Exploring Pedestrian Stress Around E-Scooters in Urban Settings: A Cross-Cultural Comparison Between Tel Aviv in Israel and Copenhagen, Denmark

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SHORT SUMMARY (150-word limit)

This study investigates pedestrian stress and infrastructure preferences concerning e-scooters in Copenhagen (CPH), Denmark, with its well-established cycling culture and infrastructure, and Tel Aviv (TLV), Israel, facing rapid e-scooter adoption. A survey of 623 participants (304 TLV, 319 CPH) reported stress perceptions across 18 experimental conditions involving pathway width (narrow/wide), design (marked, separated, shared), and e-scooter traffic direction (with/against pedestrian flow, bidirectional). Sociodemographics, Big Five personality traits, experience, and e-scooter familiarity were also analyzed.

Findings indicate higher stress among TLV participants, particularly on narrow or shared pathways, with 42.1% encountering e-scooters daily compared to 6% in CPH. Mixed Ordinal Logit models highlight varying stress perceptions for single experimental conditions. Mixed Multinomial Logit models of Choice-Based Conjoint (CBC) analysis underscore a cross-cultural preference for wide, separated pedestrian pathways. These results highlight the need for targeted interventions and policies to support effective e-scooter integration and foster livable, pedestrian-centric stress-mitigated cities.

KEYWORDS: Pedestrian, CBC, E-Scooter, Infrastructure, Stress Perception, Traffic Direction

1. INTRODUCTION

As global urbanization accelerates, e-scooter micromobility solutions are gaining traction as convenient and accessible options for short-distance travel despite ongoing debate about their sustainability (Sundqvist-Andberg et al., 2021; WEF, 2022). Promoted as eco-friendly and flexible alternatives to traditional transport modes (Badia & Jenelius, 2023; ARUP & NatCen, 2022), e-scooters rapid adoption introduces challenges, including pedestrian safety, infrastructure adaptation, and regulatory gaps (Dozza et al., 2022). Understanding pedestrian emotions and stress is crucial to improving traffic safety (NHTSA, 2010). Urban planning strategies integrating physical infrastructure improvements with psychological insights are vital in mitigating pedestrian stress (El-Didy et al., 2024). Addressing these challenges is critical to fostering pedestrian-friendly urban environments.

This study seeks to inform policymakers and urban planners on balancing e-scooter integration with pedestrian well-being (Gössling, 2020; Esztergar-Kiss & Lizarraga, 2021). It investigates the emotional impact of e-scooters on pedestrians, focusing on perceived stress as a key metric in urban planning. Stress, inherently subjective and influenced by safety, infrastructure, and traffic volume, is crucial in designing urban spaces (Gottholmseder et al., 2009; Pykett et al., 2020; Vogt et al., 2022). Prior research has predominantly centered on the user perspective of micromobility (Butler et al., 2020; Abduljabbar et al., 2021), leaving the experiences of non-users, such as pedestrians, underexplored (Zhang et al., 2023).

Copenhagen (CPH) and Tel Aviv (TLV) provide contrasting case studies to analyze these dynamics. CPH benefits from a well-established cycling culture and infrastructure, supporting smoother e-scooter integration, while TLV faces challenges stemming from rapid adoption and underdeveloped infrastructure (Siebert et al., 2023; EIT, 2020). These cities highlight regulatory and design gaps exacerbating pedestrian urban stress and travel well-being concerns (Potter, 2016; Mokhtarian, 2019; Singleton, 2019).

To address these gaps, this research employs a mixed-methods approach to answer two critical questions:

A. How does e-scooter traffic influence pedestrians' stress perception across different urban contexts?

B. What urban design combinations are most preferred, and how do demographics, familiarity, and experience shape these preferences?

By analyzing urban contexts, including variables like pedestrian pathway width, traffic direction, and infrastructure design, this study aims to provide evidence-based insights to guide the development of pedestrian-friendly, stress-mitigating, and accessible urban environments.

2. METHODS

This study employed a mixed-methods approach, combining quantitative data to identify trends with qualitative insights to capture the subjective nature of stress perception. A within-subject design enhanced statistical power while reducing participants by accounting for individual differences. Randomization and counterbalancing using an orthogonal design ensured validity, managed workload, and minimized order effects and lexicographic responses (Hess et al., 2010). Data collection was conducted via a Qualtrics online survey executed by panel companies.

Eighteen experimental conditions (ECs) were designed based on three critical factors identified in an early investigation:

- Pedestrian pathway/Pathway Width: narrow (N), and wide (W)
- E-scooter Traffic Direction: same direction (S), opposite direction (O), and in both directions (BD) relative to the pedestrian walking direction.

- Infrastructure Design: marked (M), separated (SP), shared (SH).

A photorealistic, high-definition (HD) image was generated for each EC, simulating a real urban environment to provide an immersive and realistic visual context. These images, developed using advanced transportation- and mobility-specific VR technology (Specktor et al., 2023), accurately portray various walking experiences from a first-person perspective. This approach was adopted to enhance participant engagement and allow for the assessment of pedestrian stress perceptions in different urban settings.

The Self-Reported Stress (SRS) scale was employed to measure subjective experiences for each EC. The validity of SRS as a stress measurement tool has been established through prior surveys (Morgan et al., 2014). In this study, participants evaluated each EC, presented as an image with a description, by responding to the statement, "I would feel stressed walking here," on a 7-point Likert scale ranging from "Totally disagree" to "Totally agree." The mid-point ("About equal") provided a realistic neutral option, enhancing the realism of the assessment (Kankaraš and Capecchi, 2024).

Additionally, 36 Choice-Based Conjoint (CBC) pairwise scenarios were generated using an orthogonal design (Green et al., 2004; Ben-Akiva et al., 2019; Benjamin et al., 2014). Participants were shown pairs of EC images and asked, “When walking, which image represents an environment you would prefer to walk in?” They indicated their preference by selecting an icon near their chosen image.

Qualitative data was gathered through an optional free-text question: “If you would like to elaborate freely on your stress and perception as a pedestrian near electric scooter traffic, here is the place.” Sociodemographics, Big Five personality traits, walk experience, and e-scooter familiarity were also collected via a survey.

Figure 1 outlines the research framework. The study began with informed consent, followed by a survey collecting background information such as sociodemographics, personality traits, walk experience, e-scooter familiarity, awareness of regulations, and perceptions of infrastructure. In the center section, counterbalancing between the SRS and CBC components ensured the task order did not bias results. In the SRS component, participants were exposed to six out of 18 ECs, randomly assigned three with narrow pathways and three with wide pathways. The sequence of narrow and wide pathways was alternated to mitigate order effects such as fatigue or familiarity bias. In the CBC component, participants evaluated a randomized selection of six out of 36 pairs of ECs, each represented by two photorealistic images. This provided comparative insights into pedestrian preferences under varying urban scenarios. Finally, participants shared recommendations on e-scooter regulation, infrastructure design, and enforcement alongside free-structured opinions on their experiences, for potential qualitative insights to complement the quantitative data.

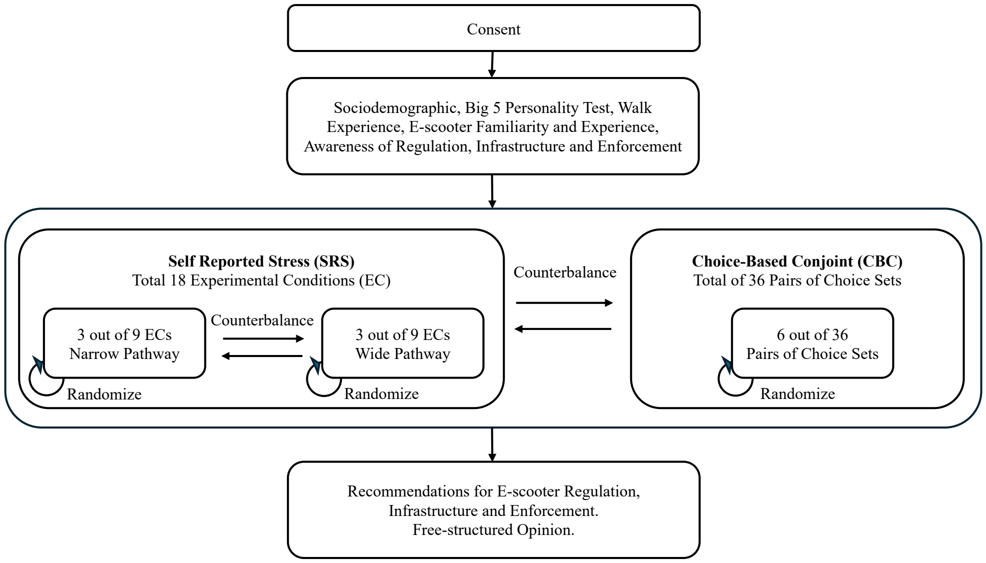

Figure 1. Research Framework

We employed Mixed Ordinal Logit (MOL) models to analyze SRS for individual ECs and Mixed Multinomial Logit (MMNL) models to assess pairwise preferences in the CBC analysis, accounting for within-subject dependencies.

For qualitative data from the open-ended question, thematic analysis was conducted using Quirkos to identify recurring themes.

3. RESULTS AND DISCUSSION

Across both locations, the sample was balanced in gender and included a diverse age range, with the largest group aged 25-34 (25%). Residential distribution showed that 36% of TLV participants lived in the city center, compared to 20.1% in CHP. Personality traits varied, with TLV participants reporting higher emotional instability (19% vs. 14%) and CHP participants showing greater extroversion (14% vs. 6%). Walking near e-scooters was frequent in TLV, with 42% encountering e-scooters five or more times weekly, underscoring the higher adoption of e-scooters in TLV. Familiarity with e-scooters was also higher in TLV (42% vs. 29%), further highlighting cultural and infrastructural differences in mobility.

Figure 2 presents six charts illustrating the MOL models, which reveal the probabilities of perceived stress across different spatial contexts under varying e-scooter traffic directions. The charts are organized in three rows, each corresponding to a specific traffic direction, with results for Tel Aviv (TLV) displayed on the left and Copenhagen (CPH) on the right. Each chart compares six spatial context combinations involving narrow (N) and wide (W) pedestrian pathway widths with infrastructure designs categorized as marked (M), shared (SH), or separated (SP). The shading gradient represents perceived stress intensity, where lighter shades correspond to lower stress levels and darker shades to higher stress levels. The y-axis displays the probabilities of the various stress levels, and the x-axis represents the spatial context combinations, with the sum of probabilities for each x-axis category equal to 1. Lines connecting these discrete values are used to highlight patterns and trends across the configurations.

Figure 2. MOL probabilities of perceived stress given e-traffic direction across spatial context

While there are overarching similarities, such as a universal preference for separated pathways (W-SP) and higher stress for narrow-shared pathways (N-SH), the detailed patterns of stress probabilities reveal differences between TLV and CPH, particularly in how specific spatial contexts and traffic directions influence perceived stress. A key finding is that in TLV, narrow-separated (N-SP) infrastructure consistently results in lower stress probabilities across all traffic directions, highlighting the critical role of separation in mitigating pedestrian stress in this city. Conversely, in CPH, wide-marked (W-M) infrastructure is associated with lower stress probabilities, suggesting a preference influenced by more established micromobility infrastructure and cultural norms surrounding shared spaces. Cultural differences emerged, with TLV respondents reporting higher stress overall. These findings underscore the influence of local infrastructure design, cultural contexts, and traffic configurations on pedestrian stress perceptions.

Additional factors influencing pedestrian stress near e-scooter traffic were found to be significant (Table 1).

Table 1. Type III Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Width	1	2142	45.36	<.0001
Separation	2	2142	192.36	<.0001
Direction	2	2142	2.89	0.0558
Israel	1	2142	4.82	0.0283
Width*Separation	2	2142	4.91	0.0075
Separation*Direction	4	2142	2.10	0.0782
Israel*Separation	2	2142	17.28	<.0001
Riding frequency	1	2142	11.94	0.0006
Existing infrastructure	1	2142	6.04	0.0140
Direction recommendation	2	2142	17.56	<.0001
Big 5 Neuroticism	1	2142	8.05	0.0046
Incident	1	2142	48.37	<.0001

Wider pedestrian pathways significantly reduce perceived stress by providing more space for safe coexistence between pedestrians and e-scooters. Infrastructure Separation greatly reduces perceived stress, underscoring its critical importance in urban design. E-Scooter Traffic Direction, same, opposite, or both, suggests that opposite or mixed directions may slightly increase stress levels. Comparing location (TLV vs. CPH) shows that pedestrians in TLV report higher stress levels than those in CPH, reflecting potential cultural or infrastructural differences. The combined effect of Width*Separation Interaction significantly reduces stress, more than either factor alone. The Israel*Separation Interaction has a stronger stress-reducing effect in TLV than in CPH, highlighting the disparity in infrastructure development. Frequent e-scooter riders report lower stress levels, suggesting familiarity with e-scooters helps mitigate anxiety while walking in their proximity. Participants who indicated familiarity with existing infrastructure reported significantly lower stress levels, highlighting the critical role of infrastructure in reducing stress and its importance in urban planning efforts. Respondents who preferred "both directions" for e-scooter traffic reported lower stress. Possibly, their preference signifies familiarity with micromobility environments or confidence in their ability to navigate such situations. Higher neuroticism, a Big Five personality trait (De Raad, 2000), is associated with greater perceived stress, suggesting that emotional stability influences stress sensitivity in e-scooter traffic environments. Individuals involved in e-scooter incidents report significantly higher stress, demonstrating the lasting impact of negative experiences on pedestrian well-being.

The CBC pairwise choice-set preferences analysis employed an MMNL model with random effects to capture individual-level preference variation. The factor "Country" was insignificant, revealing no substantial differences between TLV and CPH, indicating consistent pedestrian preferences across both cities. Accordingly, Figure 3 illustrates the combined data results, as the country variable did not significantly influence preferences as a main effect or in interaction with other variables. The bar chart depicts predicted choice probabilities of participants selecting their preferred walking environments that minimize stress, categorized by pedestrian pathway width, narrow (N, light blue), and wide (W, dark blue). The x-axis represents spatial contexts as combinations of traffic direction, both (BD), opposite (OD), and same (SD), and infrastructure design, marked (M), shared (SH), and separated (SP).

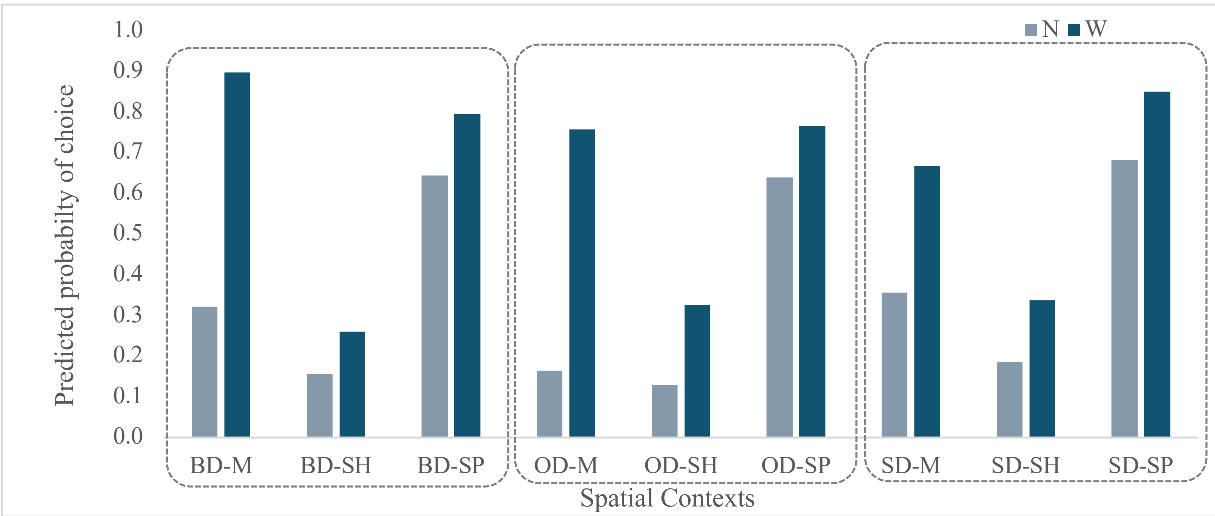

Figure 3. Universal predicted probabilities of choice

The MMNL finding suggests that urban environments with wide-separated contexts (W-SP) are the most preferred and effectively mitigate stress.

This thematic analysis in Figure 4 compares responses from CPH (43) and TLV (71), with color-coded themes: red for emotions, green for infrastructure, and blue for regulation. Circle size reflects response volume. The results align with model outcomes, confirming that e-scooters impact pedestrian stress. In CPH, themes include "stress," silent e-scooters, "ruthless" riders, and calls for stricter regulations, like age limits. Improved infrastructure, such as bike-like rules, was also highlighted. In TLV, themes emphasize stress, "danger," and "vulnerability," with a focus on "enforcement," "laws," and clear path separation. Both cities emphasize safety, with CPH leaning on regulation and TLV on enforcement.

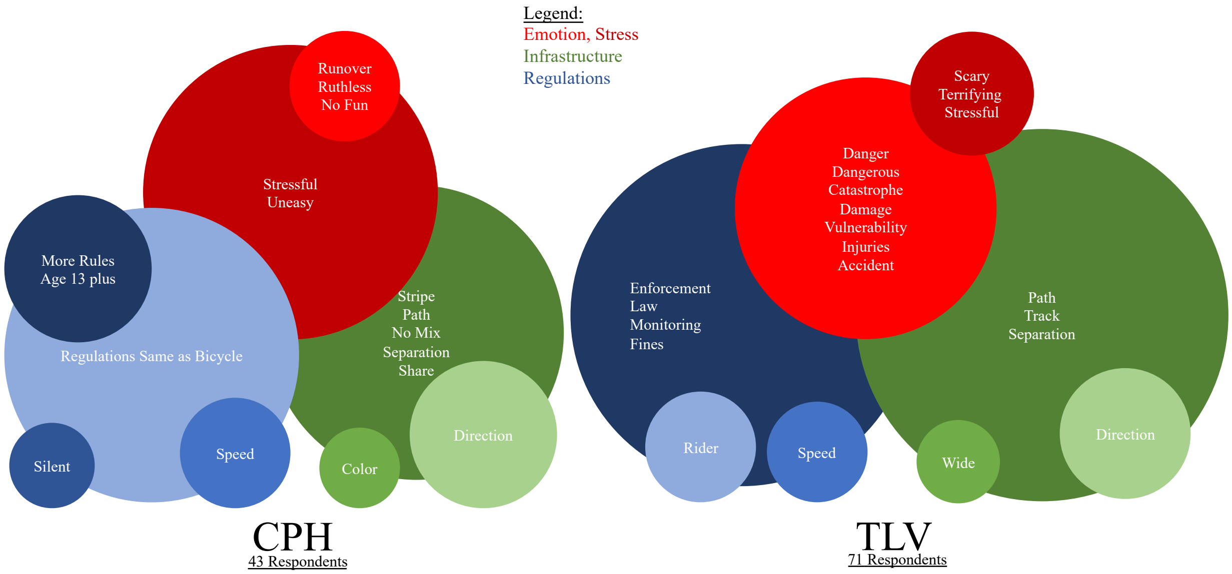

Figure 4. Thematic analysis

4. CONCLUSIONS

This study highlights the role of cultural and infrastructural context in shaping pedestrians' perceived stress near e-scooter traffic. While pedestrians in TLV reported higher stress levels - particularly in shared or opposite-direction e-scooter traffic on narrow paths - the alignment in preferences across both cities points to a universal preference for well-designed, separated infrastructure.

CPH demonstrates lower reported stress levels, which may be associated with its established micromobility infrastructure, social norms, and regulatory frameworks, contributing to lower stress levels. In contrast, TLV shows higher stress levels, likely reflecting challenges related to its rapid adoption of e-scooters and relatively limited infrastructure to support their integration. Additionally, personality traits like neuroticism and prior incident involvement further influence stress responses, demonstrating the complexity of interactions between pedestrians and e-scooter traffic.

These findings highlight the need for targeted urban interventions, especially in cities with widespread e-scooter adoption like TLV. Implementing physically separated lanes, widening pedestrian pathways, and enforcing directional controls for e-scooter traffic are practical and effective measures to reduce pedestrian stress and enhance urban mobility. Policymakers and urban planners must prioritize strategies that foster harmonious coexistence between pedestrians and e-scooters.

Future research exploring the long-term impacts of e-scooter policies and infrastructure improvements on pedestrian well-being would provide valuable insights, supporting evidence-based urban planning to create stress-mitigated, more pedestrian-friendly e-scooter environments.

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