AGILE: GIScience Series, 7, 50, 2026. https://doi.org/10.5194/agile-giss-7-50-2026
Proceedings of the 29th AGILE Conference on Geographic Information Science, 16–19 June 2026.
Eds.: Evelyn Uuemaa, Alexander Kmoch, Holger Virro, and Simon Scheider
This contribution underwent peer review based on a full paper submission.

Assessing Perceived Walkability: a case study using eye-tracking and think-aloud with street images

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Abstract. GIS has been widely used to measure objective walkability at the city and street levels. However, perceived walkability is mostly assessed at the city or neighborhood scale and relies heavily on participants' post hoc evaluations. In this case study, we propose a method to measure perceived walkability at the street level and identify its physical signifier. Our approach combines eye-tracking with retrospective think-aloud protocols while participants rate the perceived walkability of street photos. We analyzed the perceived walkability from 33 participants and assessed perceived walkability across five categories: sense of safety, sense of security, convenience, comfort, and visual interest. Results indicate that footpath quality, traffic conditions, and the presence of other pedestrians play key roles in shaping perceived walkability.

Submission Type. Case study; Analysis.

BoK Concepts. [GD] Geospatial Data, [AM] Analytical Methods

Keywords. Cognitive science, Perception, Walkability, Eye-tracking, Think-aloud

1 Introduction

Walking is a core element of urban mobility, representing the most direct and sustainable form of interaction between people and the built environment. As an integral part of nearly every journey, walking connects other transport modes and contributes to the accessibility, health, and livability of cities (Wunderlich, 2008). Walkability is an emerging topic that is at the intersection of public health, transport planning, urban design, and urban affairs (Boarnet et al., 2008; Shields et al., 2023). It addresses how the urban design and street design shape pedestrian walking ability and experience (Lo, 2009).

Many studies contribute to identifying what aspects of the urban environment make a city 'walkable'. Land use, accessibility, street network connectivity, pedestrian facility, safety and security, and streetscape design are identified as the major built environment attributes that influence walkability (Fonseca et al., 2022). Based on the objective physical attributes, many previous studies have developed walkability indices to evaluate the walkability of urban areas (Stockton et al., 2016; Lam et al., 2022).

Although the walkability can be reflected by measuring the urban environment, the pedestrian experience depends on the quality of the walking activity. For instance, evidence shows that pedestrians prefer the streets adjacent to green public spaces (Angel and Plaut, 2024). Increasing studies measure perceived walkability by asking people to self-evaluate and report their perceived walkability, such as comfort, safety, and convenience (Talavera-Garcia and Soria-Lara, 2015; van der Vlugt et al., 2025). Most of the perceived walkability is measured at the level of neighborhoods or paths, but not sufficiently measured at the street level.

To address this gap, this study investigates perceived walkability at the street level through a controlled experimental design. Specifically, we proposed three research questions (RQ):

RQ1: What physical signifier influence perceived walkability at the street level?

RQ2: How do these influences vary across different walkability dimensions (e.g., safety, comfort, pleasurability)?

This study applies a scenario-based experimental design combining eye-tracking and think-aloud protocols to investigate perceived walkability. We evaluated street environments based on 33 participants rating and explaining their perceived walkability by viewing street photos. The results provide insights into how built environment shapes perceived walkability across different dimensions. In Section 2, we review related work. Section 3 details our approach for evaluating perceived street-level walkability and describes the associated human subject study. The results are presented in Section 4, and the paper concludes with a discussion and final remarks in Section 5.

2 Related Work

As a physical activity, walking is influenced by many factors. Alfonzo (2005) proposed a five-level conceptual model describing the needs associated with walking. Feasibility represents the fundamental level, including mobility, time, and personal responsibilities of potential pedestrians. Additional walkability-related factors, such as gait speed, distance, heart rate, and step length, have been identified to evaluate walkability for the elderly (Alves et al., 2020). The second level is accessibility, which includes the proximity of activities, network connectivity, and walking-related amenities. Many studies measured areas within walking distance of physical infrastructure, such as parks, public transport stops, retail locations, and footpath networks (Mitra et al., 2015; Telega et al., 2021; Gao et al., 2022). The third level, safety, is typically reflected by crime records, traffic speed and flow, street lighting, litter, and graffiti (Suarez-Balcazar et al., 2020; Koschinsky et al., 2017). The fourth level, comfort, is associated with factors such as noise pollution, shade and sunlight conditions, temperature, and precipitation (Al Shammas and Escobar, 2019; Al Shammas et al., 2023). The fifth level, pleasurability, includes liveliness, architectural coherence, and aesthetic appeal. Many walkability indices synthesize these physical attributes to quantify the walkability of urban areas (Frank et al., 2010; Tsiompras and Photis, 2017; Cardoso et al., 2024). These indices are widely used as operational tools in urban design and planning.

Although walking is strongly linked to the built environment, perceived walkability also influences walking behavior. For example, the feeling of being “out of place” among individuals with disabilities or chronic illness can hinder their access to public spaces (Andrews et al., 2012). Understanding how the environment relates to perceived walkability can therefore provide important practical insights. Various questionnaires have been developed to measure perceived walkability in terms of accessibility, security, safety, comfort, convenience, and attractiveness (Saelens et al., 2003; Lee and Dean, 2018; Talavera-Garcia and Soria-Lara, 2015; Park et al., 2014). Interviews were also used to identify factors influencing walkability perception (Alidoust et al., 2018; Aghasi et al., 2025). These approaches provide in-depth understanding of how environments support or hinder walking. However, both questionnaires and interviews rely on post hoc cognitive processes, which may introduce omissions or recall bias.

Visual stimuli, such as images, videos, and virtual reality, are increasingly used in walkability assessment. These approaches provide detailed representations of walking environments, enabling participants to evaluate walkability and reflect on its features (Battista and Manaugh, 2017). For example, previous studies have used street images to assess perceived walkability, capturing aspects such as pavement conditions, architecture, human activity, attractiveness, and liveliness (Liang et al., 2022; Tartia, 2025). Furthermore, eye-tracking technologies have been applied to identify walkability-related environmental cues. For instance, fixation patterns on built environment elements have been analyzed to understand perceived safety related to cars and bicycles (Yao et al., 2025). The results indicate that motor vehicles and road conditions influence perceived safety, whereas bicycles do not show a significant effect. In addition, elements such as fences and greenery have been found to increase perceived safety. Another study reports that visual fixation plays an incomplete mediating role in the relationship between visual information and perceived walkability (Fang et al., 2025).

Building on this work, we combine eye-tracking and think-aloud methods to better understand the relationship between the built environment and perceived walkability.

3 Methodology

The aim of the study is to evaluate the perceived walkability on the street level with human-subject study. We asked he participants to rate on perceived walkability of on street photos based on predefined scenarios as a in-lab qualitative study. This setup ensures controlled and comparable exposure to visual stimuli, minimizing confounding factors such as weather, temporal variation, and dynamic environmental conditions. Meanwhile, we applied eye-tracking and think-aloud methods to identify the specific street conditions that cause the rating on perceived walkability. We chose an in-lab study because it can allow us to expose all the participants with the same imagined walking conditions, avoiding temporal events and weather conditions on the streets.

In this section, we first describe the selected walkability factors and scenario-based questions (Section 3.1), the study area and stimuli (Section 3.2), the participants (Section 3.3), an overview of the experiment procedure (Section 3.4), the apparatus (Section 3.5), and a short summary of the data collection (Section 3.6).

3.1 Walkability Factors and Questions

Among the five-level walk needs proposed by (Alfonzo, 2005), safety, comfort, and pleasurability are more related to street-level objects. In our study, we reflected them with six factors, including **sense of security**, **sense of safety**, **convenience**, **comfort**, and **visual interest**. More specifically, safety refers to risks arising from traffic interactions (e.g., vehicles, bicycles), whereas security relates to perceived risks of crime or social threats, particularly under conditions of low visibility or social uncertainty. Table 1 lists the selected factors. After viewing each question and corresponding photo, participants rated the walkability level from 1 (very negative) to 5 (very positive).

Table 1. The selected walkability factors and scenario-based questions.

Category	Factor	Question
Sense of safety	Safety affected by nearby bikes, scooters	Q1: If you were walking here and cyclists and e-scooter riders passed by you, how safe would you feel that they pay attention to you?
Sense of security	Security affected by visibility at night	Q2: It's late, and the streetlights are not working properly. How often would you find yourself looking around or walking faster to feel more secure?
Sense of security	Security from the visibility of nearby buildings	Q3: If you are mugged by someone on the street, how confident are you that someone in the nearby houses or businesses could see you and call the police?
Convenience	Ease of pedestrian crossing	Q4: If you needed to get to the other side of this street, how likely would you be to cross right here instead of looking for another location on the same street?
Comfort	Barrier-free accessibility	Q5: If you need to use a wheelchair on this street, how comfortable would you feel?
Visual interest	Visual variety for orientation	Q6: If you were walking through this area, how easy would it be for you to stay oriented, considering the visual variety (or lack of it) in the surroundings?

3.2 Study Area and Stimuli

This case study focused on the urban area of a city center. The city has a population of over 300,000. It has an old town in the city center. The study area is a well-used walking environment, comprising a mix of car-free zones and surrounding streets that permit vehicular traffic, and is well connected to public transportation. In addition, the area has both historical and modern buildings, commercial and residential areas. Figure 1 shows the location of the eight streets and the positions of the cameras to take the street photos. We selected various types of streets, including shopping streets, public transport stations, and parks. We also avoided some highly similar streets. Table 2 lists the functions and restrictions on vehicles of the streets.

Table 2. The description of the selected streets.

Street ID	Function	Motorized vehicles	Tram	Bike
Street 1	Tram Station	no	yes	yes
Street 2	Park	no	yes	yes
Street 3	Tram Station	no	yes	yes
Street 4	Park	no	yes	yes
Street 5	Plaza	no	no	yes
Street 6	Tramway	no	yes	yes
Street 7	Shopping Street	limited	no	no
Street 8	Shopping Street	limited	no	no

We took photos of the eight selected streets as a visual reference for the participants to answer the walkability-related questions. To ensure the photos can represent the streets, they were made with several criteria: 1) making the road surface, buildings from both sides, and sky visible in photos, 2) showing the road surface as foreground from a pedestrian view, 3) showing the street boundaries and objects on the road, 4) maintain the sky ratio in all the photos, and 5) sharing the same weather conditions. Figure 2 shows the collected street photos.

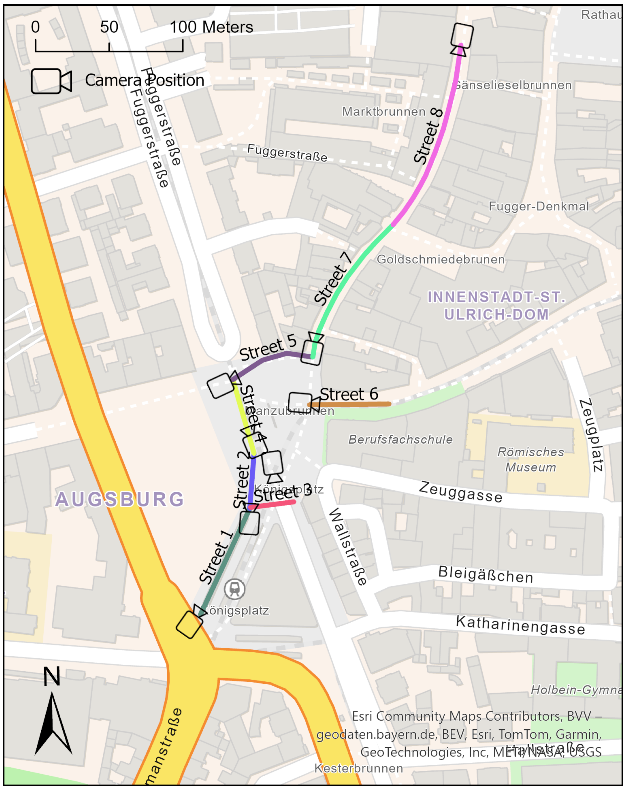

Figure 1. The overview of the selected streets.

3.3 Participants

Thirty-four participants participated in the study. One of the results was excluded because of low eye-tracking quality. The thirty-three samples were used in the results analysis, including 11 females, 19 males, 3 gender-unreleased persons, aged 20 - 44 (M=25, SD=5.3). We recruited the participants via invitations, such as emails, posters, friends, and family. The participants confirmed that they had normal or corrected-to-normal eyesight, were able to communicate verbally, and they did not suffer from

(a) Street 1 (b) Street 2

(c) Street 3 (d) Street 4

(e) Street 5 (f) Street 6

(g) Street 7 (h) Street 8

Figure 2. The photos of eight selected streets.

serious mental illness. The participants were randomly assigned to complete questions of two or three walkability factors. It consisted 15 participants for Q1, Q2, and Q6; 8 participants for Q4; 10 participants for Q3 and Q5. The experiment was conducted from December 2025 until February 2026.

3.4 Experiment Procedure

The experiment was conducted in a laboratory at our University. Figure 3 shows the procedure of the experiment. The experiment began with a short introduction and the data policy of the experiment was presented. The experiment proceeded only if the participants agreed and signed the consent form. Then the participants were asked for their demographic information, including gender, age group, education and professional background, and familiarity of the study area. Then we proceeded to the preparation stage, including eye-calibration for the eye tracking and completing task examples. Subsequently, we showed the participants a photo of a street in our study area for a maximum of 10 seconds, which is a sufficient duration but not yet bore the participants (Yao et al., 2025). The participants could jump to the next photo freely. Following each photo, the participants rated the perceived walkability on a Likert scale (from 1 very negative to 5 very positive) and retrospectively thought-aloud about their thoughts. The procedure was repeated for each street of the study area with each specific walkability factor. In order to avoid fatigue, each participant was asked to report two to three factors on perceived walkability. The experiment lasted approximately 10 to 15 minutes for each participant.

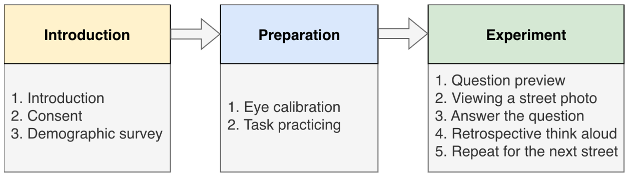

Figure 3. The procedure of the experiment.

3.5 Apparatus

The participants viewed the photos on a laptop. The eye movement data were collected by the RealEye[1] web tool and the LOGITECH 960-001585 Webcams. The TOVBMUP microphones were used to collect the voice of the participants during the think-aloud. The voice records were transcripted by the tool TurboScribe[2].

3.6 Data Collection and Analysis

We collecteded three types of data: 1) the rating of perceived walkability in six categories, 2) the eye movements on the photos, and 3) the verbal transcripts of reasons for the perceived walkability. We first calculated the perceived walkability ratings for each street. Then, we identified the physical signifiers of perceived walkability from eye fixation and verbal transcripts. We applied the thematic analysis method (Terry et al., 2017), one of the most widely used methods for analyzing qualitative data. We first familiarized with the eye fixation and verbal transcripts, then identified elements in the built environment (e.g., pedestrian flow, steps on the footpath), listed and counted the frequency of the positive and negative elements for each category of walkability, and finally, we summarized the roles of the physical signifiers.

3.7 Data and Software Availability

The shapefile data used for street selection in Figure 1 and Figure 2 was downloaded from OpenStreetMap. The collected photos and think-aloud transcripts are published at https://doi.org/10.5281/zenodo.19497691. Due to legal constraints and privacy concerns, we do not share the think-aloud and eye movement data.

[1] https://www.realeye.io/
[2] https://turboscribe.ai/

4 Results

In this section, we first present the overall ratings of perceived walkability (Section 4.1). We then describe the identification of street conditions related to walkability (Section 4.2).

4.1 Overall Rating of the Perceived Walkability

We calculate the level of the perceived walkability of the selected streets using the participants rating from 1 (very negative) to 5 (very positive). Figure 4 shows the overview of the average rating of the perceived walkability. In general, the overall perceived walkability of all eight streets is moderate (3.3). The rating of Q2 *security affected by visibility at night* is negative (2.5). The rest of the factors are positive, including Q3 *security from the visibility of nearby buildings* (3.9), Q4 *security from the visibility of nearby buildings* (3.7), Q6 *Visual variety* (3.5), Q4 *ease of pedestrian crossing* (3.4), and Q1 *safety affected by nearby bikes, scooters* (3.1). Overall, the walkability ratings for all selected streets are neutral-to-positive. Street 7 receives the highest average rating (3.8), followed by Street 5 (3.6), Street 2 (3.5), and Street 6 (3.4). Streets 4 and 1 share a rating of 3.2, while Streets 8 and 3 have the lowest ratings (3.0).

4.2 Identification of Walkability-Related Street Conditions

In the following, we investigate the results of the walkability factors from the think-aloud transcripts.

Safety affected by nearby bikes, scooters. Multiple street conditions are identified as influencing perceived safety in the presence of bicycles and scooters. The results indicate that the most influential factors are *traffic mix*, *pedestrian walkway width*, and *the clarity of pedestrian zone markings*. In addition, *traffic volume*, *traffic speed*, *pedestrian density* (with overcrowding and the presence of intoxicated individuals perceived negatively), and *visual openness* are also found to affect perceived safety. Furthermore, *traffic regulations* (e.g., unclear pedestrian priority), *pavement conditions* (such as cobblestone that can slow the traffic down), and *the presence of construction sites or temporary obstructions* are identified as well.

Security affected by visibility at night. *Traffic* and *the presence of other people* are identified as two major conditions influencing perceived walkability at night, with both positive and negative effects. On the one hand, moderate traffic levels and the presence of other pedestrians can enhance feelings of safety by increasing social visibility. On the other hand, traffic can also reduce perceived security when poor visibility and fast-moving vehicles make pedestrians feel vulnerable. The presence of intoxicated individuals or groups is consistently associated with heightened feelings of unsafety. In addition, *street lighting*, *spatial openness*, and *the presence of shops* are identified as important factors shaping nighttime safety perceptions. Finally, *cleanliness* is also found to influence perceived safety, with poorly maintained environments contributing to feelings of unease after dark.

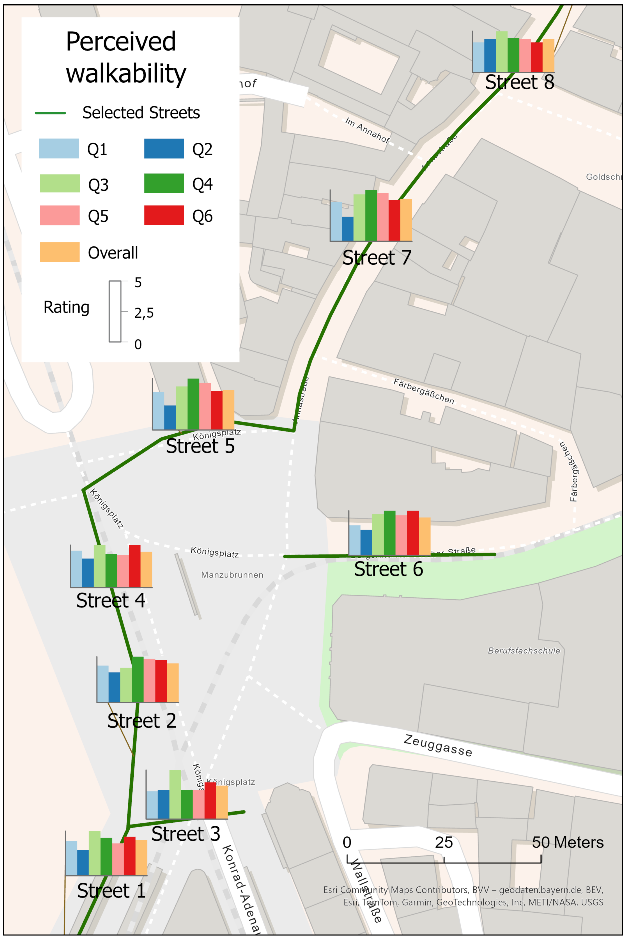

Figure 4. The rating of the perceived walkability.

Security from the visibility of nearby buildings. The participants paid considerable attention to the *presence of other people* when evaluating perceived security. In general, higher presence of pedestrian is associated with increased feelings of security; however, several participants noted that not all individuals contribute positively to perceived safety. *Land use* is identified as another important condition, with participants reporting better feelings of security near buildings—particularly residential buildings than commercial areas. In addition, *time of day*, *spatial openness*, and *sight openness* are identified as relevant conditions influencing perceptions of security.

Ease of pedestrian crossing. Safety and easiness to walk are mostly considered in this category. The *traffic flow*, including cars, trams, and bikes, draw most attention of the participants. More specifically, parked cars hinder the ease of pedestrian crossing, but parked bikes do not. *Visual overview* of the streets were also mentioned multiple times. *Traffic lights* and *marked crosswalk* increases the ease of pedestrian crossing, but not necessary for all the occasions. *Short passing distance* and *smooth footpath* are preferred. In addition, the *present of other pedestrians* were attended by the participants, but its role to the ease of pedestrian was not explained by the participants.

Barrier-free accessibility. Reported conditions related to barrier-free accessibility primarily concerned the *smoothness of footpath*, including pavement quality and the presence of steps. The *physical obstacles*, such as construction sites, parked vehicles, and tram rails, were mentioned several times. The participants also emphasized the importance of *sidewalk width*, *pedestrian density*, and the availability of *a clear marking of the walking area* in supporting accessible and comfortable walking conditions.

Visual variety for orientation. Visual variety plays a complex role in spatial orientation, as participants were found to rely on a combination of cues rather than a single dominant factor (often in safety and security). The results indicate that *linear street layouts* and *visually salient landmarks* (e.g., shops, tram infrastructure, construction sites, and parks) support orientation by providing recognizable reference points. In addition, some participants used *pedestrian flow intensity* as an orienting cue. *Visual openness* and *road signage* are also found to aid orientation when present at moderate levels. However, excessive openness or an overload of signage could hinder wayfinding. Furthermore, *environmental stressors*, including heavy traffic and high pedestrian density, were reported to reduce orientation ability.

5 Discussion and Conclusion

This pilot study explores perceived walkability at the street level by combining subjective rating, eye-tracking, and think-aloud methods. The walkability of the study area is in general from positive to neutral. More specifically, perceptions are collected across six walkability perspectives, including traffic safety, sense of night-time security, sense of crime security, ease of crossing, barrier-free accessibility, and visual variety for orientation. The integration of eye-tracking on street photos and think-aloud methods could enables cross-validation and mutual enrichment between visual attention and verbalized reasoning. The methodology limitation is regarding the stimuli. We have only included the daytime photos in this stage, and we are planning to include nighttime photos and virtual reality to better represent the streets.

In the preliminary work, we have identified some physical signifiers for the perceived walkability on the street level. We will analyze the eye movement on the signifiers as the next step, including time to first fixation, fixation duration, fixation count, heatmap, and scan path. The results will support to rank the importance of the physical signifiers, which can be integrated into walkability models.

Declaration of Generative AI in writing

The authors declare that they have used Generative AI tools in the preparation of this manuscript. Specifically, the AI tools were utilized for language editing, improving grammar, and sentence structure, but not for generating scientific content, research data, or substantive conclusions. All intellectual and creative work, including the analysis and interpretation of data, is original and has been conducted by the authors without AI assistance.

Acknowledgments

This research is funded by the "Green Transformation" program at the University of Augsburg under the project Walkable Augsburg (N2024-02).

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