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Perceptions of Pedestrian Safety in Delhi: A Rasch Analysis Approach

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Abstract

Safety perception about the built environment influences a pedestrian's walking and crossing decisions. Rasch analysis, a relatively underutilized psychometric technique in the road safety domain, can provide deep insights into pedestrian's perceptions and decision making process. This paper evaluates pedestrian safety perception based on built environment features in Delhi, India. Pedestrians' perceptions of built environment was collected and analysed using the Rasch technique to simultaneously compute pedestrian performances and safety constructs. The analysis highlights key areas that need immediate interventions. Results revealed that most safety-related constructs are beyond the safety thresholds of even the most capable pedestrians, suggesting that the general pedestrian environment in Delhi is hostile to walking. This paper also discusses the implications of Rasch analysis for revising survey questions, providing valuable insights for early researchers about survey questionnaire design.

Keywords

Pedestrian Safety, Rasch Analysis, Pedestrian infrastructure Planning, Traffic Behaviour

1. Introduction

Pedestrians travel unprotected in their built environment, making them particularly vulnerable to crashes. As a result, they account for over 23% of global road traffic fatalities [1]. In Southeast Asian countries like India, this proportion is as high as 35%, where pedestrians are forced to share space with other modes of traffic [2]. However, pedestrian-related research often focuses on factors such as interactions with vehicles, crash severity, and crash frequency, overlooking safety issues from a pedestrian's perspective.

Pedestrians have a keen sense of recognising potential safety issues [3] and studying these safety issues from their perspective can aid in proactive planning. This sense of recognition, otherwise termed safety perception, is a cognitive activity that describes a pedestrian's observation of the built environment. These perceptions often stem from exposure or past experiences, preferences, socioeconomic status, attitudes, health, habits, beliefs, and self-efficacy [4,5]. Safety perception varies from person to person due to socioeconomic and demographic factors, trip characteristics, and built environment features. Therefore, designing pedestrian facilities that accommodate specific requirements of pedestrians is essential for ensuring pedestrian safety.

Since safety perception is a latent trait that cannot be directly observed or measured, researchers often use statistical methods, known as psychometric methods, to estimate it. Common psychometric methods like factor analysis and structural equation modelling help in getting an overall sense of how safe people feel. However, these traditional methods usually provide an average measure of safety perception, which can overlook specific variations among different groups, such as those related to age and gender [6]. This oversight can lead to mismatched allocation of pedestrian services, resulting in infrastructure that may not meet the diverse needs of all pedestrians.

Rasch analysis, a modern psychometric technique, offers a more focused approach to address these limitations. This analysis technique focuses on the relationship between an individual's unobservable latent trait, such as safety perception, and their likelihood of responding to a specific scale category [7]. This method can account for variations in safety perceptions across different demographic groups, making it a valuable tool for assessing how pedestrians perceive the safety levels of their built environment. Despite its advantages, Rasch analysis is rarely used in safety research.

This paper aims to address pedestrian safety issues using Rasch analysis, specifically by evaluating safety perceptions across different demographic groups in New Delhi, India. The paper is structured as follows: Section 2 reviews the literature used to prepare the questionnaire and provides a brief overview of the Rasch analysis method. Section 3 describes the data collection process, followed by the analysis in Section 4. Section 5 presents a detailed discussion of the results, and the final section summarizes the conclusions and outlines future research directions.

2. Literature review

2.1. Pedestrian safety perception

The built environment plays a crucial role in shaping pedestrians' perceived safety, especially in countries like India, where motorised and non-motorised traffic often share the same carriageway. In such conditions, pedestrians face significant challenges, including direct interaction with high-speed, high-volume traffic—not just while crossing, but even while walking. Therefore, unlike previous studies that relied on existing questionnaires [8,9], this study developed a context-specific questionnaire tailored to the unique traffic conditions pedestrians encounter in a developing country setting.

Pedestrian safety perception is influenced by multiple factors, including traffic characteristics, pedestrian behaviour, and built environment conditions. Among these, street crossing poses one of the greatest risks, particularly in mixed-traffic environments where pedestrians must interact with high-speed or high volume traffic [10,11]. In the absence of safe crossing facilities, pedestrians often make risk-based decisions, influenced by personal convenience [12] and traffic conditions [13]. When faced with high-speed traffic, they may resort to running across streets [14] or crossing outside designated locations [15], especially when in a hurry [9]. Similarly, in high-volume traffic, pedestrians may weave through stationary vehicles in an attempt to find gaps, a risky behaviour that increases their exposure to road hazards [16]. These challenges are particularly evident at midblock locations [17] and near bus stops [18], where crossing facilities are often absent.

Given these risks, well-deigned infrastructure interventions such as designated crosswalks, overpasses, and underpasses have been found to improve pedestrians' sense of safety [19]. However, compliance with such infrastructure depends on its availability, convenience, and accessibility, with many pedestrians opting for riskier alternatives if these facilities are not well-integrated into their walking routes [20,21]. In particular, the absence of crossing aids at midblock sections, sub-arterial, and collector roads often forces pedestrians to make unsafe crossings, further increasing their exposure to traffic risks. In such situations, a central median refuge island can serve as a critical safety measure, allowing pedestrians to cross in two stages—particularly on roads with a greater number of lanes [22].

Another significant concern in mixed traffic conditions is the encroachment of footpaths by two-wheelers and parked vehicles [23,24]. In many developing countries, high rates of powered two-wheeler ownership [25,26] lead to two-wheelers using footpaths to bypass congestion in high volume traffic. This creates an unsafe environment for pedestrians, forcing them onto the carriageway and increasing their exposure to traffic risks. Raised footpaths and guard rails [27] can help mitigate this issue by acting as a buffer between motorized traffic and pedestrians. They physically prevent vehicle encroachment, ensuring dedicated pedestrian space and reducing pedestrian-vehicle conflicts.

Personal safety is another pressure point in pedestrian safety. Crime, particularly in urban areas limits pedestrian movement, especially at night [28]. Visible signs of crime, such as vandalism, graffiti, and deteriorated or abandoned buildings, contribute to feelings of unease [29]. Social issues, including public arguments, fights, illegal parking attendants, and the presence of unsupervised dogs or rowdy youth, increase this vulnerability [30]. Moreover, the presence of homeless individuals, panhandlers, and drunkards, can evoke discomfort or fear for some pedestrians [29]. Enhanced lighting and surveillance in the form of cameras or police, can increase pedestrians' sense of security [31,32]. The presence of other people, such as street vendors, positively impacts walking [33].

Understanding the complex interplay of traffic conditions and built environment features is crucial for developing targeted interventions that improve pedestrian safety in mixed-traffic.

2.2. Perception data analysis

Perceptions are perceptual. For instance, if pedestrians in Delhi are asked, “How safe do you feel while walking on the streets after sunset?", their responses may differ based on age, gender and past experiences. Young males may consider walking at night relatively safe, while women, children, and elderly pedestrians may perceive significant risks. The same question posed to pedestrians in London may yield entirely different responses. Given that individuals have varying backgrounds (education, personality, attitudes, geographic settings, etc.), it is essential to consider how individuals perceive their safety.

Perception-based studies commonly use Likert scales [34], rating scales [31], and hierarchical rankings [32] to assess safety. These methods capture latent variables like perceived safety by structuring survey responses into quality ratings (e.g., bad to excellent) [13], level of agreement (e.g., completely agree to completely disagree) [34], and importance scales (e.g., not important to very important) [35]. However, many perception scales rely on generic questions rather than directly asking pedestrians how safe they feel, limiting their ability to capture personal safety accurately. This gap highlights the need for a scale that directly measures pedestrians' sense of safety rather than relying on indirect indicators.

Traditional statistical methods such as logistic regression (rank ordered, multivariate linear, Poisson etc.), Principal Component Analysis (PCA), Structural Equation Modelling (SEM), and chi-square tests have been widely used to analyse safety perceptions. Table 1 summarizes past studies on pedestrian safety perception and the statistical tools they have employed.

Table 1 Summary of prior studies on pedestrian safety perceptions

Study	**Variable measured**	**Measurement scale**	**Statistical tool**
[8]	Walking and crossing safety	5-point Likert scale (Strongly agree to 'Strongly disagree')	Structural Equation Model
[9]	Walking and crossing safety	6-point Likert scale (never to very often)	Principal Component analysis
[10]	Crossing safety	6-point Likert scale (Not Difficult to Highly Difficult)	Ordered Logit regression
[11]	Walking safety	Rank based ordering of variables	Rank ordered Logit regression
[12]	Crossing safety	4-point Likert scale (Do not agree to Agree)	Principal Component analysis
[19]	Crossing safety	5-point Likert scale (strongly disagree to strongly agree)	Structural Equation Model

[28]	Walking safety and security	5-point Likert Scale (totally disagree to totally agree)	Multivariate linear regression
[30]	Walking safety and security	5-point Likert scale (very dissatisfied to very satisfied)	Multilevel Poisson regression
[31]	Walking safety and security	Qualitative data collection	Content and sentiment analysis
[32]	Walking safety	Rank based ordering of variables	Analytical hierarchical process

While these methods have contributed valuable insights, they present three key limitations when applied to pedestrian safety perception.

Firstly, they assume equal safety levels across different tasks, failing to recognize that walking, crossing, and navigating complex traffic environments may involve different risk perceptions. For example, the perceived safety associated with a ‘walking task’ may be significantly different from that associated with a ‘crossing task’, but traditional models treat these experiences uniformly.

Secondly, most conventional models fail to meaningfully quantify individual differences in perception. A young male pedestrian might feel completely safe walking alone at night, while an elderly woman might perceive the same environment as highly unsafe.

Thirdly, these techniques assume that the difference between responses (e.g., ‘very safe’ vs. ‘safe’) is equal across all categories. However, psychometric research suggests that ordinal ratings are not always linear, making it difficult to draw precise conclusions from such data [6].

Rasch analysis is a suitable technique to address these challenges as it positions both pedestrians' perceived safety levels and actual risk factors on a shared scale, ensuring a more accurate and interpretable measurement of safety perception.

2.3. Rasch analysis

Rasch analysis is a psychometric technique developed by Georg Rasch in 1960. In the Rasch model, persons and items are measured on a common measurement unit (called logit) by transforming the raw test scores into a linear scale logit [36]. These logit scores are used to compute linear "item measures" that express the safety levels of each item [6]. Initially developed to be used with dichotomous variables, the Rasch model was later generalised to accommodate polytomous variables by Andrich [37] and Masters [38].

Rasch analysis has been used in transportation research to assess various aspects of user experience and system performance. It has been applied to evaluate railway network dwell times and station-level variability [39], analyze situational avoidance behavior among drivers [40], and measure public transport usage of passengers with low vision and limited mobility [41]. However, Rasch analysis has been mostly used to evaluate travel satisfaction and user perceptions in public transport systems [42].

The Partial Credit Rasch model, used in this study, belong to the polytomous Rasch family. It is particularly useful when the responses are not spaced at equal intervals [38]. This model is particularly suited here due to the polytomous nature of data and varied rating scales for the survey items, contributing to a better understanding of how perceived safety influence pedestrian behaviours.

In Partial Credit Rasch Model, the probability of a respondent *n* selecting a particular rating (category *k*) for item *i* is given by:

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

where,

ϕ_{kni} = probability of person *n* selecting category *k* for item *i*.

π_{kni} = probability of person *n* responding to category *k*

β_n = person ability (in this study, the pedestrian's perceived safety level)

δ_{ik} = item difficulty (in this study, the actual level of safety for each item)

Equation (1) represents a choice probability function as it follows a logistic model, similar to the logit function used in discrete choice models. The parameters in Partial Credit Rasch analysis, β_n and δ_{ik}, are not directly observed but are estimated using maximum likelihood estimation (MLE) [43]. In this model, when $\beta_n > \delta_{ik}$, the pedestrian is more likely to perceive the task as safe, whereas where when $\beta_n < \delta_{ik}$, the pedestrian is more likely to perceive the task as unsafe.

Unlike regression models, which assumes a linear relationship between predictors and outcomes, Rasch analysis not only determines whether a pedestrian perceives safety but also quantifies both the person's perception and the actual level of safety of items on a shared measurement scale.

The output from Rasch analysis is called an item person map or Wright map. This map offers both person and item measures on the same linear scale [6]. In the context of this paper, a Wright map represents the range of pedestrians' perception along with the safety levels for each related task.

Since this paper aims to bring out the variability in pedestrian perceptions, we use Rasch analysis to examine pedestrian safety perceptions in Delhi, accounting for the diverse backgrounds and experiences of the respondents.

3. Survey Method and Data

3.1 Study area setting

New Delhi, the capital city of India, with an estimated population of 20 million [44], was chosen as the study area for this research. The National Capital Territory of Delhi is divided into 11 districts, further subdivided into smaller wards. Delhi's road network follows a hierarchical structure, categorizing roads into arterial, sub-arterial, collector, and residential, based on traffic volume and function. This hierarchical structure significantly impacts pedestrian safety, with arterial roads often presenting the highest risks due to high-speed and high-volume traffic [45].

The traffic stream in Delhi is highly heterogeneous, comprising motorised transport such as cars, trucks, two-wheelers, and autorickshaws, alongside non-motorised transport including pedestrians, bicycles, animal or human drawn vehicles. Delhi has the highest motor vehicle ownership per capita in the country [46]. This rapid increase in motorcycle ownership has contributed to a rising road fatality rate, which stands at 9 per 100,000 population [2].

Pedestrian fatalities constitute a significant portion of Delhi's road traffic deaths. In 2022, 43% of the 1,461 fatal crashes involved pedestrians [47]. However, since official estimates of pedestrian deaths are extremely low compared to independent researchers' estimates, this share could be as high as 35% [2]. On the other hand, nearly 26.3% of all commuter trips in Delhi are walking trips [48]. Despite such higher modal share and alarming fatality rate, Delhi's transport infrastructure is generally hostile to pedestrians. Many pedestrian facilities are poorly maintained, discontinuous, or entirely absent, forcing pedestrians to share the carriageway with motorized traffic. Additionally, pedestrians often face difficulties when crossing roads due to restrictive measures like high medians and guard rails, or poorly designed pedestrian subways, which compel them to risk their lives while walking or crossing roads [23,49]. Government initiatives, such as construction of foot overbridges and the implementation of traffic calming measures, have had limited success, highlighting ongoing gaps and challenges in pedestrian safety [16,18]. These features make Delhi an ideal case study for capturing users' safety perceptions. Understanding these perceptions is crucial for developing targeted interventions to improve pedestrian safety in urban environments.

3.2. Survey Questionnaire design

The survey questionnaire was developed based on an extensive review of literature. The questionnaire aimed to capture various dimensions of safety, including traffic-related and personal safety concerns. It was divided into two sections: (i) safety perception and (ii) socio-demographics of the pedestrian. The questionnaire is summarized in Table 2.

Table 2 Safety measures used in the questionnaire

Safety dimension	Item label	Safety Measure
Crossing safety	1	Using the median as a waiting area while crossing
	2	Safety while crossing in fast-moving traffic
	3	Safety while crossing in high-volume traffic
	4	Safety concerns near bus stops without crossing facilities
	5	Safety concerns near crossings with parked vehicles
Walking safety (on footpath)	6	Safety concern with motorized two-wheelers on the footpath
	7	Safety concerns with parked vehicles on the footpath
	8	Safety concerns on a raised footpath
	9	Safety concern due to lack of guard rails
	10	Safety concerns on a crowded footpath
Personal security	11	Safety concerns while walking after sunset
	12	Safety concerns on footpaths with street vendors nearby
	13	Safety concerns on footpaths without CCTV/ Security cameras
	14	Safety concerns on footpaths without police/ traffic enforcement

15	Safety concerns on footpaths without proper street lighting

The safety perception section included 15 items designed to assess different aspects of traffic and personal safety. These items were derived from key studies that highlighted common safety issues faced by pedestrians in the urban environment. The questions were categorized into three main dimensions: safety while crossing the street, safety while walking on the footpath, and security concerns while walking.

Responses were recorded on a 5-point Likert scale: “Very safe", “Safe”, “No effect”, “Unsafe”, and "Very unsafe." To ensure that respondents understood all items, a pilot survey was conducted with a sample of 45 pedestrians. Feedback from this pilot survey was used to refine the questionnaire, ensuring clarity and relevance of each question. The socio-demographic section collected data on respondents' age, gender, and education level. This information was crucial for analysing variations in safety perceptions across different demographic groups.

3.3. Survey Procedure

A ward-wise pedestrian survey was conducted in New Delhi’s South Delhi district. Eight wards from South Delhi were selected based on a three-step criterion: - pedestrian trips, land use mix, and pedestrian crashes (from Police Reports). This criterion was chosen to ensure a comprehensive representation of different pedestrian environments and safety conditions. An L9 Taguchi orthogonal array design in Minitab was used to determine ward combinations based on these factors at three levels (low, medium, and high). This design allows for efficient and balanced sampling across diverse conditions. Locations of survey are shown in Figure 1.

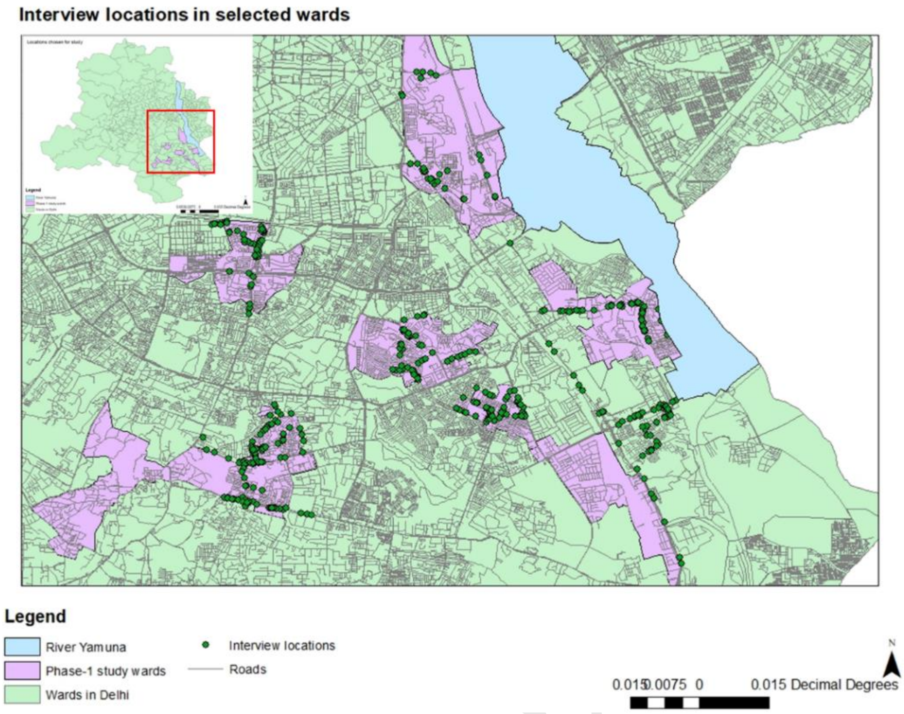

Figure 1 Map showing the wards selected for study and interview locations in New Delhi

The data was collected in March 2022 on arterial and sub-arterial roads. Four research assistants were recruited and trained to assist with data collection. Pedestrians were approached randomly at public places such as bus stops, metro stations, and marketplaces while they were walking to their respective destinations.

Participants were provided with a brief explanation of the survey's purpose and content, and informed consent was obtained before proceeding. The research assistants conducted face-to-face interviews, filling out the questionnaire on behalf of the participants. This method was chosen to ensure high response rates and the accuracy of data recording. Participants were encouraged to ask for clarifications if they did not understand any questions, and research assistants were trained to provide consistent explanations.

The survey was discontinued if the pedestrian's origin (or destination) did not fall within the eight study wards to maintain the focus on the selected areas. This criterion ensured that the collected data accurately reflected the safety perceptions of pedestrians familiar with the specific study areas.

The survey aimed to gather data from a representative sample of pedestrians to understand their safety perceptions accurately. A total of 426 responses were recorded, with approximately equal response rates from all wards. Data collection was spread across different times of the day and both weekdays and weekends to capture a broad range of pedestrian experiences.

4. Data Analysis and Results

The final dataset consisted of 426 responses, with 87% men and 13% women. The lower representation of women (13%) in the sample may not necessarily indicate selection bias. According to the 2011 Census of India, 83% males and 17% female commuters in Delhi travelled on foot [50]. The higher levels of immobility among women in Delhi can be attributed to factors such as childcare responsibilities, household tasks, employment levels, cultural barriers, and safety concerns [51]. Younger respondents aged between 25 and 60 represent most of the sample. Most respondents had an education level that varied from primary school to high school. Detailed demographics are provided in Table 3.

Table 3 Descriptive statistics of data

Covariate (n=426)		**Number of samples**	**Percentage of the total sample (%)**
Gender	Female	54	12.68
	Male	372	87.32
Age	<25	114	26.76
	25-44	186	43.66
	45-60	106	24.88
	>60	20	4.69
Education	Illiterate	66	15.49
	Primary School	134	31.46
	High school	130	30.52
	Graduate	96	22.54

Due to the mixed response formats (i.e., polytomous items), we employed the Partial Credit Rasch model detailed in Section 2.2. The data was analyzed using Winsteps 5.2.4. To ensure the data fit the Rasch model, we conducted item reduction based on unidimensionality, reliability, item polarity, threshold order, and model fit statistics.

4.1. Unidimensionality

Rasch analysis is a unidimensional measurement model, meaning that a single latent variable sufficiently explains most of the variation in item responses [52]. Unidimensionality can be checked using Principal Components Analysis of the Residuals (PCAR), where the pattern of residuals from the differences between observed and expected item responses indicates data dimensionality [52]. In Rasch Principal Components Analysis (PCA) of the residuals, a smaller eigen value (< 2.0) in the first contrast, suggests unidimensionality [53]. If the loadings of item residuals on the first contrast display contrasting patterns, multidimensionality may be present [54].

For this dataset, the first contrast eigenvalue was 1.79 (<2), confirming that no substantial secondary dimension exists, thus supporting the assumption that the items collectively formed a unidimensional scale, measuring a single latent trait.

4.2. Item polarity and threshold order of items

Category probability curves were used to examine the alignment of response categories with the latent safety trait [36]**.** In Rasch analysis, the response categories should increase logically with the latent trait measured (here, perceived safety). However, items 2, 5, 6, and 7 showed disordered thresholds, meaning that certain response categories were underutilised, reducing the effectiveness of the scale. Specifically, respondents primarily selected “very safe”, “no effect”, or “very unsafe” while "safe" and "unsafe" categories were infrequently used. This lack of distinction led to inefficiencies in category functioning. To address this, "very unsafe" and "unsafe" were collapsed into rating scale 1; while "very safe" and "safe" were collapsed into rating scale of 3. Collapsing categories ensured that each response category represented a distinct portion of the latent trait, making it easier for analysis. Post-rescoring, the category probability curves showed no further disordered thresholds (Figures 2 and 3).

Figure 2 presents the original category probability curves before rescoring, where disordered thresholds were observed. Figure 3 shows the revised curves after rescoring, with well-defined categories.

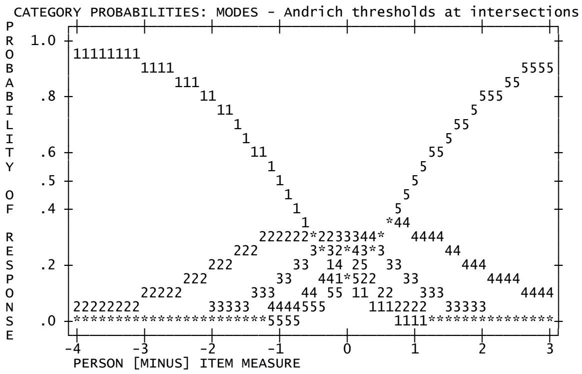

Figure 2 Category probability curves before rescoring

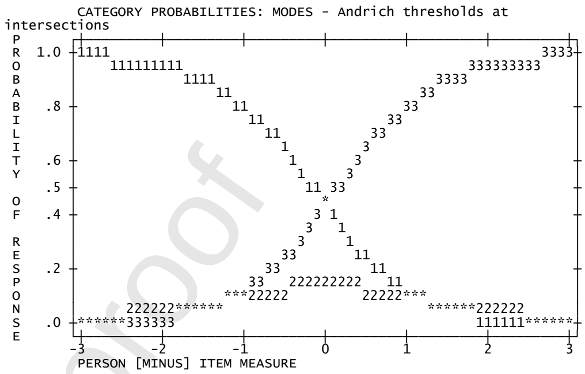

Figure 3 Category probability curves after rescoring

Item polarity checks if safety items align with a pedestrian's safety perception. All items had correlations above 0.8, indicating good alignment (Refer to ‘PT-Measure Correlation’ column in Table 4).

4.3. Reliability

Reliability scores indicate how well the instrument differentiates between perception levels [55]. The Rasch model yielded a person reliability score of 0.34 and an item reliability score of 0.99. The low person reliability and Cronbach's alpha (0.378) suggest that the questionnaire needs more items to improve discrimination among different pedestrian perceptions. However, an almost perfect item reliability score of 0.99 suggested that the sample size was adequate to accommodate pedestrians of varying ability levels.

4.4. Model fit statistics

Unexpected or misfitting responses are denoted by infit and outfit statistics. Infit shows the discrepancy between observed and expected responses, while outfit is an unweighted statistic that indicates whether unexpected responses or outliers are found [36]. Standardised Mean-Square statistics (MNSQ) can be used as an indicator to show the statistical probability of the discrepancy in the model. MNSQ values below 0.5 indicate items that are too predictable, meaning they contribute little new information to the model. While high predictability may seem beneficial, extremely low MNSQ values suggest redundancy, implying that the item does not differentiate between respondents effectively. Conversely, values above 1.5 suggest excessive noise, indicating inconsistent responses that do not align well with model expectations [56]. Pedestrians with large infit or outfit statistics may have under or over-perceived their safety compared to their actual level of safety or may have misunderstood the rating scale. Therefore, an acceptable MNSQ range (0.5-1.5) ensures that items provide meaningful variation without being too predictable or too erratic.

Table 4 Item score and fit statistics of safety items (in increasing order of item score)

Item Label	Item score	Std. Dev	Infit MNSQ	Outfit MNSQ	PT-Measure Correlation
7	1.2	0.08	1.09	1.08	0.09
2	1.12	0.08	0.97	0.93	0.28
4	0.52	0.07	1.08	1.08	0.15
6	0.49	0.08	1.03	1.02	0.19
15	0.37	0.07	0.92	0.87	0.4
5	0.29	0.08	1.09	1.08	0.1
10	0.18	0.06	0.98	0.97	0.35
13	0.17	0.06	0.9	0.86	0.43
11	0.02	0.05	0.94	0.92	0.44
3	0.01	0.05	1	1	0.38
14	-0.05	0.05	0.94	0.97	0.45
9	0.19	0.06	0.98	0.92	0.36
1	-0.96	0.04	1.08	1.09	0.34
8	-1.42	0.05	1.06	1.1	0.29
12	-1.75	0.06	0.93	0.93	0.42

The 426-person infit and outfit Mean Square statistics (MNSQ) were computed, and only those pedestrians within the acceptable range of 0.5 to 1.5 were utilized for analysis. The relative infit and outfit mean square statistics for 15 safety items are presented in Table 4. Since all items had an infit-outfit within the range of 0.5 to 1.5, none of them were excluded based on misfit.

Items such as 13 ("Safety concerns while walking in the absence of CCTV/Security cameras") and 15 ("Safety concerns while walking in the absence of proper street lighting") have infit and outfit MNSQ values close to 1.0 and relatively high PT-measure correlations, suggesting they are well-targeted and consistently perceived by respondents.

Items such as 1 ("Usage of the median as a waiting area while crossing the street") and 8 ("Safety concerns while walking on a raised footpath") have slightly higher infit and outfit values. These higher values could indicate some variability in how respondents interpret safety concerns.

4.5. Item-person Map

The output from Rasch analysis is called the Item-person map or Wright Map (Figure 4). This map illustrates the distribution of both pedestrian safety perceptions and the perceived difficulty or safety level of items. Pedestrians who associate less safety with dangerous items have positive logit measures and are shown at the top left side of the Wright map. In contrast, unsafe items are placed at the top right. Those pedestrians who perceive items as relatively unsafe are placed at the bottom left, while the safest item, receiving negative logit measures, are shown at the bottom right.

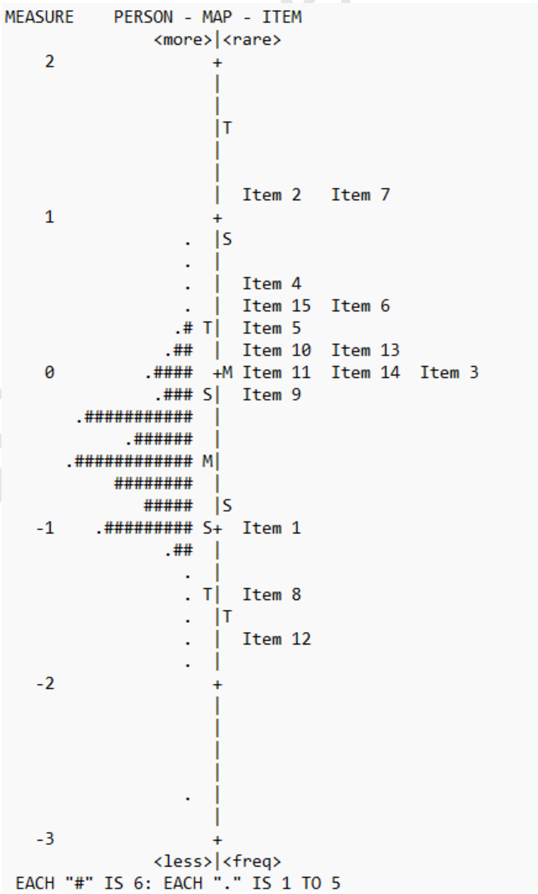

Figure 4 Item-person Map generated for the data

In Wright map, the greater the spread (distribution) of persons, the more the instrument can differentiate between more or less safety-conscious participants. Similarly, the broader the lateral spread of items, the more variance the survey instrument captures [6]. This map can be used to assess the degree to which safety items are distributed based on pedestrian perception by calculating the distance between the mean person measure ("M" on the left side of the Wright map) and the mean item measure ("M" on the right side). Mistargeting can be suspected when the item and person differ by more than one logit [57].

However, the distance between the mean person measure and the mean item measure on the Wright Map in Figure 4 suggests some level of mistargeting. Most items are either perceived as too safe or too dangerous, rather than matching the average pedestrian's safety perception. This mismatch indicates that the safety items listed were not in line with the abilities of the pedestrians.

Items such as 1 ("Usage of the median as a waiting area while crossing the street") and 8 ("Safety concerns while walking on a raised footpath") are placed at the bottom right, indicating they are perceived as relatively safe by most pedestrians. Conversely, items like 2 ("Safety while crossing a street in fast-moving traffic") and 7 ("Safety concerns due to parked vehicles on the footpath") are located at the top right, showing they are considered unsafe by nearly all respondents.

4.5. Differential Item Functioning test (DIF)

A differential item functioning (DIF) test was conducted to assess the item-wise variation in safety perceptions with age and gender. This test assesses how sample characteristics interact with items by estimating item difficulty for different groups while keeping other factors constant. P-values and logit contrasts between Rasch item scores are used to determine significance. DIF contrasts > 0.43 indicate moderate to large differences between groups [58]. DIF scores were calculated separately for age and gender and are presented in Table 5. DIF scores revealed significant differences in the perceptions between males and females and also between age groups.

Table 5 Items with significant DIF scores

Item No	**Item description**	**Person**	**Item**	**Person**	**Item**	**DIF Contrast**	**p value**

		class I	score I	class II	score II		
1	Median as a waiting area	Female	-2.03	Male	-1.54	-0.49	0.01***
2	Street crossing in fast moving traffic	<25	1.51	>60	0.4	1.11	0.06*
2	Street crossing in fast moving traffic	25-45	1.69	>60	0.4	1.29	0.03**
2	Street crossing in fast moving traffic	46-60	2.46	>60	0.4	2.06	0.01***
3	Street crossing in high volume traffic	46-60	-0.29	<25	-0.81	0.52	0.01***
3	Street crossing in high volume traffic	46-60	-0.29	>60	-0.9	0.61	0.07*
6	Use of motorized 2-wheelers in footpath	25-45	1.16	<25	2.32	-1.16	0.04**
7	Parked vehicles on footpath	Female	3.29	Male	2	1.29	0.08*
8	Raised footpath	25-45	-2.59	<25	-2.16	-0.43	0.02***
8	Raised footpath	25-45	-2.59	>60	-1.82	-0.77	0.02***
9	Absence of guard rails between footpath & road	Female	0.76	Male	0.1	0.66	0.06*
12	Presence of people/hawkers nearby	25-45	-2.33	>60	-1.57	-0.76	0.02***
13	No CCTVs/Security cameras	25-45	0.72	46-60	0.26	0.46	0.05**
14	No Police/ Traffic officials for enforcement	25-45	0.16	46-60	-0.26	0.42	0.02***

(indicates p < 0.10, ** indicates p < 0.05, *** indicates p < 0.01)*

5. Discussion

This study evaluated pedestrian safety perceptions in Delhi, focusing on three key dimensions: safety while crossing, safety while walking, and sense of security. Using Rasch analysis, we assessed perception-based data to understand the varying safety concerns among pedestrians. The analysis revealed that most of the items (12 out of 15) were perceived as unsafe, indicating significant safety concerns.

Items with positive item score were perceived as unsafe by pedestrians. For instance, item 2 (two-wheelers on footpaths) was rated as dangerous by all pedestrians, irrespective of their socio-demographic situations. This misalignment between safety items and pedestrian perceptions suggest that many items were too obvious to be considered safe, resulting in responses skewed towards the 'dangerous' rating scale. Consequently, these items were placed at the top in the Wright map.

5.1. Sense of safety while crossing

Four out of five crossing safety items— crossing in high-speed traffic, crossing in high volume traffic, absence of a crossing facility near bus stops, and presence of parked two-wheelers on the footpath —were rated as the most unsafe. These results are understandable, considering these items are generally challenging even for the most able-bodied pedestrian globally. However, the gravity of the situation intensifies in countries like India where mixed traffic exists.

Speed is one of the leading causes of pedestrian crashes, as pedestrians cross arterial roads at speeds exceeding 50 km/h [59]. These speeds are associated with high probabilities of pedestrian crash risks. Traffic calming measures such as raised crosswalks can be a suitable solution to this problem.

Pedestrians also raised safety concerns regarding the absence of a crossing facility near bus stops (item 4). This finding aligns with Tiwari [49], who classified bus stops as high-risk locations for pedestrians due to adverse traffic conditions and changes in bus locations leading to longer walking distances [18]. The provision of crossing facilities near bus stops, coupled with crossing aids, can enhance safety.

The presence of parked vehicles near crossing locations is common in Delhi. Previous research has shown that pedestrians feel protected since parked vehicles act as a buffer between motor vehicles and pedestrians [60]. However, the current study shows that parked vehicles negatively impact on pedestrian safety perception, as they reduce pedestrian walking speed and cause delays. Restricting parking near pedestrian crossing locations can address this issue.

Interestingly, the only crossing item with a negative item score (-0.96) was median as a favourable crossing facility (item 1). This indicates that pedestrians appreciate having a median as a refuge island while crossing. However, medians in India are often fenced or raised, preventing pedestrians from accessing them and becoming fatal crash locations [16,59]. Medians reduce a pedestrian's average waiting time [61] which explains why pedestrians favour them as refuge islands.

5.2. Sense of safety while walking

The analysis indicated that presence of two-wheelers and parked vehicles on the footpath were rated as unsafe by pedestrians. Whereas a raised footpath and the presence of other pedestrians were favoured.

Motorised two-wheelers pose a significant threat to pedestrian safety, as they are responsible for 8–25 % of pedestrian deaths in Indian cities [62]. Due to extreme traffic congestion, two-wheelers often ply on footpaths, thereby taking up the space for pedestrians. This leads to unsafe walking environments in Delhi. Unlike flush footpaths, raised footpaths can restrict motorised two-wheelers and cars from entering them, which likely contributes to their favourable perception among pedestrians.

Additionally, the presence of other pedestrians on the footpath was widely appreciated. This observation aligns with Gupta et.al [63], who noted that pedestrians in Delhi tend to walk in groups. Walking in groups reinforces feelings of safety, especially for older adults and the elderly [64]. This underscores the need for street designs that make pedestrians feel more confident to enter the road space.

5.3. Sense of security

This study provided insights to items which enhanced a pedestrian's security such as proper street lighting, presence of street vendors, police and surveillance systems.

The safest item on the Wright map was the presence of street vendors along the walking path (item 12) with an item score of -1.75. Street vendors are commonly seen along footpaths selling food, drinks and other essential items in demand by road users. Their constant presence makes them naturally watchful, allowing them to act as "eyes and ears" on the footpath. This shows that pedestrians highly appreciate street vendors, as they feel safe in their presence. Hence, the provision of hawker spaces in the road environment is justified [65]. However, the varying influence of different types of street vendors on pedestrians' safety perceptions remains an area for further research.

Similarly, absence of streetlights and travel after sunset is seen to negatively impact pedestrians' safety perceptions. The streetlights in Delhi are often placed at the center of the road or only to one side of the road with the light barely reaching the pavements on either side thus making pedestrians vulnerable to crime. This makes poorly lit roads and inner streets the brooding spots for harassment or violence [66]. This fear is justifiable given that Delhi has the highest crime rate in India especially at night [67]. The presence of surveillance systems and police enforcement have a positive impact on pedestrian safety. However, from their relative locations on the Wright map, absence of police is less concerning as opposed to the absence of cameras. This is probably because the presence of traffic police in Delhi is limited at night and offenders can get away undetected [68].

5.4. Demographic Influences

Three items—median as a waiting area, parked vehicles on footpaths, and absence of guardrails—revealed significant differences in perceptions between males and females. Females favoured medians more than males, as indicated by their item score of -2.03. Similarly, females showed greater concern about the presence of parked vehicles and the absence of guardrails.

It is worth noting that although the overall person score of 0.19 for item 9 suggests that pedestrians are not bothered by the absence of guardrails, this perception is predominantly held by males. However, since the sample population was mostly male, this result is not generalisable.

The DIF scores for age indicated a notable difference in safety perceptions, as seen in Table 5. As age increased, the safety perceptions regarding crossing in high speed traffic also increased, with item scores rising from 1.56 to 2.4. Younger pedestrians (under 25) were relatively confident and exhibited fewer concerns compared to other pedestrians, likely because young adults have significantly higher crossing speed as compared to their counter parts [69]. Surprisingly, elderly pedestrians showed little concern (item score: 0.4) about the speed of approaching vehicle while crossing. This behaviour may be due to age-related cognitive and sensory decline, which affects their ability to accurately judge vehicle speeds and often leads to unsafe crossing decisions [70,71]. However, given the underrepresentation of elderly people in the sample, this finding requires further investigation.

On the other hand, security concerns were more prevalent for pedestrians aged between 25 to 45 years. They exhibited more concerns in the absence of police and surveillance and had a welcoming approach to the presence of street vendors compared to older adults.

Although a raised footpath was generally preferred, such raised footpaths can create discomfort due to the absence of ramps or kerb cuts for smooth ascent or descent. Our study also revealed that elderly pedestrians consider the presence of a raised footpath to be extremely safe, with a person score of -1.82 compared to the overall item score of -1.42. This finding reiterates the need to accommodate for all pedestrians while planning pedestrian facilities.

5.5. Survey Instrument

Rasch Analysis is a robust statistical method to evaluate safety perceptions due to its unique strengths and capabilities. This method allows for precise measurement of a latent trait like safety perception and thereby enables a detailed examination of how different safety items align with pedestrian perceptions. It provides a clear, objective measure of perceived safety level.

A significant challenge in perception based studies is ensuring that the items accurately measure the underlying latent trait. Rasch Analysis addresses this by evaluating the fit of each item to the model, ensuring that the survey items reliably measure the intended construct. This results in a more valid and reliable assessment of pedestrian safety perceptions.

The Wright Map, a key output of Rasch analysis, visually represents the distribution of item difficulty and respondent ability. This map revealed a significant misalignment between the safety items and pedestrian perceptions, highlighting that the survey instrument needs refinement. This is consistent with the low person reliability scores from this survey. Similarly, DIF analysis highlights the importance of considering gender differences in safety perceptions when planning and implementing urban infrastructure improvements.

The Rasch analysis highlighted limitations in the survey instrument, such as low person scores and reliability. This indicates the need for more items to fully capture the latent trait of safety. Future surveys should include a broader range of safety items and consider using a more nuanced rating scale to better assess pedestrian perceptions.

The insights gained from Rasch Analysis not only highlight current safety concerns but also provide a clear direction for enhancing the survey instrument, ultimately leading to more effective interventions and policies for improving pedestrian safety in Delhi.

6. Conclusion

This study sheds light on significant safety concerns among pedestrians in New Delhi, emphasizing the urgent need for infrastructural improvements to enhance walkability. Using

Rasch analysis, we were able to pinpoint critical areas where pedestrian safety is compromised, underscoring the importance of prioritizing pedestrian needs in urban infrastructure redesign.

6.1. Policy Implications

Policymakers should focus on the following actions to improve pedestrian safety:

- Enhance street lighting and security measures, including the installation of CCTV cameras and increased police presence, to make pedestrians feel safer, especially at night.
- Create designated crossing areas near bus stops and implement crossing aids to facilitate safer pedestrian movement.
- Enforce regulations to restrict the use and parking of motorized two-wheelers on footpaths and crosswalks to ensure pedestrian safety.
- Incorporate designated spaces for street vendors into urban design, as their presence was found to enhance the perceived safety of pedestrians.
- Ensure that raised footpaths are accessible to all users, including the elderly and mobility-impaired, to promote safer walking environments.

6.2. Limitations

This study has several limitations. Firstly, the study sample was predominantly male (87%), which may not fully represent the broader population's safety perceptions. Future studies should aim for a more balanced demographic representation to enhance the generalizability of the findings. The low person reliability score suggests that the safety items were insufficient to comprehensively represent the latent trait of safety. There is a need for a more extensive set of safety items to improve the reliability and validity of the survey instrument.

Enhancing pedestrian safety is a critical component of urban planning and should be prioritized over vehicle-centric development. The findings from this study offer valuable insights for urban planners and policymakers, highlighting the need for infrastructure improvements that focus on pedestrian needs. This study also aims to inspire researchers to consider potential pitfalls in survey preparation and analysis, ultimately contributing to the creation of safer pedestrian environments globally.

Conflict of Interest

None

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Highlights

- Safety perceptions play a crucial role in walking decisions in low- and middle-income countries
- Rasch analysis is used to simultaneously evaluate pedestrian and item safety
- Most items listed are beyond the safety threshold of pedestrians
- Results show that Delhi's pedestrian environment is highly hostile
- Rasch analysis highlight items that need immediate interventions.