1. Acknowledgements

We are grateful to Ziwen Lu from the Department of Computer Science and the Acoustics Research Group at UCL for their invaluable support and insightful discussions throughout this study.

PEDESTRIAN WALKING SPEED IN RELATION TO TRAFFIC NOISE SHARPNESS

Kening Guo[1], Jian Kang[1]

[1] *Institute for Environmental Design and Engineering, The Bartlett, University College London (UCL), UK*

Abstract

Urban streets are shaped not only by their physical form but also by their sensory environment, particularly sound. While previous research has focused on perceptual responses such as annoyance, less is known about how acoustic conditions relate to actual pedestrian behaviour in real-world settings. This study examines the relationship between traffic noise and walking behaviour using a non-intrusive observational approach on a London street. Using simultaneous binaural audio recording and video tracking, the research extracted psychoacoustic indicators—acoustic sharpness, a key metric reflecting the high-frequency spectral balance characteristic of urban traffic noise—to analyse its correlation with pedestrian walking speed. Results show that acoustic sharpness exhibits a significant, non-monotonic relationship with pedestrian movement. Specifically, walking speed increased at moderate levels of sharpness, followed by a decrease as the auditory stimulus reached higher, more "piercing" intensities. The magnitude of these behavioural modulations—ranging from 0.11 to 0.12 m/s—represents a quantifiable shift in the rhythmic use of public space. This suggests that sound acts as a subtle yet persistent regulator of the urban tempo, providing a new perspective for the development of more responsive and pedestrian-oriented urban spaces.

Keywords: *street soundscape, pedestrian behaviour, walking speed, traffic noise, sharpness*

2. Introduction

Urban streets are often seen as spaces that structure and support human activity, yet how they are experienced depends not only on their physical form but also on the surrounding sensory environment. Among these, sound plays a particularly important role, shaping how people perceive and engage with urban space. In the UK, the average daily travel time is about 61 minutes [1], meaning that exposure to urban sound environments is both routine and prolonged. At the same time, policies such as the Cycling and Walking Investment Strategy and the UN Sustainable Development Goal 11 aim to transition cities from car-oriented to people-oriented designs [2], [3]. Yet, this shift unavoidably increases pedestrians' exposure to traffic noise, which, over time, has been linked to adverse health outcomes such as hypertension and anxiety [4].

Extensive research has established the relationship between traffic noise and human perception, with a predominant focus on annoyance and subjective evaluations. Evidence from large-scale noise surveys [5] to controlled audio–visual laboratory experiments [6] provides a solid foundation for understanding how individuals perceive and evaluate traffic noise. The ISO 12913 soundscape framework (Figure 1) emphasises that human responses to sound environments encompass not only short-term reactions and emotional states, but also behavioural changes [7]. However, while subjective perception has been widely studied, empirical evidence on how sound influences actual pedestrian behaviour in real urban settings remains limited. This behavioural gap is critical, as street design fundamentally acts as an intervention in spatial behaviour for urban designers and policymakers.

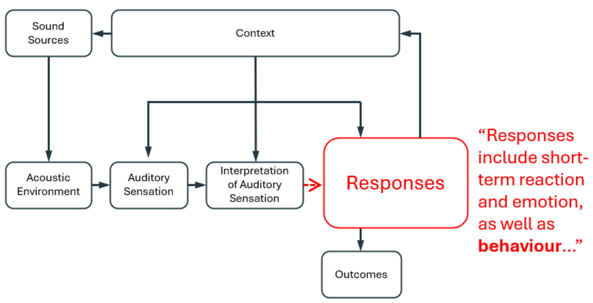

Figure 1. ISO 12913 soundscape framework, with a focus on human responses, particularly behaviour

Therefore, this study aims to investigate, in real-world in situ street environments under non-interventional (observational) conditions, whether acoustic sharpness, as a key psychoacoustic indicator of traffic noise, is associated with pedestrian walking behaviour.

3. Methodology

The study was conducted on an urban street in London with both daily pedestrian movement and vehicular traffic. A non-intrusive observational design was adopted to capture real-world conditions without interfering with the environment. Audio and video data were recorded simultaneously using a Head Acoustics SQobold portable microphone and a GoPro Max camera. The microphone was positioned at ear height (1.5 m), while the camera was mounted at an elevated viewpoint to capture pedestrian movements.

Figure 2. Pedestrian movement detection and synchronised audio recording

The raw acoustic signals were processed using Artemis SUITE software to extract physical and psychoacoustic indicators, providing a more comprehensive characterisation of the street's acoustic environment beyond overall sound level. Acoustic sharpness was selected as a key parameter, as it reflects the balance between high- and low-frequency components and is closely related to the spectral centre of mass, with higher values corresponding to greater perceived sharpness. The calculation followed the standardised procedure defined in DIN 45692, and values are expressed in acum.

Additionally, pedestrian movement was extracted from the video data using the YOLO11n real-time object detection model (Figure 2). The model was used to detect and classify road users, including pedestrians, bicycles, cars, motorcycles, buses, and trucks, thereby capturing the dynamic context of the street environment. Individuals were tracked based on bounding box coordinates, which were transformed from image space to real-world distances using a homography transformation. This enabled the estimation of average walking speed at a 1-second resolution, allowing fine-grained temporal alignment with the acoustic data.

To further reduce temporal dependency and account for potential delays in behavioural responses to changes in the acoustic environment, the data were sampled in 3-second blocks. This temporal aggregation allows sufficient time for pedestrians to perceive and respond to the soundscape. After removing transition periods and synchronisation errors, the final dataset was divided into 324 independent samples for subsequent correlation and tertile-based analyses.

4. Results

Results are organised in two parts. First, we describe the overall acoustic and behavioural characteristics of the street, including both aggregate measures and their temporal variation. We then examine how changes in acoustic conditions relate to differences in walking behaviour.

4.1 Acoustic and Behavioural Overview

The street environment was characterised by relatively high and stable noise levels. The mean LAeq reached 70.70 ± 3.63 dB, a level well above the WHO guideline of 53 dB L_den for road traffic noise, indicating a potentially high exposure context. Psychoacoustic indicators further define the soundscape's character: sharpness was relatively high (mean = 2.45 ± 0.28 acum; median = 2.40; interquartile range = 2.25–2.58 acum; range = 1.94–4.22 acum).

In addition, the temporal variation of the acoustic environment is illustrated in Figure 3. The spectrogram shows that acoustic energy is mainly concentrated in the low-frequency range (below ~100 Hz), with sustained energy extending into the mid-frequency range up to around 1 kHz. Higher-frequency components above 1 kHz are weaker and more intermittent. This pattern is consistent with typical traffic noise, where low-frequency energy is associated with engine sources, particularly from heavier vehicles, and mid-frequency energy with tyre–road interaction. Consistent with this spectral structure, sharpness values remain relatively stable over time, with most observations clustering between approximately 2.2 and 2.7 acum. Occasional higher values (exceeding 3.5 acum) suggest transient increases in high-frequency content, likely associated with short-duration events such as braking, honking, or passing vehicles. Overall, the temporal pattern indicates a predominantly low-frequency-dominated acoustic environment with intermittent high-frequency contributions.

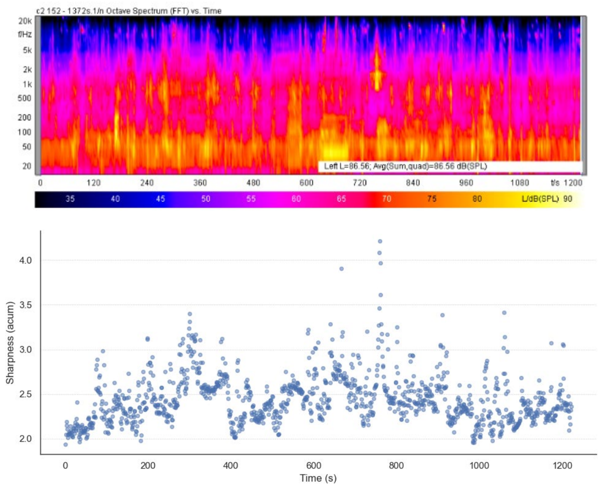

Figure 3. Temporal variation of spectrogram and sharpness in the street acoustic environment

***Corresponding author**: kening.guo.23@ucl.ac.uk*

Table 1 summarises the overall behavioural characteristics of the street environment. During the 1220-s observation period, 301 vehicles and 387 pedestrians were recorded, with light vehicles (e.g. cars and motorcycles) accounting for 88% of traffic and heavy vehicles (e.g. buses and trucks) for 12%. This corresponds to approximately 15 vehicles and 19 pedestrians per minute, indicating a moderate level of vehicular traffic alongside relatively active pedestrian movement (within typical urban ranges of around 5–30 vehicles/min and 5–20 pedestrians/min, consistent with moderate urban traffic conditions). The average walking speed was 1.27 ± 0.48 m/s. Figure 4 further shows the temporal variation in walking speed, where, beyond a stable overall trend, noticeable fluctuations can be observed at finer time scales. To capture these finer patterns, the per-second data were further examined using a discretised analysis.

Table 1. Summary of traffic and pedestrian characteristics

Total vehicles	Light Ratio	Heavy Ratio	Pedestrians	Walking Speed (m/s)
301	0.88	0.12	387	1.27±0.48

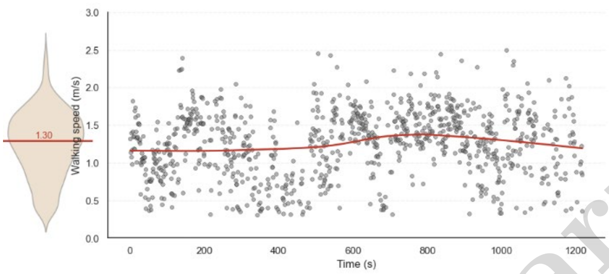

Figure 4. Temporal variation in walking speed

4.2 Relationship Between Acoustic Indicators and Walking Speed

To further investigate the instantaneous influence of the soundscape on pedestrian behaviour, the acoustic sharpness were categorised into low, medium, and high tertile groups based on their 33.3rd and 66.6th percentile values. This discretisation ensures balanced sample sizes across groups and is suitable for non-normally distributed environmental data.

Figure 5 presents the relationship between acoustic sharpness and walking speed. First, a Kruskal–Wallis H test revealed a statistically significant overall difference across the three sharpness groups (H = 6.04, p = 0.049), indicating that acoustic sharpness significantly influences walking speed. To further investigate these differences, post-hoc pairwise comparisons were conducted using Mann–Whitney U tests. The results showed that walking speed increased from 1.19 m/s in the Low sharpness group to 1.31 m/s in the Mid group (∆ ≈ +0.12 m/s; U = 4777.00, p = 0.022). However, as sharpness increased further into the High group, walking speed decreased to 1.20 m/s (∆ ≈ −0.11 m/s relative to the Mid group; U = 6723.00, p = 0.053). Notably, no significant difference was observed between the Low and High groups (1.19 vs 1.20 m/s; ∆ ≈ +0.01 m/s; U = 5769.00, p = 0.892). Collectively, these findings demonstrate a clear non-monotonic, inverted V-shaped pattern, suggesting that walking speed is highest at a moderate level of acoustic sharpness, while both excessively low and high sharpness levels lead to a comparable reduction in walking speed.

As sharpness reflects the spectral balance of the acoustic environment, this non-monotonic relationship suggests that pedestrian behaviour is related to the distribution of acoustic energy across frequencies. Walking speed increases from lower to moderate levels of sharpness, typically associated with a shift from low-frequency-dominated to more spectrally balanced environments, while higher sharpness levels—characterised by increased high-frequency content—are associated with reduced walking speed.

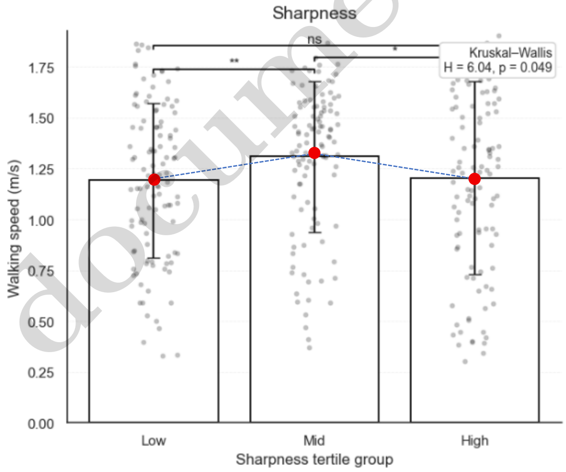

Figure 5. Walking speed (mean ± SD) across tertiles of acoustic sharpness (Significance levels: *p < 0.1, **p < 0.05, ***p < 0.01; ns, not significant.)

5. Discussion and Conclusion

This study shows that traffic noise is not only perceived but is also associated with measurable changes in pedestrian walking behaviour. In particular, acoustic sharpness was linked to non-monotonic variations in walking speed, with speed increasing from the low to the medium sharpness group (∆ ≈ +0.11 m/s), and decreasing from the medium to the high group (∆ ≈ −0.12 m/s). This corresponds to a displacement of over 1 metre within 10 seconds. In a busy street context, such differences may be meaningful in shaping how space is used and how pedestrian flows are organised.

From a theoretical standpoint, the observed inverted “V-shaped” patterns indicate that pedestrian responses vary across acoustic conditions, rather than showing a consistent increase or decrease, possibly reflecting a dynamic shift from sensory distraction to active evasion. This aligns with the "arousal-response" theory in environmental psychology, where where moderate levels of stimulation can facilitate behavioural performance, whereas excessive stimulation may impair it [8].

From a practical perspective, these findings reposition the urban soundscape as a subtle yet active regulator of movement and spatial behavior. Contrary to conventional noise-mitigation strategies, reducing overall sound pressure levels does not necessarily lead to better perceptual outcomes. For example, lowering traffic noise may even increase annoyance by weakening the masking effect of continuous background sound, thereby making discrete and impulsive noises more perceptually salient [9]. Furthermore, the behavioral relevance of the soundscape is evident in its capacity to positively shape spatial occupancy. The introduction of beneficial acoustic interventions—such as music or natural sounds—has been shown to encourage people to stay longer in public spaces, increase levels of social interaction, and promote more active use of the urban environment [10], [11]. By extension, this line of evidence could inform the design of street environments: the placement of landscape elements, street furniture, and even adjacent commercial frontages can be strategically configured to work in synergy with the acoustic environment.

Consequently, sound should be treated as an active design element rather than a passive by-product of urban activity, shaping how people move through, occupy, and experience urban streets. It can also contribute to more behaviourally supportive and health-promoting cities—with just a small shift in perspective.

6. Acknowledgements

We are grateful to Ziwen Lu from the Department of Computer Science and the Acoustics Research Group at UCL for their invaluable support and insightful discussions throughout this study.

References

[1] Office for National Statistics, 'Time use in the UK'. 2023.

[2] Department for Transport and Active Travel England, 'The second cycling and walking investment strategy (CWIS2)', 2022.

[3] United Nations, 'Transforming our world: the 2030 Agenda for Sustainable Development', 2015.

[4] World Health Organization, 'Environmental noise guidelines for the European Region', 2019.

[5] H. Tong and J. Kang, 'Characteristics of noise complaints and the associations with urban morphology: A comparison across densities', *Environmental Research*, vol. 197, p. 111045, Jun. 2021, doi: 10.1016/j.envres.2021.111045.

[6] A. Fiebig and C. Jakobs, 'Psychoacoustic properties of tire-road noise and the relation to noise annoyance', Institute of Noise Control Engineering. doi: 10.3397/IN_2022_0803.

[7] ISO 12913-1, *Acoustics — Soundscape — Part 1: Definition and conceptual framework*, 2014.

[8] A. Mehrabian and J. A. Russell, *An approach to environmental psychology*. in An approach to environmental psychology. Cambridge, MA, US: The MIT Press, 1974, pp. xii, 266.

[9] Jian Kang and Brigitte Schulte-Fortkamp, *Soundscape and the Built Environment*. CRC Press, 2016.

[10] F. Aletta, F. Lepore, E. Kostara-Konstantinou, J. Kang, and A. Astolfi, 'An Experimental Study on the Influence of Soundscapes on People's Behaviour in an Open Public Space', *Applied Sciences*, vol. 6, no. 10, Sep. 2016, doi: 10.3390/app6100276.

[11] X. Chen and J. Kang, 'Natural sounds can encourage social interactions in urban parks', *Landscape and Urban Planning*, vol. 239, p. 104870, Nov. 2023, doi: 10.1016/j.landurbplan.2023.104870.