Unveiling Pedestrian Safety Perceptions using Rasch Analysis

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SHORT SUMMARY

Despite a global focus on pedestrian-vehicle interactions in road safety studies, pedestrian behavior and safety perceptions are often overlooked. This research investigates pedestrian safety perceptions and behaviors in urban environments, with London as a case. Rasch analysis, a novel approach in road safety, is applied to analyze pedestrian safety perceptions and their impact on walking and crossing activities. The analysis identified items such as *crossing in red signal phases* and *running across streets* to be unsafe. Differential Item Functioning test revealed age-related variations in safety perceptions. Additionally, the test reveals that factors such as walking and crossing in a group and pedestrian friendly facilities significantly influence safety perceptions. The study contributes to Ajzen's theory of planned behavior, emphasizing the importance of perceived behavioral control in pedestrian activities. This research provides a robust model for researchers to predict and understand pedestrian safety perceptions.

Keywords: Pedestrian safety perceptions; Rasch analysis; Walking decisions

1. INTRODUCTION

Approximately 1.19 million people are killed in road accidents annually, with pedestrians accounting for over 23% of these fatalities (WHO, 2023). In London alone, 23,465 road casualties resulted in 41 pedestrian fatalities and 1194 serious injuries (Tfl, 2023). Pedestrians are particularly vulnerable as they are directly exposed to collisions.

While numerous studies have investigated the nature and causes of pedestrian fatalities, many focus on pedestrian-vehicle interactions, crash severity and frequency, often overlooking pedestrians' behavioral patterns. Pedestrians possess a good sense of recognizing safety issues, a trait shaped by their exposure and past experiences in the built environment (Aceves-González et al., 2020). This sense of recognition, termed perception, is subjective and influenced by sociodemographic, trip characteristics, and built environment features (McCormack, 2007).

Perceived safety influences a pedestrian's risk-taking behavior and provides critical information regarding an individual’s travel behaviors (Rankavat & Tiwari, 2020). Human perception often stems from exposure or past experiences, preferences, socioeconomic status, attitudes, habits, and beliefs. Therefore, it is particularly important that transportation researchers take into consideration pedestrians' perception of safety with respect to their walking and crossing behavior (Park, 2008).

Despite the importance of safety perception in altering pedestrian behavior, researchers and policymakers seldom consider safety features from a pedestrian's viewpoint when designing pedestrian facilities. While many studies have examined the safety of walking and crossing in various situations, they typically concentrate on one or a few activities. No study has simultaneously explored the effects of pedestrian safety perception levels and safety levels of walking and crossing items. This research aims to fill this gap by applying Rasch analysis, a method that transforms ordinal scales into interval-level measurements, providing a more precise and reliable assessment of pedestrian safety perceptions. By examining the variability in pedestrian perceptions and how different walking and crossing tasks contribute to these perceptions, this study offers novel insights into pedestrian safety.

Walking and crossing safety plays crucial roles in a pedestrian's safety perception. Crossing activity can be carried out at grade (in the form of zebra crossings, pelican crossings, signalized crossings, etc.) or grade-separated (in the form of foot over-bridges and subways). Crossing behaviors at grade crossings can be influenced by several factors such as age, gender, behavior of fellow pedestrians, or other circumstances such as personal convenience and traffic conditions (Granié et al., 2014; Lord et al., 2018). Pedestrians are likely to cross outside delineated markings under numerous circumstances such as in cases of urgency or when the pedestrian is in a hurry (Holland et al., 2009). Physical obstacles like parked vehicles, high/unmountable medians, trash bins, and poor lighting at crossing facilities also affect pedestrian crossing behavior (Christie et al., 2007; Granié et al., 2014).

Similarly, the safety and security perceptions while walking on the footpath have a serious effect on pedestrians' mode choice decisions. Security concerns arise due to issues such as threats, violence, crime, deteriorated buildings, and the presence of rowdy youth or unfamiliar people (Lindelöw et al., 2014; Loukaitou-Sideris, 2016). For women, security concerns are particularly pronounced, often influencing their route choices, especially after dark (Lindelöw et al., 2014).

Although numerous studies have assessed crossing and walking safety in different scenarios, very few have investigated this from the perspective of pedestrian safety levels. This research uses Rasch analysis to explore how different segments of the population perceive walking safety.

The remainder of the paper is structured as follows: Section 2 provides a brief description of Rasch analysis and explains its relevance to this research. It further details the survey questionnaire and methodology adopted for data collection. Section 3 discusses the data analysis process and presents the key results obtained. The final section discusses these results and draws conclusions from them.

2. METHODOLOGY

Proposed Methodology

Consider three pedestrians- A, B and C and their safety perceptions (Table 1). Pedestrian C is mobility impaired and feels unsafe while crossing at night and crossing the street during the red pedestrian phase. Pedestrians A is worried about her personal safety. Based on the responses, the pedestrian safety levels can be arranged as in Figure 1.

Table 1: Conceptual illustration

Pedestrian	Crossing at night	Running to cross a street
A	Safe	Safe
B	Unsafe	Safe
C	Unsafe	Unsafe

This example shows that the perception levels of A, B, and C are different. It also underscores the variations in safety levels across the two crossing activities. However, in traditional models, this individual perception level gets overlooked. For instance, crossing in red phase would be incorrectly considered safe since 2 out of 3 people perceived it to be safe. This approach also puts individuals like C at a disadvantage. Rasch analysis addresses this issue by representing a pedestrian's perception and the actual safety level of items on the same scale (Figure 1). This helps the investigator to identify where each item and each individual is located, allowing for designs that accommodate everyone's needs.

Similarly, conventional mathematical models using rating-scale data such as factor analysis or structural equation modelling, assume equal relative distances between category scores across all items (Boone, 2016). However, the level of "unsafety" person A experiences while walking at night may differ significantly from running to cross the street. Rasch analysis can be a useful tool to overcome such shortcomings.

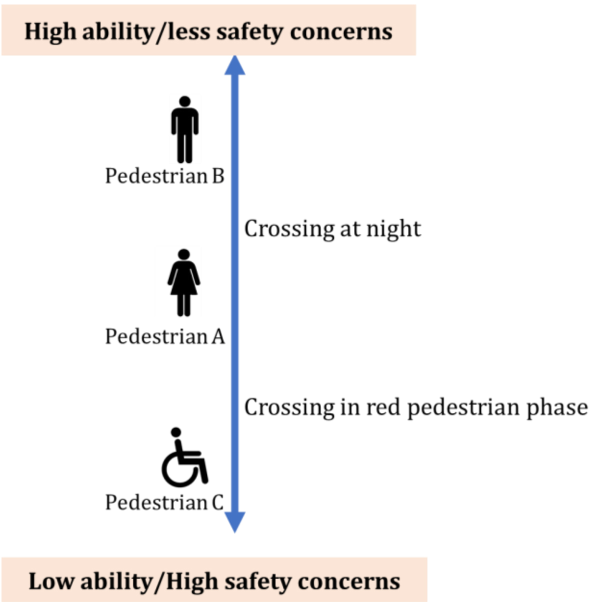

Figure 1: Conceptual diagram

Rasch Analysis

Rasch analysis, developed by George Rasch in 1980, is a modern psychometric method used to explain latent traits such as safety perception (Boone, 2016). In the Rasch model, both persons and items are measured on a common measurement unit, the logit, by transforming raw test scores into a linear scale (Tennant & Conaghan, 2007). These logit scores are used to compute linear "item scores" that express the safety levels of each item and "person scores" describing the respondent's perception level (Boone, 2016). While widely applied in healthcare for developing, revising, and equating questionnaires, the Rasch model is relatively underutilized in road safety.

This study adopts a Partial Credit Rasch model, a member of the polytomous Rasch family, which is specified when items have several ordinal response categories that are not considered to have equally spaced intervals (Masters, 1982). It is expressed as:

$$\phi_{kni} = \frac{\pi_{kni}}{\pi_{k-1,ni} + \pi_{kni}} = \frac{exp(\beta_n - \delta_{ik})}{1 + exp(\beta_n - \delta_{ik})} \quad \text{for k= 0,1,2} \qquad (1)$$

ϕ_{kni} is the conditional probability; π_{kni} is the probability of person 'n' responding to category 'k' in item 'i'. β_n denotes the level of safety associated with a particular item by pedestrian 'n'. δ_{ik} denotes the actual level of safety for item 'i'. These thresholds are empirically estimated for each item.

The result of Rasch analysis is called a Wright map, which represents the range of pedestrians' perception in relation to the safety levels for each task (Bond & Fox, 2007). It is constructed with the average measure of all item parameters fixed at zero logit (M). A vertical line separates items and respondents, with the left representing the distribution of persons, and the right side displaying the mean logit estimated for each item. Items with higher logit values are perceived as unsafe by most pedestrians and vice versa. Pedestrians located above 'M' are those feeling secure for all items below them and vice versa.

Survey Questionnaire

A survey questionnaire (Table 2) was constructed to explore pedestrians' safety perceptions while walking and crossing the streets from extensive literature review. The questions were assessed on a three-point Likert scale: - Very safe, somewhat safe, and not at all safe. Information on gender and age was also collected. The survey questionnaire was approved by the UCL Research Ethics Committee (Approval Number: 24657/001).

Table 2: Pedestrian safety perception questionnaire

Safety dimension	**Item label**	**Safety Measure**
Walking safety	1	Walking during day
	2	Walking with other pedestrians
	3	Walking on the road to avoid overcrowding on footpath
	4	Walking on the road to avoid obstacles
	5	Walking on well-lit streets
	6	Presence of street vendors
	7	Walking on a raised footpath
	8	Presence of security cameras
Crossing Safety	9	Crossing with other pedestrians
	10	Absence of crossing facility
	11	Crossing in poor visibility
	12	Crossing between stationary vehicles in traffic
	13	Using the median as refuge island
	14	Crossing diagonally at an intersection
	15	Running to cross the street

	16	Crossing outside markings to avoid signal delays
	17	Crossing outside markings due to distance from destination
	18	Crossing in red pedestrian phase
	19	Crossing outside markings in emergencies
	20	Presence of traffic calming measures

Survey Methodology and data

The survey conducted in London borough of Camden (United Kingdom), serves as a case study illustrating the application of Rasch analysis in assessing pedestrians' safety perceptions.

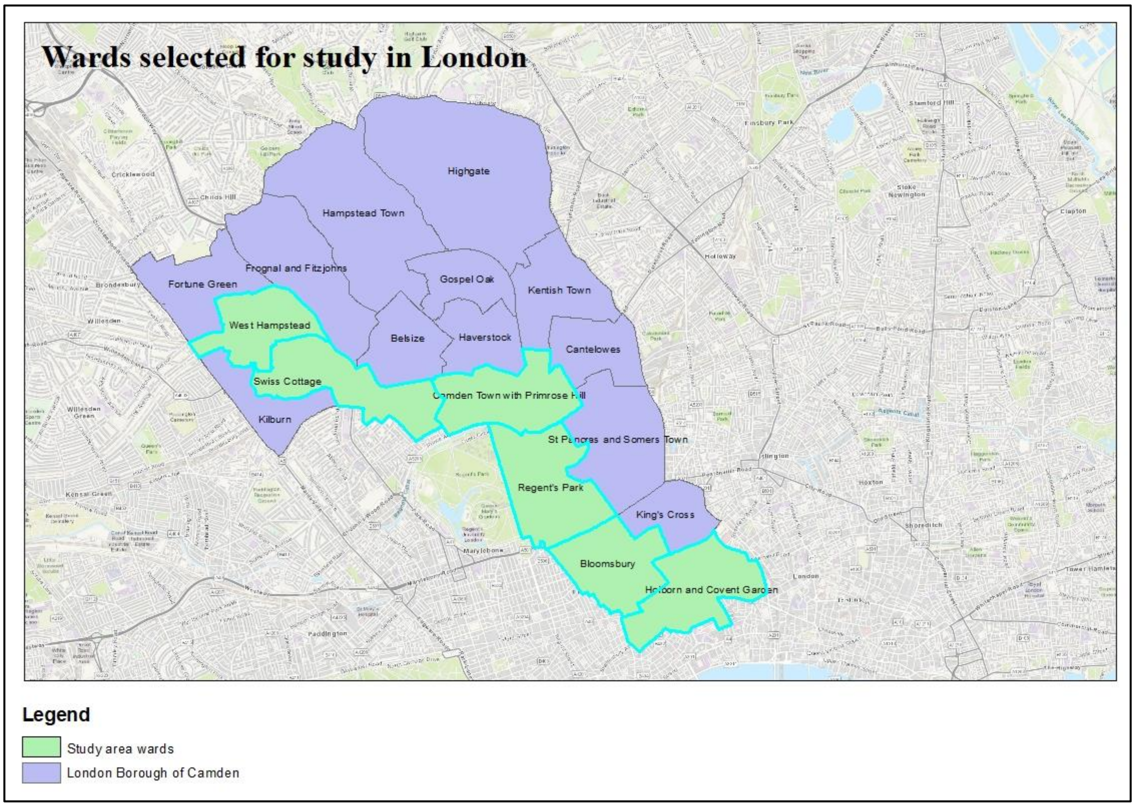

Figure 2 Wards selected for study in London

A three-stage criteria, based on based on total pedestrian trips (from Camden Council Census dataset), land use mix (from Camden Council open data), and pedestrian crash data (from STATS19 database by Department of Transport), was used to select data collection locations. Pedestrian trip data is crucial for analyzing safety, as areas with higher foot traffic typically experience more pedestrian-vehicle interactions, increasing crash risk. Land use mix is also significant, influencing pedestrian activity due to proximity to amenities and services, while presenting unique safety challenges. The crash rate is a direct indicator of safety, highlighting areas where pedestrians are at higher risk of accidents. Using this criteria, six wards within the London Borough of Camden were chosen for study (Figure 2).

Pedestrians were encountered at bus stops, parks, and community centers. They were presented with a participant information sheet and the survey questionnaire. Data was collected through a combination of online and return post card methods, wherein the respondents were handed paper questionnaires with QR codes to access the online questionnaire or a Freepost envelope to return the survey via post. This survey yielded 348 responses.

Table 3 summarizes sample characteristics. According to the 2022 census, Camden's total population was 218,049, with 46.9% males and 53.1% females. The survey sample has a higher percentage of females (58.3%) and a lower percentage of males (40.2%) compared to the actual population. The age distribution in Camden's actual population is as follows: below 18 years (4.6%), 18-45 (51.9%), 45-60 (11.7%), and above 60 (14.1%). Minors (under 18) are underrepresented in the sample (2.6%) due to the lack of ethical clearance, while other age groups were fairly represented.

Table 3: Sample characteristics

Socio-demographics *(N=348)*		**Statistics**
Gender	Male	140
	Female	203
	Prefer not to say	5
Age	<18	9
	18-45	209
	45-60	38
	>60	92

3. ANALYSIS AND RESULTS

Rasch Partial Credit Model was applied using Winsteps ® 5.3.0.0 software. To assess suitability, the data was checked for item polarity, threshold order, unidimensionality, reliability, and fit statistics.

Positive correlations for item polarity indicated consistency with the metric estimate of the underlying construct. Analysis of category threshold curves revealed no disordered thresholds among items, indicating that no rescoring was necessary (Bond & Fox, 2007; Tennant & Conaghan, 2007). Similarly, the data was found to be unidimensional since a single latent variable (safety) was sufficient to explain most of the variation in item responses (McCormack, 2007).

The overall data reliability of the model for London was good, with a person reliability of 0.88, and item reliability of 0.99. This meant that the survey questionnaire was sensitive enough to accommodate people with varying levels of safety perceptions (Cappelleri et al., 2014).

Infit and Outfit mean-square statistics (MNSQ) were analyzed to identify any unexpected participant responses (Bond & Fox, 2007). MNSQ ranging from 0.5 to 1.5 fit the Rasch model (Linacre, 2002). While item fit statistics fell within acceptable boundaries (Table 4), the person fit statistics revealed aberrant response patterns for three pedestrians. Hence, the revised model utilized 345 pedestrians.

Table 4: Item scores and fit statistics

Item label	Item score *(logit)*	Infit MNSQ	Outfit MNSQ
1	-1.84	1	1.14
2	-1.87	1.08	1.06
3	0.92	1.23	1.41
4	1.33	1.01	1
5	-1.04	1.2	1.27
6	-0.89	0.95	0.91
7	-1.29	0.88	0.87
8	-2.08	1.29	1.53
9	-2.31	1	1.05
10	0.58	0.9	0.97
11	2.14	0.94	0.84
12	1.00	0.95	0.89
13	-0.17	1.09	1.07
14	0.64	0.88	0.83
15	1.92	0.77	0.69
16	0.87	0.9	0.96
17	1.24	0.77	0.75
18	1.17	0.92	0.94
19	0.48	0.93	0.9
20	-0.81	1.13	1.29

Wright Map

The Wright map and item scores are presented in Figure 3 and Table 4 respectively. The relative locations of items on Wright map reveal that pedestrians associate more safety with walking activities than crossing activities because all, except two walking tasks, were rated as safe.

Eleven items, located above the person mean suggest that pedestrians perceive them to be above their safety threshold, with fewer pedestrians feeling confident in safely undertaking these tasks. Item 13, near the midpoint, aligned with the safety levels of an average pedestrian. Nine safety items fell below the midpoint, indicating most pedestrians could safely perform these tasks. Items such as poor crossing visibility (item 11), running to cross (item 15), walking on road to avoid footpath obstacles (item 4), crossing outside a facility due to distance (item 17), and crossing in the red phase (item 18) were considered unsafe. The safest items were crossing and walking with other pedestrians (items 9 and 2), presence of security cameras (item 8) and daytime walking (Item 1).

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Figure 3 Wright map

A Differential Item Functioning (DIF) test was conducted to explore potential interactions between items and sample characteristics by assessing individual difficulty within sample subgroups for each item while keeping other factors constant (Tennant & Conaghan, 2007). DIF contrasts exceeding 0.64 suggest a substantial difference between person classes (Zwick et al., 1999). DIF scores were observed only for age (Table 5).

Table 5: DIF Scores

Item label	**Person Class I**	**Item score I** *(logit)*	**Person Class II**	**Item score II** *(logit)*	**DIF Contrast**	**p value**
7	>60	-0.82	18-45	-1.49	0.67	0.003
7	>60	-0.82	46-60	-1.57	0.75	0.030
9	18-45	-0.66	46-60	-2.53	1.87	0.017
9	18-45	-0.66	>60	-2.22	1.56	0.041

11	18-45	2.37	>60	1.66	0.7	0.023
12	>60	1.67	18-45	0.78	0.89	0.003
13	18-45	0.18	>60	-0.99	1.17	0
13	46-60	-0.22	>60	-0.99	0.78	0.034

4. DISCUSSION

Pedestrian crossing safety

The perception of crossing during a red pedestrian phase (score: 1.17) and running across the street (score: 1.92) as unsafe may be linked to pedestrians making crossing decisions based on the speed and distance of approaching vehicles. Misjudgments often occur due to incorrect estimations (Abughalieh & Alawneh, 2020). Consequently, crossing during a red phase is associated with faster walking or running to avoid potential collisions (Kaparias & Tsonev, 2023).

Crossing outside a facility, although considered to be unsafe, yields varying effects. For instance, pedestrians consider it safe to cross in urgent situations (score: 0.48). Whereas crossing when the destination is near and the facility is far, raises safety concerns (item score: 1.24). This aligns with findings by Anciaes & Jones (2020), who noted that as distance to the nearest crossing facility increases, the probability of walking to it and returning to the same place but across the road, decreases.

The presence of other pedestrians, whether crossing (item score: -2.08) or walking (score: -1.87), is perceived as the safest. Studies reveal that pedestrians walking alone tend to walk or cross faster and are more likely to cross on red compared to those in groups (Kaparias & Tsonev, 2023). Crossing in groups reinforces feelings of safety, particularly for older adults and the elderly. This behavior makes pedestrians more likely to wait for a green signal to avoid breaking the group, emphasizing the importance of street designs that boost pedestrian confidence.

The midpoint location of item 13 suggests that pedestrians consider the presence of medians as a waiting area to be neither safe nor unsafe. This aligns with a previous study that found no significant influence of medians on crossing behaviours, especially at mid-blocks (Papadimitriou, 2016). Notably, older people find medians safer, whereas younger individuals view them as complicating crossings due to inconsistent median openings at many locations in London.

Pedestrian walking safety

Two walking tasks, walking on the carriageway due to footpath overcrowding (score:0.92) and obstacles (score: 1.33), are considered unsafe. These results suggest that an obstacle-free footpath with more space and less crowding encourages pedestrians to have a relaxed walk at their preferred speed (Kaparias & Tsonev, 2023).

The concept of a raised footpath is not widespread in the United Kingdom, where the typical kerb height is 120mm. Although a raised footpath is considered safe by all age groups, elderly pedestrians associate it with less safety (item score: -0.82) compared to younger pedestrians, mainly due to difficulties in mounting and dismounting from such footpaths.

5. CONCLUSIONS

The study findings align with Ajzen's (1991) theory of planned behavior, emphasizing the critical role of perceived behavioral control on walking and crossing activities. The results indicate that pedestrians tend to take fewer risks and are less inclined to cross in unsafe situations. Given that pedestrians tend to commit violations, it is important to bring in engineering interventions to address such behaviors rather than relying solely on attitudinal changes.

Rasch analysis, a relatively novel technique in road safety, has proven valuable in highlighting those constructs that need immediate attention. The Wright map effectively visualizes pedestrians' ability to assess the safety of items and proves useful for predicting pedestrian safety perceptions.

Despite providing valuable insights into pedestrian perceptions and behaviors, the study has certain limitations. The sample underrepresents differently abled and child pedestrians, which may affect the generalizability of the findings. Moreover, this study focused exclusively on urban pedestrians within just one borough in London. Future research should aim to include diverse pedestrian groups and explore different geographical settings with varying pedestrian infrastructures to assess the transferability of the findings. Future studies could also aim to assess the correlation between perceived safety and actual behavior among pedestrians in these scenarios.

The findings are expected to provide valuable insights to transport researchers in understanding pedestrian behaviors. By highlighting the importance of perceived behavioral control and the effectiveness of engineering interventions, the study provides a foundation for developing strategies to enhance pedestrian safety.

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