

Do modern cities encourage or discourage walking of health-impaired seniors?

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Abstract

Walking outdoors is essential for healthy ageing. Cities and especially 15-minute cities stimulate this walking by making facilities accessible on a short distance and by investing in sidewalks. Not much is known however about how effective different sidewalk improvements are in increasing the frequency and length of seniors' walking, especially for people facing mobility impairments. Our paper provides novel insights by running a stated choice experiment, in which participants in the age of 65 to 85 repeatedly select between walking routes that differ not only on sidewalk characteristics but also in walking time. The trade-off respondents make in the experiment is: am I willing to walk longer if the sidewalk is attractive. We vary the purpose of being outside (walk to the supermarket or a recreational stroll), and specify the walking route characteristics in terms of comfort and enjoyment. Using various model specifications, we find the probability of leaving home for a walk for mobility-impaired seniors to be around 60%, against 90% for a more healthy peer. Once outside, mobility-impaired older people

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walk only half as long as non-mobility impaired peers. We show that the most effective way to reduce this gap in willingness-to-walk is investing in benches. Benches along the route raise the probability of going outdoors for the mobility-impaired from 60% to 75% and increase the time spent walking by 8 minutes. Greenery along the route also strongly boosts the time spent walking. We illustrate how obtained insights can be used in practical urban design to improve the walkability of public spaces around senior homes.

Keywords: healthy ageing; walking frequency and duration; 15-minute city; sidewalks; mobility-impaired seniors

1 Introduction

Walking outdoors is essential for healthy ageing. It helps prevent various diseases and leads to a higher quality of life for an individual and to lower health care costs for the society. Cities and especially 15-minute cities stimulate walking by making facilities accessible on a short distance and by investing in sidewalks. The list of criteria for elderly-inclusive sidewalks is extensive. For example, various Dutch cities mention in their urban plans: wide and obstacle-free pavements, high frequency of benches or handrails, raised crossings to slow down traffic, no car or cycle parking immediately adjacent to intersections, good lighting, recognizable routes, layout that facilitates spontaneous meetings, toilets on the route, etc.¹ However, due to geographical and budget restrictions, it is not always possible to meet these criteria. Therefore, a ranking is desirable - which sidewalk characteristics are most effective in increasing the frequency and length of senior walking and which are least. In this paper, we aim to provide novel insights into this topic.

Walking is the most common type of outdoor activity, for which a person only needs to leave the home. Still, a combination of physical limitations (e.g. arthritis) and specific elements of the built environment (e.g. stairs on the path) can make walking outside almost prohibitive. This paper aims to figure out how much different sidewalk characteristics increase respectively decrease the

¹See Section 3 for an overview per city.

willingness to walk not only for healthy but also for mobility-impaired seniors.

There exists a small literature on the role of the built environment in cities as determinant of physical activity of the seniors (see [Clarke and Twardzik 2021](#) for an overview and also later studies by [Cerin et al. 2020](#); [Song et al. 2024](#); [Hu et al. 2024](#)).² Many of these studies focus on parks, and [Van Cauwenberg et al. \(2016\)](#) is to our knowledge the only study that specifically looks at the sidewalk design and how elderly experience different elements of it. The paper however does not quantify how effective different sidewalk improvements are in increasing the frequency and length of seniors' walking, neither does it look at the specific needs of the large group elderly with mobility impairments. We fill this gap by designing and running a stated choice experiment, in which participants in the age of 65 to 85 repeatedly select between walking routes that differ not only on sidewalk characteristics but also on walking time. The trade-off respondents make in the experiment is thus: am I willing to walk longer if the sidewalk is attractive.

Sidewalk designs in the experiment are inspired by a combination of insights from (i) urban design research ([Gehl, 1987](#)); (ii) elderly health and mobility research; (iii) the common street design in Dutch cities; (iv) observational research done in Dutch city of Rotterdam in preparation to the experiment. We frame the experiment in such a way as to allow to distinguish between the utilitarian (walk to the supermarket) and the recreational walking goals as the importance of sidewalk design may differ between the two. Further, we use two alternative model specifications to describe the decision about the frequency and length of walking: a discrete choice (logit) and a continuous censored (tobit) model. We show that both yield similar results, supporting our conclusions.

In the experiment, we find the probability of leaving home for a walk to the supermarket to be 60% for the mobility-impaired seniors, and 90% for the healthy peers. Also the length of the walk for the mobility-impaired is on average only half as long as for the more healthy peers. We find that inclusive street design can reduce this gap, with the most effective solution being benches. Benches

²Other determinants are e.g. the socio-economic status (e.g. [Boyd et al. \(2018\)](#)), the effectiveness of various social and smart technology interventions (e.g. [Sipila et al. \(2018\)](#)).

along the route raise the probability of going outdoors for the mobility-impaired from 60% to 75% and increase the time spent walking with two-and-a-half times. Restorative greenery also strongly boosts the walking frequency for the mobility-impaired (to 70%) and doubles the walking length. We illustrate how obtained insights can be used in practical urban design to improve public spaces and walking routes around senior homes.

There are three reasons why our results are of special interest for practitioners developing senior policies and policy makers aiming at 15-minute cities. First, populations around the world are ageing at a fast pace and various countries make arrangements to stimulate older people to live independently at home for as long as possible (Mosca et al., 2017). According to the United Nations (2019), senior-friendly physical environments and public spaces are amongst the most important determinants of healthy ageing and independent living. We show which sidewalk improvements can enable older people to continue with or even increase their outdoor activities thus supporting a higher quality of life and better health.

Second, we contribute novel practical knowledge about inclusive urban design for people having difficulty with walking. For example, in the Netherlands, one fifth of the adults over the age of 55 experiences a physical impairment (RIVM, 2015). This considerably reduces the intensity of (mild) physical exercise people perform. Thus, out of healthy 55+ individuals, 80% perform mild physical activity for 30 minutes during 5 or more days per week. For people with physical impairments, this percentage is only half as large: 40% (RIVM, 2015). Sidewalks that stimulate these people to walk are thus of primary importance.

Finally, our study contributes to solving the trade-off between standardization and customization that urban developers face (see Hofman et al. 2006). In this paper we apply the empirical results to evaluate the quality of existing walking routes surrounding senior homes, and optimally select the interventions that maximally stimulate the physical activity of older people, while meeting other (e.g. financial) restrictions.

The rest of the paper is organized as follows. Section 2 discusses the contributions of the paper to the related literature. Section 3 introduces the institutional

background, the conceptual framework for the experiment and formulates hypotheses. Section 4 deals with the visualizations and the experimental design. Section 5 explains two formal models that allow to derive the willingness-to-walk and will be used to analyse the data. Section 6 reports the data and the results, while Section 7 applies these results to evaluating and improving the quality of existing walking route in one of the Dutch cities. Section 8 concludes.

2 Related literature

Our paper is connected to several streams of literature. A fairly large literature examines the relationship between public space design on the one hand, and activity and exercise levels of older people, on the other hand. Early observational work by [Jacobs \(1961\)](#) and [Gehl \(1987\)](#) distinguished a number of attractive qualities of sidewalks that stimulate walking: sufficient width to accommodate people with different speeds, lack of obstacles, clear delineation from transport, as well as rails, benches and greenery along the route. Later papers ([Sugiyama et al., 2009](#); [Hirsch et al., 2014](#); [Zhai and Baran, 2017](#); [Boyd et al., 2018](#); [Chang, 2020](#); [Zhai et al., 2020](#); [Veitch et al., 2022](#)) used quality-of-life surveys to formally derive correlations between the quality of the built environment in the neighbourhood and the physical activity of older people.³ Recent papers exploit new smart techniques to study the topic: text mining and social media ([Liu and Jing, 2021](#); [Donahue et al., 2018](#)); sensors and GPS to track activity ([Zhai et al., 2021](#); [Cerin et al., 2020](#)); a combination of revealed (records about the actually walked routes) and stated (giving street links a score) preferences ([Borst et al., 2008, 2009](#)). Still, all the discussed studies face the challenge of self-selection: it is not clear whether higher physical activity *causally* follows from the better quality of the environment. The opposite may also be possible: people that tend to exercise more, self-select into neighbourhoods with better quality of public spaces. The stated choice experiment used in this paper does not face this caveat by

³Positive correlations with outdoor physical activity have been documented for (the list is not exhaustive): better quality of paths; directness of routes offered; variety and attractiveness of views and natural elements along the route; facilities as benches and toilets on the route; low levels of vehicular traffic; ease of street crossings and absence of steps on the main walking route.

construction.

A smaller body of literature aims to solve the discussed challenge by using stated choice experiments and deriving from them the willingness of older people to visit public spaces. Experiments allow to independently vary the attributes of the public spaces. A pioneer paper of [Aspinall et al. \(2010\)](#) asks respondents to choose which park in their proximity they would prefer, whereby the park alternatives vary on a large number of characteristics. Lack of nuisance, park upkeep, (sport) facilities and sights to watch are documented as most important attributes for the seniors, while walking time to the park surprisingly appears to be of little importance. [Van Hecke et al. \(2018\)](#) improves on the methodology, describing parks attributes not by means of a text, but with the help of manipulated photographs, and [Van Cauwenberg et al. \(2016\)](#) does a similar study for sidewalks. While providing useful information on the valuation of different attributes of public spaces, the discussed studies do not quantify the effect of public space design on the frequency and length of walking. On the contrary, our paper does exactly this. Further, the described literature does not allow for heterogeneity by mobility impairments. Our paper does.

Finally, our study is related to papers that study the determinants of outdoor activities for older and physically impaired people. [Moreira et al. \(2022\)](#) and [Hill and Heesch \(2018\)](#) find prevalence of insufficient physical activity for the mobility-impaired. [Moura et al. \(2017\)](#) use a participatory Delphi method to examine requirements different groups of people put on sidewalks. They show that seniors and people with impaired mobility find comfort (sidewalk width, pavement) much more important than an average respondent. An overview article by [Zhai and Baran \(2017\)](#) concludes that more studies are needed that focus specifically on evidence-based health design for people with mobility impairments. Our paper gives quantitative insights into how much urban design of walking routes can encourage or discourage walking.

3 Institutional background and conceptual framework

3.1 Age-inclusive sidewalks in the Netherlands

In the Netherlands, urban public spaces belong to the policy domain of municipalities. Most cities aim at creating inclusive sidewalks,⁴ but operationalizations vary considerably. The largest Dutch city Amsterdam (1 mln inhabitants) formulated the following design criteria for inclusive walking routes along the main facilities in neighbourhoods (Suurenbroek and Kootstra, 2019): wide and obstacle-free pavements, support and rest elements such as benches or handrails, raised crossings to slow down traffic, no car or cycle parking immediately adjacent to major intersections, good lighting. In the second largest city Rotterdam (0.6 mln inhabitants), the guidelines include fewer elements: 1.80 meters wide pavements, high bench frequency, intensive maintenance, recognizable routes (Municipality Rotterdam, 2021). A middle-large city Tilburg (0.2 mln inhabitants) focusses on rest areas and toilet facilities on important walking routes, as well as a layout that facilitates spontaneous meetings (Municipality Tilburg, 2022). Etcetera.

The large variety of solutions for inclusive sidewalks raises the question which interventions are most pivotal for the elderly and mobility-impaired users and which are most cost-efficient. To get a first impression, we performed a preliminary study on the walking habits of older and mobility-impaired people in the second largest Dutch city Rotterdam. Six groups of students of the Educational Track Architecture of the Delft University of Technology did observational research in six different neighbourhoods of the city, focusing on the geographic areas surrounding elderly housing flats. During early 2020 (just before the covid lock down), students joined in total 18 people in their daily walks. Seniors with and without walking aids were targeted.

Although small-scale, this research provides a number of useful insights. First, for the observed seniors, walking to the grocery or the supermarket was the most frequent outside activity. This especially holds for people with mobility impairments. Further, the respondents stressed a twofold goal of this walk: not

⁴In this, cities often build upon the report ‘Accessible sidewalks for everyone’ of the Dutch foundation Building Advice Accessibility (Haug and Schuurman, 2020).

only doing groceries but also having physical exercise. Third, due to the latter goal, the elderly did not necessarily take the shortest route to the grocery shop. A longer route could be preferred if it offered a pleasant walking experience through green surroundings, had rest points (benches) and was free of obstacles such as bad/no pavement or objects on the sidewalk. We conclude that investing in improving sidewalk quality can increase the willingness-to-walk and the length of walking for older and physically impaired people.

3.2 Conceptual framework

In the next section, we design a stated choice experiment to quantify by how much exactly various attributes of sidewalks increase the frequency and duration of walking outside for healthy and mobility-impaired seniors. The main underlying question in the experiment will be: are you willing to walk longer if the sidewalk is attractive. Below the operationalization of an ‘attractive’ sidewalk is discussed.

Note first, that, for the same sidewalk, the willingness to walk may vary depending on the walking goal. Following [Gehl \(1987\)](#) and the insights from the preliminary observational research, we distinguish between two different walking goals: utilitarian (going to a supermarket) and recreational (walking for leisure).

Seminal urban design studies specify three main qualities for the sidewalks (see e.g. [Gehl 1987](#)): protection (against accidents, harm and unpleasant experiences); comfort (options for mobility, seating, standing, etc.); enjoyment (sensory experiences and human scale). All three have health-related benefits as they increase the frequency and length of going outdoors. Enjoyment (restorativeness) also may have additional health benefits because it leads to stress reduction and a greater ability to face problems (see e.g. [Ulrich et al. 1991](#)). In our experiment, we will vary comfort and enjoyment, given a sufficient level of protection.

Table 1 gives an overview of the attributes and levels that describe enjoyment and comfort, and specifies the expected heterogeneity in their effects on the willingness-to-walk for healthy and mobility-impaired seniors. We operationalize enjoyment in terms of scenery of surroundings, that differ in three levels of greenness. Based on a large literature describing the importance of urban

Table 1: Attributes and levels in the experiment

Attribute	Level 0	Level 1	Level 2	Expected heterogeneity in L1/L2 effect
Walk duration	5 minutes	15 minutes		Higher disutility for mobility-impaired
Enjoyment attributes				
Scenery along the route	Buildings	Buildings & green	Green (park)	Equal effect healthy & mobility-impaired
Comfort attributes				
Pavement type	Tiles	Asphalt		Higher effect for mobility-impaired
Pavement width	Narrow (0.9m)	Wide (1.5m)		Higher effect for mobility-impaired
Benches on the route	No	Yes		Much higher effect for mobility-impaired

greenery for wellbeing, physical activity, stress reduction, etc., we expect that greener surroundings stimulate longer walking. However, no specific hypothesis is formulated in advance about whether the effect differs for mobility-impaired old people.

Comfort is operationalized through binary attributes reflecting the quality of the path and availability of seating. First of all, uneven pavement may increase the probability of trips and falls, more so for people with mobility restrictions. This feature is operationalized by varying the materialization of the pavement. Tiles and asphalt are most used materials for pavements in many European cities. Tiles, as opposite to asphalt, create an uneven, not smooth surface. We expect the respondents to dislike this, more so the mobility-impaired. Further, a broader sidewalk likely increases the walking comfort, especially for older and physically impaired. Their walking speed is lower than that of the average person (Bollard and Fleming, 2013), and a broader sidewalk facilitates people passing by each other easily. We specify a narrow sidewalk of 0.9 metre and a broader sidewalk of 1.5 metre. Finally, benches may be a crucial attribute for those unable to walk long without taking a rest. We hypothesize thus that comfort attributes should have a relatively higher effect on the walking frequency and duration of the mobility restricted older people in general but also relative com-

pared to the enjoyment attributes. We aim at quantifying these effects in terms of extra walking time people are willing to spend dependent on the sidewalk characteristics.

The above setup allows to study both, the external margin (does urban design affect the willingness to go for a walk) and the internal margin (the length of the walk, conditional on having left the house) of seniors' walking. The walking time is a crucial metric as it will be used to derive how the sidewalk characteristics affect the frequency and length of walking for older people. We define two levels for the length of the walk: 5 minutes and 15 minutes.

4 Visualizations and experimental setup

Below we discuss the framing of the experiment for the two walking goals - a trip to a supermarket and a recreational stroll, the visualization of the sidewalks and the resulting choice task presented to respondents.

4.1 Walk to the supermarket

In the experiment, participants are asked to imagine they have to go for groceries, the weather is good, the temperature comfortable and they have no car/bike at their disposal. They are then offered three alternatives: two walking routes that may vary on a number of sidewalk attributes and walking time, and an outside option of staying at home (letting the groceries be delivered for 2.5 euro delivery cost).

In order to make the choice alternatives concrete for the respondents and to ensure an unambiguous interpretation of the attributes, the alternative sidewalks are visualized. This is done by taking a photograph of a typical Dutch street in a way that this clearly depicts the four attributes corresponding to enjoyment and comfort, and manipulating it to introduce the required variation in the attribute levels as reflected in Table 1 (the method of manipulating the photographs is similar to [Van Cauwenberg et al. 2016](#); [Van Hecke et al. 2018](#)). Then, the fifth attribute -time- is manually printed on the photograph, as well as keywords describing the comfort attributes.

The total number of possible attribute-level combinations (profiles) in this

experiment amounts to $(2^4 * 3 =)$ 48. To increase the efficiency of the experiment, we use an orthogonal and balanced fractional factorial design (Hensher et al., 2015), whereby the number of alternative profiles is reduced to 8. Figure 1 reports the visuals for the resulting profiles. Participants in the experiment were offered random tuples from these eight visuals to choose from, plus an outside option of having groceries delivered.

4.2 Recreational stroll and the choice task

For a walk to the supermarket that has a predetermined location, a choice from two alternative routes (more attractive but longer versus less pleasant but shorter) is a realistic task. In the case of walking for leisure, however, the duration of the walk is fully at the discretion of the person. For this reason, for the recreational goal, we ask the respondents to indicate for each of the sidewalks shown whether they would like to walk along this route and if yes, how long.⁵ There are five possible answers: no; 15 minutes at most; 30 minutes at most; 45 minutes at most; and 60 or more minutes at most.

Figure 2 gives an example of the resulting choice task. Each choice task includes three distinctive choices. First, for the grocery shopping, one of the three alternatives has to be selected: one of the two visualized routes to the supermarket or the outside option of staying at home and having groceries delivered. See Figure 2 panel A. Afterwards, the respondent is told they do not need groceries and is asked to indicate for each of the same two routes if they would like to take a stroll and if yes, for how long at most. (See Figure 2 panel B).

4.3 Administration of the experiment; definition of mobility-impaired

The experiment took place in the fall of 2021 through an online tool Limesurvey. The respondents were recruited through a large national Dutch online panel Panelclix. The targeted sample of older people involved individuals aged 65-85 living in urbanized areas of the Netherlands. The sample was stratified to ensure that the age groups 65-75 and 75-85 were equally represented. People in the sample got an invitation with a link to the tool and a request to participate

⁵For the recreational goal, the number of choice tasks each respondents had equals thus $2 \times 5 = 10$ (two alternative routes in each screen, 5 screens).

Figure 1: Fractional factorial design with 8 visualizations



Notes: The upper two visualizations are for scenery with no greenery, the lower tuple is for scenery with all greenery, the middle four include buildings and greenery.


Figure 2: Example of a choice task

(a) First choice

*Choice 1/5

Below are two routes to the supermarket. Would you please indicate which you prefer. You can also choose not to walk any of the routes and have groceries delivered for €2.50.


Route 1



5 minuten

Voetpad asfalt Breed Geen bankjes

Route 2



5 minuten

Voetpad tegels Smal Bankjes op de route

Choose one of the following answers

Route 1 Route 2 I stay home and have groceries delivered for €2.50

(b) Second choice

*Now imagine that you do not need any groceries.

Would you like to take a walk along Route 1? And if yes, how long?

Choose one of the following answers

Please choose... ▾

***Would you like to take a walk along Route 2? And if yes, how long?**

Choose one of the following answers

Please choose... ▾

- Please choose...
- No
- Maximum of 15 minutes
- Maximum of 30 minutes
- Maximum of 45 minutes
- Maximum of 1 hour or more

in a research of the universities of Eindhoven and Delft in order to help design daily walking routes for the people having walking difficulties.

When entering the online tool, respondents were asked to indicate how often they had walked outside in the last two weeks. Only those who had walked at least once -and thus can be expected to evaluate the walking routes in the

experiment based on own recent walking experiences- could proceed. Further we asked participants to use a computer or a tablet, in order to see the visuals in detail. The experiment consisted of two main sections. In the first section respondents were asked to provide data about their individual and household socio-economic characteristics, answer questions about subjective wellbeing and loneliness, and indicate whether they face physical impairments that complicate walking. In the second section, respondents got explanation about the choice tasks and were presented with five of these.

In the first section of the experiment, we added a number of questions to distinguish people who have mobility impairments. The main question was: "How long can you walk without taking a rest?", with five multiple choice answers including: at most 5min, at most 15min, at most 30min, at most 45min and more than 45min. The respondents who can walk 5 or 15 minutes at most, are assigned to the mobility-impaired group. We will also test robustness of the results to other definitions of mobility-impaired.

5 Theoretical framework

The setup of the experiment implies that the utilitarian and the recreational walking tasks produce different types of outcome data. For the utilitarian task - walk to the supermarket - we have a discrete outcome variable based on the three alternative choices: walking route 1, walking route 2 or staying at home. For the recreational walking task, the outcome variable can be seen as censored continuous. The choices there include not willing to walk (left censoring at 0) or the number of minutes to walk, taking the values 15 minutes, 30 minutes, 45 minutes, 60 minutes or more (right censoring at 60).

To process the utilitarian task data, a random utility (logit) model is used. To process the recreational task data, we apply a censored data tobit model. As will be shown later, both models produce results that are remarkably in line with each other, stressing the robustness of the obtained insights. The models are introduced below.

5.1 Utilitarian walking: discrete choice model

Taking as a starting point the random utility model (e.g. Ben-Akiva and Lerman 1985), we assume that the utility of walking is a function of the attributes of the walking routes and a random component that captures the influence of unobserved factors. Further, we assume that the utility of staying at home and letting the groceries be delivered equals a constant plus a random component. We expect the constant to take a negative value reflecting e.g. the reluctance to pay the delivery fee and the belief that walking is good for health. However, for mobility-impaired elderly, the constant may also take a positive value if nuisance connected to walking is high enough. When deciding whether to walk or not, the elderly compare the utility of different walking routes with each other and also with the utility of staying at home, and choose the alternative that generates the highest utility.

Formally we write the choice the individual makes as a vector: $x = m, j$. Here m can take two values: $m = 0$ indicates non-walking and $m = 1$ indicates walking, while $j \in J$ is the set of possible walking route alternatives. We assume that individual i makes her choice based on the maximization of the following utility.

$$U_{imj} = m \left[\sum_{k=1 \dots K} A_{jk} \beta_{jk} + \epsilon_{i1} + \epsilon_{i1j} \right] + (1 - m)[\alpha_0 + \epsilon_{i0}] \quad (1)$$

Let us discuss the first term of Equation (1) in more detail. We assume that the utilities of various walking routes j share a common random utility component (ϵ_{i1}). If this component differs from zero, the utilities of different routes are mutually correlated. In this case, if adjustments are made to one of the routes j^* , this has a larger effect on the probabilities of choosing other routes than on the probability of choosing non-walking. We believe that such a feature of the model captures the actual way decision-making takes place, and will also test it econometrically.⁶

To proceed further we need assumptions about the distribution of the error

⁶A similar model was used in (Ossokina et al., 2021) to describe the choice of a tenant between not renovating a house and several renovation alternatives offered by the public housing association.

terms. For purposes of analytical tractability we choose for a logit specification of the model. The total errors of each of the $J + 1$ alternatives (so ϵ_{i0} as well $\epsilon_{i1} + \epsilon_{i1j}$) are assumed to be standard Gumbel distributed with variance $\frac{\pi^2}{6}$. The alternative-specific error terms of the walking alternatives ϵ_{i1j} are assumed to be Gumbel distributed with scale $1/\mu$ and a variance $\frac{\mu^2\pi^2}{6}$. These assumptions are in line with a nested or mixed logit structure of the model (Train 2003, ch. 6).

In line with the utility theory interpretation above, we expect $\mu \in (0, 1]$ (see e.g. Ben-Akiva and Lerman 1985). If $\mu = 1$, then the correlation between the utilities of the walking alternatives is zero, the Independence of Irrelevant Alternatives (IIA) assumption holds and we cannot reject a multinomial logit structure of the model. If $\mu < 1$, the IIA assumption can be rejected and alternatives j in the walking nest $m = 1$ are indeed mutually correlated. The value of μ will be determined empirically, together with the other parameters of the model.

The coefficients in Equation (1) can be estimated in a usual way with Maximum Likelihood estimators (see Hensher et al. 2015). The predicted probabilities to choose one of the walking routes or the non-walking alternative equals (see Ben-Akiva and Lerman (1985), chapter 10.3):

$$\begin{aligned}
P_{j|m=1} &= \frac{\exp\left(\frac{1}{\mu} \sum_{k=1}^K A_{jk}\beta_k\right)}{\sum_l \exp\left(\frac{1}{\mu} \sum_{k=1}^K A_{lk}\beta_k\right)} \\
P_{m=0} &= \frac{e^{\alpha_0}}{e^{\alpha_0} + e^{\gamma}}, \quad \text{where } \gamma = \mu \ln \left[\sum_l \exp\left(\frac{1}{\mu} \sum_{k=1}^K A_{lk}\beta_k\right) \right] \\
P_{m=1} &= 1 - P_{m=0} \\
P_j &= P_{m=1} * P_{j|m=1}
\end{aligned} \tag{2}$$

Coefficients $\beta_k \in \beta$ describe the relative importance individuals attach to the k -th element of the route. Let β_0 be the coefficient by walking time (see Table 1). Then we can express the value of attribute k in minutes, as the willingness to walk additionally if a route has attribute k :

$$WTW_k = \beta_k / \beta_0 \quad (3)$$

The willingness-to-walk is a useful metric that allows to compare the importance of different attributes of the routes by expressing these in common terms. In this sense, the willingness-to-walk we introduce here is similar to the conventional willingness-to-pay indicator.

5.2 Recreational walking: censored data model

To model the effects of walking route characteristics on the willingness-to-walk in the case of the recreational walking, we need to take care of censored response data, including left censoring at 0 and right censoring at 60 minutes. Equation (4) describes the relationship between the reported walking time t_{ij} and the route characteristics, where t_{ij}^* is a latent variable.

$$\begin{aligned} t_{ij} &= 0 && \text{if } t_{ij}^* \leq 0 \\ t_{ij} &= t_{ij}^* && \text{if } 0 < t_{ij}^* < 60 \\ t_{ij} &= 60 && \text{if } t_{ij}^* \geq 60 \end{aligned} \quad (4)$$

where

- $t_{ij}^* = \gamma + \sum_{k=1}^K A_{jk} \beta_k + \zeta_{ij}$,
- γ is the average walking time of person i when all the route characteristics take level 0,
- A_{jk} is the value of attribute k of walking route j ,
- β_k is the marginal effect of attribute k on the reported walking time,
- ζ_{ij} are individual- and route-specific error terms, which follow a standard normal distribution.

6 Results

6.1 Data

A sample of 415 respondents completed the experiment. We remove as outliers those who spent less than 10 minutes on the tasks, as well as respondents who

indicated to use a wheelchair or a scooter when outside. The 10-minutes threshold is meant to filter out the respondents who did not take sufficient time to read the questions thoroughly. The wheelchair/scooter users can be expected to have different requirements to sidewalks than walkers. These people are worthwhile to look into separately, but the number of such users in our data is very small. After these corrections, 394 respondents are left. Table 2 reports the descriptive characteristics of the respondents and their dwellings. Our sample is representative for different regions and living environments of the Netherlands. Respondents live in 145 municipalities and 316 four-digit zip codes in different parts of the country,⁷ with half of these locations being very strongly urbanized and the other half strongly or moderately urbanized.⁸ The household composition, dwelling type distribution and share of retired are comparable to the elderly population statistics as reported by Statistics Netherlands; males and higher educated are somewhat overrepresented in our sample.

Table 3 describes the sample in terms of mobility impairments and life satisfaction. While 13% of the respondents uses a walking aid, 21% cannot walk more than 15 minutes without taking a rest. This is fairly in line with the national statistics stating that one fifth of the people beyond 55 years of age experiences a physical impairment (RIVM, 2015). Some 15% walks outside less than twice a week, the rest goes outside more frequently. We will use all these variables as alternative definitions of mobility-impairment. The loneliness share in our sample is somewhat lower than the national statistics.

6.2 Frequency and duration of utilitarian walking

We tested for presence of correlation between walking alternatives in the logit model -i.e. H_1 of $\mu \neq 1$ against H_0 of $\mu = 1$ in Equations (1) and (2)- and could not reject H_0 , see Appendix A for the details. With $\mu = 1$, correlation is 0 and Equations (1) and (2) reduce to a standard multinomial logit model. Table 4 reports the estimation results of this model for two specifications: a

⁷In Dutch cities, a four-digit zip code is an area covering around one square kilometer and including some 1500 dwellings.

⁸We are interested in *urban* sidewalks, so only people living in an urban environment were approached to participate.

Table 2: Socio-economic characteristics of
the study sample

Variable	Characteristic	%
Age	65-69	27%
	70-74	25%
	75+	48%
Gender	Male	62%
	Female	38%
Urban area	Very strongly urbanized	24%
	Strongly urbanized	49%
	Moderately urbanized	27%
Household	Living Alone	27%
	Living with Partner	71%
	Household includes Child	6%
Dwelling type	Rental	43%
	Owner-occupied	57%
Education	Low	31%
	Middle	27%
	High	42%
Retired	Yes	93%

baseline reporting the average valuations for all the attributes of walking routes (column A) and a heterogeneity specification where valuation is allowed to vary for respondents with and without mobility impairments (column B). The coefficients reflect: (i) the utility of not walking (α_0 in Equation (1)); (ii) marginal changes in utility following a change in the respective attribute level of the sidewalk from L0 to L1 (β in Equation (1)). The errors are clustered at the level of an individual respondent.

Looking at the results of the baseline model (column A), first note that all

Table 3: Physical impairments, loneliness and frequency of outside activities

Mobility impairments and walking		%	Loneliness and life satisfaction		%
Mobility impairments	Uses walking aid	13%	Satisfaction life	Low (1-6)	12%
	Has difficulty standing from a sitting position	28%		Average (7-8)	72%
	Has difficulty getting into out of dwelling	9%		High (9-10)	16%
Walking frequency	Walks outside twice or more/week	85%	Regular contact outside of household	Yes	79%
	Walks outside less than twice/week	15%		Medium	13%
				No	8%
Max walking distance (without a break)	Max 5 min	5%	Regularly feel lonely	Yes	8%
	Max 15 min	16%		Medium	14%
	Max 30 min	13%		No	78%
	Max 45 min	11%			
	More than 45 min	55%			

the coefficients have the expected sign and are highly statistically significant. The utility of staying home (not walking) is strongly negative. This means that when choosing between walking to the supermarket along the reference route (all attributes at reference level 0) and ordering a delivery, the majority of the respondents chooses walking. Increasing the walking length to 15 minutes has a negative effect on utility, but this is smaller in absolute value than the utility of non-walking. So, also when choosing between a 15 minutes walk to the supermarket and ordering the groceries, the majority chooses to walk. Improving the walking route by adjusting its attributes to level 1 has, as expected, a positive effect on utility.

Consider now the model that allows for heterogeneity between healthy seniors and older people with mobility impairments (column B). Here we define mobility-impaired as the group that self-reported to be able to walk at most 15 minutes without taking a rest (Appendix B reports robustness checks for other definitions

Table 4: Utilitarian walking logit

Variable	Baseline	Heterogeneity by mobility impairments	Additional willingness to walk per attribute
	(A)	(B)	(C)
Utility of not walking	-1.607*** (0.195)	-2.152*** (0.254)	
x mobility impaired		1.820*** (0.442)	
Walking time 15 min (ref.: 5 min)	-0.519*** (0.092)	-0.415*** (0.102)	
x mobility impaired		-0.505*** (0.244)	
Scenery residential no green (ref.: residential some green)	-0.036 (0.073)	0.035 (0.081)	0 min
x mobility impaired		-0.414** (0.198)	-5 min
Scenery all green (park) (ref.: residential seom green)	0.502*** (0.101)	0.530*** (0.114)	12 min
x mobility impaired		-0.091 (0.254)	5 min
Pavement asphalt (ref.: tiles)	0.461*** (0.072)	0.423*** (0.080)	10 min
x mobility impaired		0.179 (0.184)	4 min
Pavement broad (ref.: narrow)	0.365*** (0.084)	0.362*** (0.091)	8 min
x mobility impaired		-0.013 (0.230)	3 min
Benches on the route (ref.: no benches)	0.310*** (0.072)	0.219*** (0.079)	5 min
x mobility impaired		0.557*** (0.201)	8 min
Number of respondents	394		
Number of choice tasks	1970		

Notes: Standard errors in parentheses, clustered at individual level. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

of mobility-impaired). What immediately catches attention is the large and statistically significant difference in the utility of non-walking between those

who face mobility restrictions and those who do not. For the mobility-impaired, the utility of non-walking is small in absolute value, suggesting that only 60% of this group will choose to walk along the reference route with all attribute levels set to zero, while the other 40% prefers ordering a delivery (we used Equation (2) for this calculation). For healthy seniors, the share choosing to walk, amounts to 90%. Therefore, we see a large difference in the frequency of walking between healthy and mobility-impaired seniors, for the reference sidewalk.

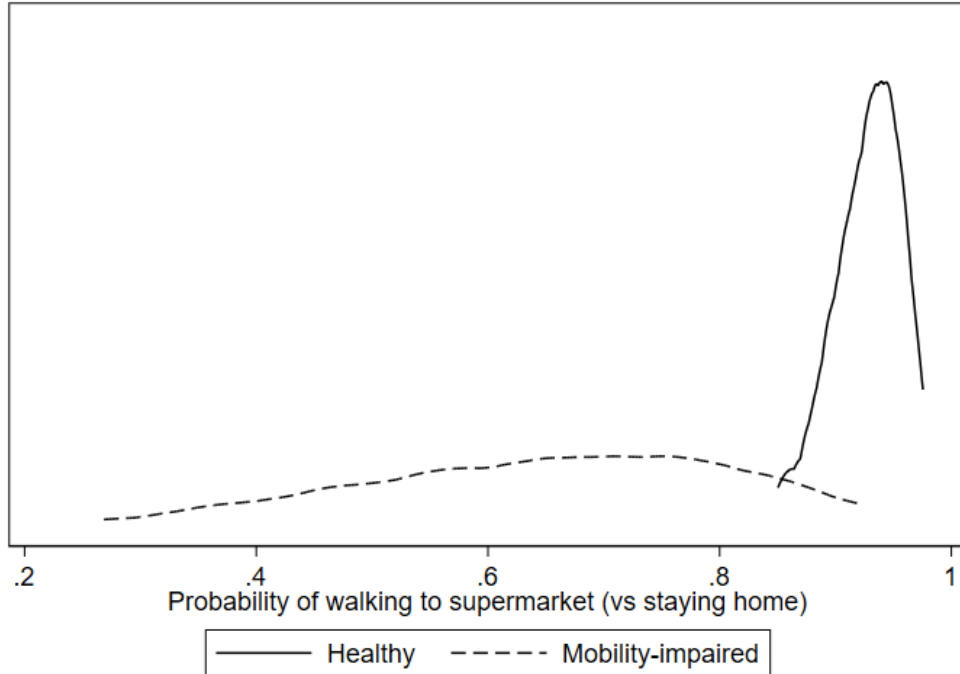
Variations in sidewalk design have a heterogenous effect on the two groups as well. Using again Equation (2), we have predicted the probability of walking the route versus staying at home for all possible sidewalk designs from our experiment. The resulting distribution of the walking frequencies is depicted in Figure 3. Healthy seniors' willingness-to-walk, is not very sensitive to the route characteristics; the frequency of walking lies around 90%. For the mobility-impaired, however, the route design is crucial for the decision whether to walk or not. By improving route design, the frequency of walking can be increased from 30% to 80%.

The last column of Table 4 expresses the marginal utility effects β in terms of the additional walking length (Equation (3)). For example, healthy respondents are willing to walk 12 minutes more (so 3.5 times longer than the reference) if the route goes through a park and 5 minutes more (twice longer than the reference) if there are benches on the route. For mobility-impaired, the effect of greenery and benches is of reversed order: green scenery doubles the walking length, while benches increase it more - by factor 2.5.

6.3 Frequency and duration of recreational walking

Table 5 reports the estimation results for the recreational walking model. The table again contains two specifications: the baseline reporting the average effects of walking route attributes on the walking time (column A) and a specification where effects are allowed to vary for respondents with and without physical impairments (column B). The reported coefficients indicate: (i) the average walking time along a route where all the attributes have level zero (γ in Equation (4)); (ii) marginal changes in walking time following a change in the respective attribute

Figure 3: Distribution of routes to supermarket, by probability of walking along them



level of the walking route from L0 to L1 (β in Equation (4)).

Consider first model (A). An average respondent is willing to walk for 17 minutes along the reference sidewalk. Route design attributes have a large and statistically significant effect on walking time. For instance, green surroundings increase the walking time by 30%, improvement of all the comfort attributes has a comparable effect of 25% increase. Allowing for heterogeneity (model B) reveals large differences between the mobility-impaired people and their more healthy peers. The latter are willing to walk on average between 20 and 30 minutes, depending on the attractiveness of the offered route. The former, on the contrary, will on average choose for not walking, unless the sidewalk design is very comfortable and enjoyable. However also then, the walking duration is 5 to 10 minutes at most.

Let us compare the results from the utilitarian and recreational willingness-to-walk models. Both suggest that walking route attributes do affect the frequency and length of outside walking activities of older people. The analysis for

the elderly with mobility impairments suggests furthermore that, for this group, an attractive design of a sidewalk may make a difference between staying at home and going for a walk. Further, a cautious conclusion can be made that route design and especially the comfort attributes - is more effective in stimulating outdoor activities in the case of utilitarian walking.

Table 5: Recreational walking tobit

Variable	Baseline (A)	Heterogeneity by mobility impairments (B)	Additional willingness to walk per attribute (C)
Constant (average walking time)	17.250*** (1.171)	21.754*** (1.250)	
x mobility impaired		-20.942*** (2.301)	
Scenery residential no green (ref.: residential some green)	-1.584* (0.802)	-1.868** (0.848)	-2 min
x mobility impaired		-0.247 (1.851)	-2 min
Scenery all green (park) (ref.: residential seom green)	5.185*** (0.980)	5.031*** (1.079)	5 min
x mobility impaired		-1.035 (2.131)	5 min
Pavement asphalt (ref.: tiles)	2.861*** (0.812)	3.083*** (0.885)	3 min
x mobility impaired		-1.674 (1.736)	3 min
Pavement broad (ref.: narrow)	0.946 (0.843)	1.124 (0.891)	0 min
x mobility impaired		-1.118 (1.893)	0 min
Benches on the route (ref.: no benches)	1.361* (0.718)	1.147 (0.750)	0 min
x mobility impaired		3.180* (1.792)	3 min
Number of respondents	394		
Number of choice tasks	3940		

Notes: Standard errors in parentheses, clustered at individual level. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

6.4 Robustness checks

In Appendix B we study the effect of sidewalk design on walking activity for three other subgroups of elderly that might have specific walking needs due to mobility impairments: seniors who self-report using a walking aid (e.g. a walking stick); people who seldom walk outside; and elderly with a low life satisfaction. For all three subgroups, we find a lower than average frequency and length of walking, both for the utilitarian and recreational goals. For people who seldom go outdoors, benches are the most important element of sidewalk design, while elderly with low life satisfaction are sensitive to the greenery. Overall however, the difference from the average is less pronounced in the robustness checks than in the mobility-impaired group that was defined based on the self-reported maximal walking time without a rest.

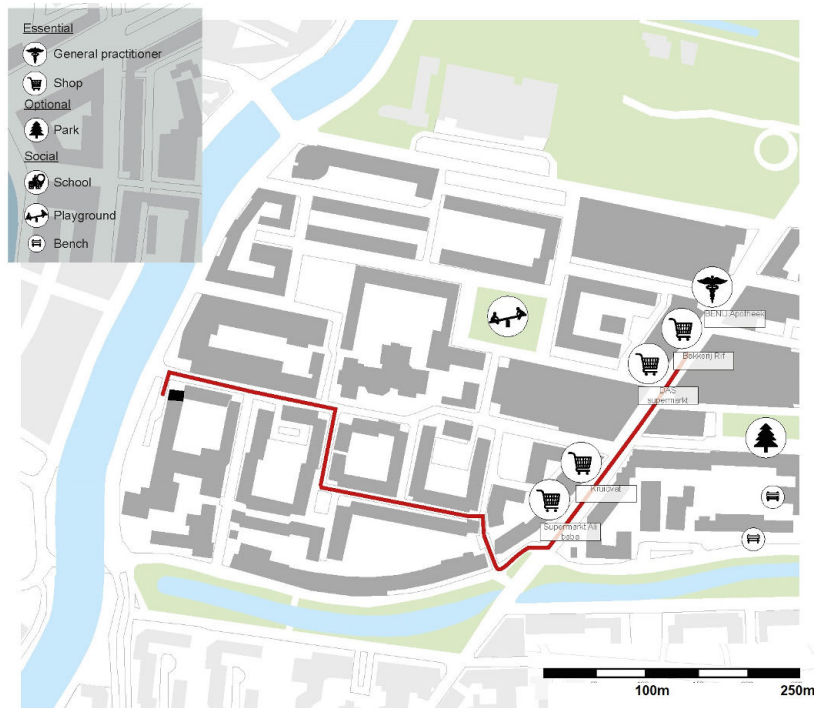
7 Implications for sidewalk design for older people with mobility restrictions

In this Section, we use a concrete example to illustrate how the findings from the above analysis help evaluate and optimize current public space design. We focus on the design of sidewalks for the target group of older people with mobility restrictions, for whom stimulating daily outside activity may be especially challenging.

We take one of the routes that the elderly walked who were followed in the preliminary observational study (see Section 4). The route is located in the neighbourhood Crooswijk of the second largest Dutch city Rotterdam. The route is some 500 meter long implying a 15 minutes walking time for an elderly person. The sidewalk leads along a residential neighbourhood with greenery, the pathway is wide, has an even surface but no benches. Using these attributes, we can map the route into one of the visualized experimental profiles. Figure 4 shows the route on the map. Figure 5a depicts it as a visualization used in the experiment.

Applying Equation (2), we derive the probability that an older person with mobility restrictions chooses to walk this route to the supermarket as compared to staying at home and ordering delivery. We also run two scenarios in which

Figure 4: Senior walking route in Crooswijk on the map



(i) the route is improved by placing benches, (ii) the even surface of the route deteriorates with time. The results are shown in Figure 5b. The probability to go outside to walk along the given route to the supermarket is 55% for a mobility-impaired person. Adding benches increases this probability considerably to 73%. Deterioration of the surface leads to a drop in the walking frequency: only 44% of the elderly choose to walk.

8 Conclusion

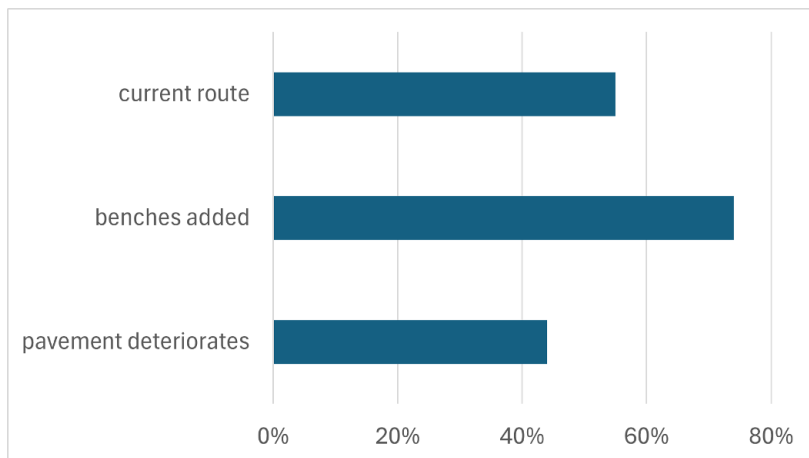
In this paper we showed that characteristics of urban sidewalks play a large role in stimulating walking outdoors at older age, especially for people facing mobility impairments. We ran a stated choice experiment, in which 400 participants in the age of 65 to 85 repeatedly selected between walking along various offered routes to the supermarket or staying at home and having groceries delivered. Walking route alternatives differed in walking time, and sidewalk characteristics related to comfort (path width, pavement type, presence of benches) and enjoyment (greenness of the landscape). We also varied the purpose of being outside: next

Figure 5: Predicted probability to walk the route for mobility impaired

(a) Route visualization in terms of experiment attributes



(b) Predicted probability to walk in three scenarios



to the utilitarian goal (groceries), we also included a recreational stroll.

Results suggest that benches and green scenery play a crucial role in stimulating walking outdoors for mobility-impaired seniors. Our model predicts, for example, that only 30% of mobility-impaired seniors are willing to take a 15min walk to the supermarket when the sidewalk has no benches and the scenery consists of buildings without green. This share more than doubles when the sidewalk runs along a park and has benches. For healthy seniors, the difference in the willingness-to-walk between the two scenarios is much smaller; for both sidewalk designs more than 80% are willing to walk. Furthermore, our results suggest that mobility-impaired people would not go on a recreational stroll, on average, if the sidewalk is not attractive (no green scenery, no benches). For comparison, the healthy peers choose to walk 20 minutes along this same sidewalk.

Our results are highly relevant in the framework of the 15-minute city that is now high on the urban agenda worldwide. The vision of the 15-minute city, introduced in Paris in 2015, implies that facilities should be on walking distance within the neighbourhood (see, e.g., a literature review in [Papas et al. 2023](#)). However, to ensure inclusiveness of the concept for health-disadvantaged groups, investments in urban design, and specifically sidewalks, are essential. Our paper shows which sidewalk improvements are most pivotal for the mobility-impaired seniors.

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A Appendix A Mixed and nested logit: testing for correlation between utilities of walking alternatives

We test for correlation between walking alternatives (i.e. $\mu \neq 1$ in Equations (1) and (2)) by (i) running a mixed logit in which we allow a random utility of not walking; (ii) running a nested logit with walking alternatives being in one nest and not-walking in the other. Table A1 reports the results. In both cases, we cannot reject the hypothesis of a zero correlation.⁹ Consequently, with $\mu = 1$, Equations (1) and (2) reduce to a standard multinomial logit model.

⁹In the mixed logit, we cannot reject the standard deviation being equal to zero. In the nested logit, we cannot reject the inclusiveness parameter μ being different from unity.

Table A1: Mixed and Nested logit

	Mixed logit		Nested logit	
	Baseline	Heterogeneity	Baseline	Heterogeneity
Utility of not walking mean	-5.369 (4.007)	-8.066 (13.970)	-2.215*** (0.373)	-2.664*** (0.334)
x mobility-impaired		3.566 (4.123)		1.560*** (0.283)
Utility of not walking sd	3.718 (2.810)	4.863 (8.390)		
x mobility-impaired		1.662 (5.163)		
Walking time 15min	-0.530*** (0.077)	-0.443*** (0.086)	-0.270 (0.171)	-0.223 (0.130)
x mobility-impaired		-0.535* (0.228)		-0.266 (0.184)
Scenery buildings no green	-0.0392 (0.078)	0.0153 (0.088)	-0.020 (0.042)	0.008 (0.0446)
x mobility-impaired		-0.376 (0.261)		-0.202 (0.194)
Scenery all green (park)	0.496*** (0.090)	0.540*** (0.100)	0.254 (0.161)	0.272 (0.162)
x mobility-impaired		-0.164 (0.245)		-0.088 (0.137)
Pavement asphalt	0.465*** (0.072)	0.426*** (0.079)	0.237 (0.148)	0.215 (0.126)
x mobility-impaired		0.228 (0.208)		0.112 (0.120)
Pavement broad	0.382*** (0.084)	0.392*** (0.096)	0.196 (0.123)	0.197 (0.114)
x mobility-impaired		-0.083 (0.243)		-0.038 (0.118)
Benches on the route	0.309*** (0.068)	0.218** (0.074)	0.158 (0.104)	0.110 (0.074)
x mobility-impaired		0.619** (0.197)		0.313 (0.210)
Inclusive value μ			0.511 (0.321)	0.505 (0.292)

Notes: Standard errors in parentheses. Clustered at individual level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

B Appendix B Robustness checks

Table B1: Robustness checks Utilitarian logit

Variable	x poor walking (A)	x walking aid (B)	x seldom outdoor (C)	x low satisfaction (D)
Utility of not walking	-2.152*** (0.254)	-1.954*** (0.236)	-1.820*** (0.228)	-1.765*** (0.223)
x crossed effect	1.820*** (0.442)	1.707*** (0.454)	1.047*** (0.457)	0.876** (0.476)
Walking time 15 min (ref.: 5 min)	-0.415*** (0.102)	-0.518*** (0.099)	-0.442*** (0.098)	-0.465*** (0.097)
x crossed effect	-0.505*** (0.244)	-0.002 (0.287)	-0.569*** (0.298)	-0.492** (0.302)
Scenery residential no green (ref.: residential some green)	0.035 (0.081)	0.006 (0.078)	-0.023 (0.079)	0.010 (0.077)
x crossed effect	-0.414** (0.198)	-0.319 (0.225)	-0.039 (0.202)	-0.402* (0.233)
Scenery all green (park) (ref.: residential seom green)	0.530*** (0.114)	0.499*** (0.110)	0.538*** (0.109)	0.516*** (0.106)
x crossed effect	-0.091 (0.254)	-0.034 (0.273)	-0.299 (0.293)	-0.166 (0.362)
Pavement asphalt (ref.: tiles)	0.423*** (0.080)	0.455*** (0.075)	0.428*** (0.077)	0.458*** (0.076)
x crossed effect	0.179 (0.184)	0.082 (0.248)	0.340 (0.224)	0.041 (0.235)
Pavement broad (ref.: narrow)	0.362*** (0.091)	0.381*** (0.090)	0.333*** (0.093)	0.396*** (0.089)
x crossed effect	-0.013 (0.230)	-0.175 (0.241)	0.223 (0.210)	-0.296 (0.262)
Benches on the route (ref.: no benches)	0.219*** (0.079)	0.276*** (0.075)	0.253*** (0.078)	0.315*** (0.078)
x crossed effect	0.557*** (0.201)	0.240 (0.250)	0.422** (0.219)	-0.022 (0.211)
Number of respondents	394	394	394	394
Number of choice tasks	1970	1970	1970	1970

Notes: Standard errors in parentheses, clustered at individual level. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

Table B2: Robustness checks Recreational tobit

Variable	x poor walking (A)	x walking aid (B)	x seldom outdoor (C)	x low satisfaction (D)
Constant (average walking time)	21.754*** (1.250)	18.469*** (1.239)	19.832*** (1.243)	18.275*** (1.219)
x crossed effect	-20.942*** (2.301)	-9.632*** (2.990)	-15.816*** (2.901)	-8.837*** (3.447)
Scenery residential no green (ref.: residential some green)	-1.868** (0.848)	-1.882** (0.876)	-1.606* (0.828)	-1.276 (0.840)
x crossed effect	-0.247 (1.851)	3.330 (2.212)	0.819 (2.321)	-2.510 (2.449)
Scenery all green (park) (ref.: residential seom green)	5.031*** (1.079)	5.641*** (1.038)	5.259*** (1.079)	4.893*** (1.039)
x crossed effect	-1.035 (2.131)	-5.342* (2.942)	-1.649 (2.493)	1.966 (3.009)
Pavement asphalt (ref.: tiles)	3.083*** (0.885)	3.205*** (0.885)	2.462*** (0.863)	2.773*** (0.869)
x crossed effect	-1.674 (1.736)	-1.303 (2.264)	1.999 (2.097)	1.917 (2.436)
Pavement broad (ref.: narrow)	1.124 (0.891)	1.064 (0.898)	0.419 (0.921)	0.862 (0.889)
x crossed effect	-1.118 (1.893)	-2.439 (2.489)	2.055 (2.255)	0.151 (2.761)
Benches on the route (ref.: no benches)	1.147 (0.750)	1.211 (0.748)	1.077 (0.814)	1.228 (0.766)
x crossed effect	3.180* (1.792)	1.407 (1.953)	2.084 (1.927)	0.682 (2.276)
Number of respondents	394	394	394	394
Number of choice tasks	3940	3940	3940	3940

Notes: Standard errors in parentheses, clustered at individual level. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$