviour: evidence from a rapidly developing city in China. Transportation 48, 431–454. https://doi.org/10.1007/s11116-019-10062-2.

Chen, W., Cao, C., Fang, X., Kang, Z., 2019. Expanding the Theory of Planned Behaviour to Reveal Urban Residents' Pro-Environment Travel Behaviour. Atmos. 10, 467. https://doi.org/10.3390/atmos10080467.

Cheng, J., Bertolini, L., 2013. Measuring urban job accessibility with distance decay, competition and diversity. Journal of Transport Geography 30, 100–109. https://doi.org/10.1016/j.jtrangeo.2013.03.005.

Chor, D., Cardoso, L.O., Nobre, A.A., Griep, R.H., de Fonseca, M., J.M., Giatti, L., Bensenor, I., del Carmen Bisi Molina, M., Aquino, E.M.L., Diez-Roux, A., de Pina Castiglione, D., Santos, S.M.,, 2016. Association between perceived neighbourhood characteristics, physical activity and diet quality: results of the Brazilian Longitudinal Study of Adult Health (ELSA-Brasil). BMC Public Health 16. https://doi.org/10.1186/s12889-016-3447-5.

Cui, M., Levinson, D., 2020. Multi-activity access: How activity choice affects opportunity. Transp. Res. Part D: Transp. Environ. 85. https://doi.org/10.1016/j.trd.2020.102364.

Curtis, C., Scheurer, J., 2010. Planning for sustainable accessibility: developing tools to aid discussion and decision making. Prog. Plan. 74, 53–106.

De Vos, J., Lättman, K., Van Der Vlugt, A.-L., Welsch, J., Otsuka, N., 2023. Determinants and effects of perceived walkability: a literature review, conceptual model and research agenda. Transp. Rev. 43, 303–324. https://doi.org/10.1080/01441647.2022.2101072.

Deboosere, R., El-Geneidy, A.M., Levinson, D., 2018. Accessibility-oriented development. J. Transp. Geogr. 70, 11–20. https://doi.org/10.1016/j.jtrangeo.2018.05.015.

Ekkel, E.D., de Vries, S., 2017. Nearby green space and human health: Evaluating accessibility metrics. Landsc. Urban Plan. 157, 214–220. https://doi.org/10.1016/j.landurbplan.2016.06.008.

Ferrer-Ortiz, C., Marquet, O., Mojica, L., Vich, G., 2022. Barcelona under the 15 - minute city lens: mapping the accessibility and proximity potential based on pedestrian travel times. Smart Cities 5, 146–161. https://doi.org/10.3390/smartcities5010010.

Fullerton, A.S., 2009. A Conceptual Framework for Ordered Logistic Regression Models. Sociol. Methods Res. 38, 306–347. https://doi.org/10.1177/0049124109346162.

Gebel, K., Bauman, A.E., Sugiyama, T., Owen, N., 2011. Mismatch between perceived and objectively assessed neighborhood walkability attributes: Prospective relationships with walking and weight gain. Health Place 17, 519–524. https://doi.org/10.1016/j.healthplace.2010.12.008.

GEMOTT, 2023. MOVACTIVA [WWW Document]. MOVACTIVA. URL https://movactiva.es (accessed 4.9.24).

Geurs, K., Ritsema van Eck, J., 2001. Accessibility measures: Review and applications. Utrecht University, Bilthoven/Utrecht.

Handy, S., 2020. Is accessibility an idea whose time has finally come? Transp. Res. Part D: Transp. Environ. 83, 102319. https://doi.org/10.1016/j.trd.2020.102319.

Haustein, S., Nielsen, T.A.S., 2016. European mobility cultures: A survey-based cluster analysis across 28 European countries. J. Transp. Geogr. 54, 173–180. https://doi.org/10.1016/j.jtrangeo.2016.05.014.

Hosford, K., 2022. Is the 15-minute city within reach? Evaluating walking and cycling accessibility to grocery stores in Vancouver. Transp. Res. Interdiscip. Perspect. 14. https://doi.org/10.1016/j.trip.2022.100602.

Jamei, E., Chan, M., Chau, H.W., Gaisie, E., Lättman, K., 2022. Perceived Accessibility and Key Influencing Factors in Transportation. Sustainability 14, 10806. https://doi.org/10.3390/su141710806.

Knap, E., Ulak, M.B., Geurs, K.T., Mulders, A., Van Der Drift, S., 2023. A composite X-minute city cycling accessibility metric and its role in assessing spatial and socioeconomic inequalities – A case study in Utrecht, the Netherlands. Journal of Urban Mobility 3, 100043. https://doi.org/10.1016/j.urbmob.2022.100043.

Lättman, K., Olsson, L.E., Friman, M., 2018. A new approach to accessibility – Examining perceived accessibility in contrast to objectively measured accessibility in daily travel. Res. Transp. Econ. 69, 501–511. https://doi.org/10.1016/j.retrec.2018.06.002.

Lättman, K., Friman, M., Olsson, L.E., 2020. Restricted car-use and perceived accessibility. Transp. Res. Part D: Transp. Environ. 78, 102213. https://doi.org/10.1016/j.trd.2019.102213.

Lättman, K., Olsson, L.E., Friman, M., 2024. Perceived accessibility: unveiling inequalities in transport justice. Sustainable Transport and Livability 1. https://doi.org/10.1080/29941849.2024.2373050.

Lättman, K., 2020. Restricted car-use and perceived accessibility. Transportation Research Part D: Transport and Environment.

Levine, J., 2020. A century of evolution of the accessibility concept. Transp. Res. Part D: Transp. Environ. 83, 102309. https://doi.org/10.1016/j.trd.2020.102309.

Lynn, P., Beerten, R., Laiho, J., Martin, J., 2001. Recommended standard final outcome categories and standard definitions of response rate for social surveys. ISER Working Paper Series, No. 2001-23, University of Essex, Institute for Social and Economic Research (ISER).

Ma, L., Cao, J., 2019. How perceptions mediate the effects of the built environment on travel behavior? Transportation 46, 175–197. https://doi.org/10.1007/s11116-017-9800-4.

MacInnis, B., Krosnick, J.A., Ho, A.S., Cho, M.-J., 2018. The Accuracy of Measurements with Probability and Nonprobability Survey Samples: Replication and Extension. Public Opin. Q. 82, 707–744. https://doi.org/10.1093/poq/nfy038.

Mandal, A., Johansson, C., Lindelöw, D., 2023. Exploring walking from the perspective of theory of planned behavior. Transp. Res. Interdiscip. Perspect. 22, 100931. https://doi.org/10.1016/j.trip.2023.100931.

Marquet, O., Ríos Bedoya, V., Miralles-Guasch, C., 2017. Local accessibility inequalities and willingness to walk in Latin American cities. Findings from Medellín. Colombia. International Journal of Sustainable Transportation 11, 186–196. https://doi.org/10.1080/15568318.2016.1230804.

Martens, K., Singer, M.E., Cohen-Zada, A.L., 2022. Equity in Accessibility: Moving From Disparity to Insufficiency Analyses. J. Am. Plann. Assoc. 88, 479–494. https://doi.org/10.1080/01944363.2021.2016476.

McNeil, N., 2011. Bikeability and the 20-min Neighborhood: How Infrastructure and Destinations Influence Bicycle Accessibility. Transp. Res. Rec. 2247, 53–63. https://doi.org/10.3141/2247-07.

Næss, P., Stefansdottir, H., Peters, S., Czepkiewicz, M., Heinonen, J., 2021. Residential Location and Travel in the Reykjavik Capital Region. Sustainability 13, 6714. https://doi.org/10.3390/su13126714.

Nordfjærn, T., Lind, H.B., Şimşekoğlu, Ö., Jørgensen, S.H., Lund, I.O., Rundmo, T., 2019. The role of social cognition in perceived thresholds for transport mode change. Transport Policy 83, 88–96. https://doi.org/10.1016/j.tranpol.2019.09.006.

Poorthuis, A., Zook, M., 2023. Moving the 15-minute city beyond the urban core: The role of accessibility and public transport in the Netherlands. J. Transp. Geogr. 110, 103629. https://doi.org/10.1016/j.jtrangeo.2023.103629.

Pot, F.J., Van Wee, B., Tillema, T., 2021. Perceived accessibility: What it is and why it differs from calculated accessibility measures based on spatial data. J. Transp. Geogr. 94, 103090. https://doi.org/10.1016/j.jtrangeo.2021.103090.

Ryan, J., Martens, K., 2023. Defining and implementing a sufficient level of accessibility: What's stopping us? Transp. Res. A Policy Pract. 175, 103792. https://doi.org/10.1016/j.tra.2023.103792.

Salas-Eljatib, C., Fuentes-Ramirez, A., Gregoire, T.G., Altamirano, A., Yaitul, V., 2018. A study on the effects of unbalanced data when fitting logistic regression models in ecology. Ecol. Ind. 85, 502–508. https://doi.org/10.1016/j.ecolind.2017.10.030.

Singer, M.E., Cohen-Zada, A.L., Martens, K., 2022. Core versus periphery: Examining the spatial patterns of insufficient accessibility in U.S. metropolitan areas. J. Transp. Geogr. 100, 103321. https://doi.org/10.1016/j.jtrangeo.2022.103321.

Solbraa, A.K., Anderssen, S.A., Holme, I.M., Kolle, E., Hansen, B.H., Ashe, M.C., 2018. The built environment correlates of objectively measured physical activity in Norwegian adults: A cross-sectional study. J. Sport Health Sci. 7, 19–26. https://doi.org/10.1016/j.jshs.2017.11.002.

Song, G., He, X., Kong, Y., Li, K., Song, H., Zhai, S., Luo, J., 2022. Improving the Spatial Accessibility of Community-Level Healthcare Service toward the "15-Minute City" Goal in China. ISPRS Int. J. Geo Inf. 11. https://doi.org/10.3390/ijgi11080436.

Staricco, L., 2022. 15-, 10- or 5-minute city? A focus on accessibility to services in Turin, Italy. Journal of Urban Mobility 2. https://doi.org/10.1016/j.urbmob.2022.100030.

Suarez-Balcazar, Y., Early, A.R., Garcia, C., Balcazar, D., Arias, D.L., Morales, M., 2020. Walkability Safety and Walkability Participation: A Health Concern. Health Educ Behav 47, 430–438. https://doi.org/10.1177/1090198120903256.

Tsou, K.-W., Hung, Y.-T., Chang, Y.-L., 2005. An accessibility-based integrated measure of relative spatial equity in urban public facilities. Cities 22, 424–435. https://doi.org/10.1016/j.cities.2005.07.004.

Tuckel, P., Milczarski, W., 2015. Walk Score, Perceived Neighborhood Walkability, and Walking in the US. Am J Hlth Behav 39, 242–256. https://doi.org/10.5993/AJHB.39.2.11.

Ulloa-Leon, F., Correa-Parra, J., Vergara-Perucich, F., Cancino-Contreras, F., Aguirre-Nuñez, C., 2023. "15-Minute City" and Elderly People: Thinking about Healthy Cities. Smart Cities 6, 1043–1058. https://doi.org/10.3390/smartcities6020050.

Vale, D., Lopes, A.S., 2023. Accessibility inequality across Europe: a comparison of 15-minute pedestrian accessibility in cities with 100,000 or more inhabitants. Npj Urban Sustain 3, 55. https://doi.org/10.1038/s42949-023-00133-w.

Van Acker, V., Derudder, B., Witlox, F., 2010. Assessing objective and subjective spatial influences of modal choice. Presented at the Proceedings of the European Transport Conference, Glasgow, Scotland.

Van Der Vlugt, A.-L., Curl, A., Wittowsky, D., 2019. What about the people? Developing measures of perceived accessibility from case studies in Germany and the UK. Applied Mobilities 4, 142–162. https://doi.org/10.1080/23800127.2019.1573450.

Van Der Vlugt, A.-L., Curl, A., Scheiner, J., 2022. The influence of travel attitudes on perceived walking accessibility and walking behaviour. Travel Behaviour and Society 27, 47–56. https://doi.org/10.1016/j.tbs.2021.11.002.

Willberg, E., Fink, C., Toivonen, T., 2023. The 15-minute city for all? – Measuring individual and temporal variations in walking accessibility. J. Transp. Geogr. 106, 103521. https://doi.org/10.1016/j.jtrangeo.2022.103521.

Zhang, D., Ma, S., Fan, J., Xie, D., Jiang, H., Wang, G., 2023. Assessing spatial equity in urban park accessibility: an improve two-step catchment area method from the perspective of 15-mintue city concept. Sustain. Cities Soc. 98, 104824. https://doi.org/10.1016/j.scs.2023.104824.