”Nuisance is Better Than Nothing?”: Exploring How Pedestrians and Cyclists Perceive Automated E-Scooter Alerts in Shared Spaces

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Electric scooters (e-scooters) offer flexible urban mobility but raise safety concerns in shared spaces. This study investigates how e-scooters can better communicate their presence to pedestrians and cyclists in shared active mobility environments. A focus group with e-scooter riders identified notifying others of arrival as a key challenge. To address this, we co-designed audio and visual alerts in a participatory workshop and evaluated them in a real-world Wizard of Oz (WoZ) study involving live encounters. WoZ self-report data showed that voice and bell alerts were rated significantly higher in visibility, safety, communication, and acceptance than continuous sounds and flashing lights. These findings were supported by video analysis, which captured clear spatial responses such as turning or moving aside. Cyclists rated alerts as more distracting than pedestrians. Eye-tracking data revealed increased pedestrian attention during overtaking. By combining self-reports, video, and gaze data, we provide in-situ evidence and design recommendations to improve e-scooter signalling and reduce conflict. The dataset, including anonymized ratings, fixation data, alert designs, and analysis scripts, is available at https://github.com/HiruniNuwanthika/User-Perception-Evaluation-Escooter-Alerts.git.

CCS Concepts: • **Human-centered computing → Empirical studies in ubiquitous and mobile computing**.

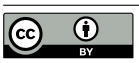
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1 Introduction

Electric scooters are an emerging mode of urban transportation, offering benefits such as avoiding traffic congestion, reducing parking challenges, enhancing portability, and providing a cost-effective travel option [41, 43, 55]. However, despite these advantages, other road users who share space with e-scooters (e.g., pedestrians, cyclists) raise concerns regarding footpath riding, obstructed side

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walks due to improper parking, and reckless riding behaviour [17, 17, 18, 22]. To regulate these behaviours, various cities have implemented legal restrictions, including prohibit e-scooters on side walks, enforce mandatory helmet use, and impose a minimum age requirement for riders [17]. Beyond regulations, technological interventions have also been introduced to improve compliance and safety. These include footpath detection technology [3, 36], GPS-based geofencing to restrict riding zones [28], mobile app-integrated sobriety tests [4, 39], and IoT-enabled systems to detect tandem riding [10, 37].

However, unavoidable interactions between e-scooter riders and vulnerable road users in narrow shared paths remain challenging. Previous studies indicate that pedestrians generally perceive e-scooter riders as annoying and intrusive, often reporting feelings of discomfort and reduced safety when they operate on side walks [7, 21, 56]. A key concern is e-scooters moving too close to pedestrians without signalling [54]. Another factor contributing to these challenges is the low noise levels of e-scooters, making them difficult for others to detect [51]. Research by Walton et al. [50] found that without any alert sounds, the detection rate for e-scooters in a typical 60 dBA urban environment is as low as 23%. To navigate these challenging interactions safely, e-scooter riders practice various strategies, such as manoeuvring off-road, using verbal communication, ringing a bell, or making hand gestures to signal their approach to other road users [25].

While diverse interventions, including vehicle design improvements, infrastructure modifications, and technological advancements, have been introduced to enhance e-scooter safety, research highlight the importance of evaluating and validating their effectiveness [32]. One such intervention is the integration of warning systems into e-scooters. A growing body of research has explored audio and visual warning systems. Some studies have focused on developing Acoustic Vehicle Alerting Systems (AVAS) and evaluating their detectability among pedestrians through lab-based experiments [44, 52]. Although visual alert systems (e.g., light placement, intensity, and visibility aids) have been widely studied in cycling [13], research on their effectiveness for e-scooters remains limited. A study tested contrasting visibility aids found that strategically integrated high-visibility colours improved e-scooter detection [13, 27]. Despite these advancements, critical gaps remain in our understanding of how e-scooter alerts function in shared active mobility contexts. Existing studies often rely on retrospective surveys, limiting ecological validity. Moreover, while pedestrian responses have been studied, there is limited empirical insight into how cyclists perceive and respond to e-scooter interactions. Finally, most prior work adopts a single-method approach—either surveys or passive video—failing to connect user experience with observed behaviour. These limitations highlight the need for real-time, multi-modal research to generate context-rich insights into alert effectiveness and safety in shared environments.

To bridge this gap, we initiated our study with a preliminary focus group discussion involving e-scooter riders, which revealed that a key challenge lies in effectively notifying pedestrians and cyclists of the e-scooter's presence. Among the solutions discussed, we chose to pursue an automated audio and visual alert system. This decision was grounded in the understanding that, while regulatory frameworks and infrastructure redesign are essential, these areas are being actively addressed by specialists in urban planning and policy. As researchers in human-computer interaction, our expertise lies in designing intuitive, user-centred technologies. We approached automation not as a replacement for manual signalling, but as a complementary mechanism—a baseline signalling layer that can reduce inconsistency, hesitation, or social discomfort in shared mobility interactions.

Our selected intervention avoids the limitations of peripheral-dependent systems, such as wearables, by allowing direct integration into existing e-scooter platforms. Building on these, we refined our alert designs through a participatory design workshop involving e-scooter riders, pedestrians,

and cyclists, and conducted a real-world Wizard of Oz (WoZ) study to evaluate their effectiveness under natural conditions.

In summary, the contribution of this work includes:

- We evaluated the perception of automated e-scooter alerts among both pedestrians and cyclists in an outdoor environment, examining five key aspects – visibility, safety, communication, distraction, and acceptance – which contrasts with previous studies that have primarily focused on pedestrian responses in controlled lab settings, mainly assessing detectability and annoyance.
- We employed a multi-modal method integrating self-reports, video observations, and eye-tracking data to capture both perceived experience and observable behavioural responses. The dataset, including anonymized ratings, fixation data, alert designs, and analysis scripts, is publicly available at https://github.com/HiruniNuwanthika/User-Perception-Evaluation-Escooter-Alerts.git to support future research.
- We provide design recommendations for e-scooter alerts that emerged from engaging diverse stakeholders; pedestrians, cyclists, and e-scooter riders ensuring that the solution addresses the concerns of multiple stakeholder groups sharing urban spaces.

2 Related Work

2.1 E-scooter Interactions With Pedestrians and Cyclists

Since their introduction, e-scooters have reshaped the landscape of urban mobility. Depending on local regulations, their use is permitted across a range of transport infrastructures, including roadways, cycle lanes, and footpaths [2, 15]. However, riding on roadways exposes e-scooter users to increased risk due to close proximity with motor vehicles [8]. Even in active mobility environments, such as cycle lanes and footpaths e-scooters often disrupt existing norms due to their distinct operational characteristics. Their unique profile in terms of speed, acceleration, manoeuvrability, and riding posture creates the potential for conflicts with both pedestrians and cyclists [24].

Several studies have explored public concerns and behavioural issues emerging from e-scooter deployment. Gössling [17] analysed 173 media articles from 10 global cities, highlighting recurring complaints about irresponsible riding, competition for space, and safety concerns. Complementing this, Šucha et al. [56] conducted a cross-national survey with 3,385 riders and non-riders across five countries. The study revealed that 20–30% of riders reported using sidewalks at speeds above walking pace, regardless of legal restrictions, while a majority of pedestrians perceived e-scooters as disruptive. Over half of riders had experienced a near miss, often involving another road user.

Further illustrating divergent safety perceptions, Pourfalatoun et al. [38] surveyed 210 users and 199 non-users of shared e-scooters. They identified significant differences between the two groups, particularly regarding helmet use. Furthermore, contrary to non-users, users reported feeling safe regarding the speed and in a variety of e-scooter scenarios, including riding on sidewalks and walking and being passed by an e-scooter.

Virtual Reality (VR) based methods have offered deeper insights into how pedestrians react to e-scooter interactions. Hussain et al. [20] used VR simulations with 75 participants to examine pedestrian avoidance behaviour. E-scooters approached at varying speeds and from different lateral positions. Results showed that both the speed and direction of approach significantly influenced pedestrian responses. Similarly, Che et al. [6] employed VR to compare safety perceptions of 30 pedestrians and 30 e-scooter riders across 12 shared-path scenarios. Pedestrians consistently rated interactions as less safe than riders. Interestingly, moderate speeds were perceived as safer than lower speeds in face-to-face encounters. It highlights that speed alone is not the sole determinant of perceived safety and interaction direction plays a crucial role in risk assessment.

Beyond simulated environments, observational studies have captured e-scooter behaviours in real-world contexts. Hong et al. [19] analysed 473 trips using fixed cameras on a university campus, documenting hazardous behaviours and rider adjustments to traffic conditions. Their findings suggested that e-scooter riders frequently posed threats to pedestrians due to speed. In a complementary study, Tuncer and Brown [47] employed video ethnography to examine e-scooter practices in public spaces. Their analysis revealed how riders adapt to infrastructure constraints by informally transitioning between sidewalks, roads, and cycle lanes, exposing the ambiguities in spatial entitlements and regulatory enforcement.

While pedestrian-related studies are relatively abundant, interactions between e-scooter riders and cyclists remain underexplored. Ringhand et al. [40] conducted a quasi-experimental study with 52 participants to compare route preferences of e-scooter riders and cyclists. E-scooter riders rated surface quality, safety, and rule compliance as more important and travel distance as less important for route choice than cyclists. Using a social identity lens, Anke et al. [1] surveyed 179 cyclists and 64 e-scooter riders, presenting video clips of traffic rule violations. Their online experiment revealed that cyclists often view e-scooter riders as reckless, highlighting behavioural differences and a lack of shared norms between the two groups.

Exploring third party perspective, Useche et al. [48] surveyed 376 non-riders to compare cyclist and e-scooter rider behaviours. Participants rated e-scooter riders as engaging in riskier and more disruptive practices. Conversely, Kazemzadeh [23] focused on e-scooter riders' safety perceptions during interactions with cyclists. In an online survey with 920 Swedish participants, the study found that women reported feeling less safe in shared spaces, and younger riders perceived approaching encounters as more threatening than overtaking scenarios, suggesting that age, gender, and interaction type all influence perceived safety.

Despite this growing body of work, several gaps remain in our understanding of e-scooter interactions in active mobility contexts. First, much of the existing research relies on retrospective survey data, which is prone to recall bias and lacks ecological validity. Real-time, in-situ exposure to e-scooter interactions remains largely unexamined. Second, while pedestrian perspectives are relatively well-studied [6, 56], there remains limited empirical understanding of how cyclists perceive and negotiate space with e-scooter riders. Third, most studies employ a single data modality—either self-reported surveys or passive video observations. Survey-only studies lack contextual granularity and are subject to participant subjectivity, while video-only studies risk speculative interpretations without user input. Therefore, there is a need for multi-modal, real-time approaches that integrate subjective experiences with objective behavioural and environmental data to generate richer, more actionable insights into the complexities of shared mobility interactions.

2.2 Evaluating E-scooter Alerts

The efforts to enhance e-scooter safety have led to the implementation of various interventions, including safety education programs (e.g., in-app safety guidelines), vehicle design improvements (e.g., wider decks, integrated warning devices), infrastructure modifications (e.g., dedicated lanes, improved surface maintenance), policy enforcements (e.g., standardised regulations and penalties), and technological advancements (e.g., real-time speed control, dynamic geofencing). However, evaluating and validating the effectiveness of these implemented interventions are limited [32]. This section focuses on studies assessing the effectiveness of e-scooter warning systems from the perspective of other vulnerable road users.

The low noise levels of electric vehicles, due to the absence of an internal combustion engine raised safety concerns. It lead to regulations mandating acoustic alerting system for larger electric vehicles. However, acoustic alerting systems for e-scooters, remain under explored despite their increasing presence. Walton et al. [51] developed an e-scooter AVAS, aiming to create alert sounds that

balance detectability and annoyance. Their study employed ambisonic soundscapes and simulated auralisations of e-scooter passes at 20 km/h, where participants completed a detection task and annoyance rating assessment. The findings highlighted key psychoacoustic factors influencing the effectiveness of AVAS in urban soundscapes. Building on this, a laboratory-based listening study was conducted to evaluate how environmental noise and distance impact pedestrian detection rates [50]. Their findings revealed that impulsive alerts were more effective than continuous sounds, and while higher sound levels improved safety, they required careful balancing with noise regulations to prevent excessive urban noise pollution. Extending these insights, Walton et al. [52] combined VR simulations and real-world field trials to assess pedestrian detection rates, reaction times, and acceptability of different AVAS designs. Their findings showed that missed detection rates for e-scooters without AVAS were between 90–97% in typical urban soundscapes. Beyond academic research, mobility operators have also explored AVAS solutions to improve e-scooter detectability. Dott, an e-scooter service provider, explored AVAS solutions aimed at enhancing e-scooter detectability while minimizing noise pollution [44]. In a lab-based study, participants were exposed to different alert sounds, with detection speed and evaluations of pleasantness and annoyance being measured. The findings revealed that broadband sounds without tones were the most preferred, as they were perceived as relaxing and less annoying. Broadband sounds with modulated tones were also effective but considered more intrusive, whereas continuous tonal sounds were the least preferred.

While research on visual alerts for e-scooters remains limited, their effectiveness has been extensively studied in cycling safety. Edewaard et al. [13] investigated how tail-light placement, intensity, and mode influence cyclist conspicuity in daylight. Their findings showed that "always-on" lights were most effective when placed on the rider's ankles, whereas flashing lights were more effective when mounted on the seat post. Similarly, a study analysing drivers' eye movements found that cyclists using a flashing or steady seat post-mounted tail-light were recognised from significantly greater distances than those without a tail-light [12, 14]. In the e-scooter context, Komova et al. [27] examined how contrasting visibility aids affect e-scooter rider conspicuity from a driver's perspective. Using video-based detection tasks, participants identified e-scooter riders with different visibility aids. The findings revealed that detection times were significantly reduced with the wheels-backpack visibility aid (i.e., yellow stripes on the e-scooter wheels and backpack), while patterned jackets (i.e., jacket and backpack with black and yellow pattern) offered no advantage over no visibility aid. The study emphasized that strategically integrating high-visibility colours across both the rider and e-scooter was more effective than isolated colour contrasts.

However, none of these studies explored how pedestrians and cyclists perceive e-scooter audio and visual alerts that are automatically emitted in shared spaces. The closest study to ours is the field trial conducted by Walton et al. [52], which assessed pedestrian and rider responses to acoustic alert systems under real-world conditions. Building on this work, our study aims to contribute further insights by focusing on several complementary aspects. First, Walton et al. [52] focused on pedestrians and e-scooter riders, whereas we examined the perspectives of both pedestrians and cyclists—two important user groups that interact with e-scooters in active mobility spaces. Second, in addition to evaluating audio alerts, we included a visual alert to explore the potential of multi-sensory communication. Walton et al. [52]'s study tested tonal and synthetic alerts designed for acoustic detectability, such as continuous, impulsive, and mixed harmonic tones. Our study complemented this by incorporating cues that align more closely with everyday urban signaling practices, including a verbal voice alert, a bell alert, and a continuous tone. This broader range of stimuli allowed us to examine how different types of alerts are perceived in realistic shared-use contexts. Third, while Walton et al. [52] evaluation focused on approaching encounters, our study also investigated overtaking scenarios to reflect the range of interactions that occur in real-world

situations. Finally, whereas their study relied on questionnaire responses, our approach integrated multiple data modals—including questionnaire, behavioural video recordings, and eye-tracking data, enabling a more nuanced understanding of participants' attention, situational awareness, and perceived safety in situ.

To address these gaps in understanding how e-scooter alerts are experienced by non-riders in shared environments, we conducted a comprehensive, multi-phase study. This began with a focus group discussion to identify everyday challenges and expectations related to e-scooter presence and communication. We then conducted a participatory design workshop in which stakeholders collaboratively developed and refined alert designs. Finally, we implemented a real-world evaluation using a Wizard of Oz (WoZ) method, exposing participants to both overtaking and approaching interactions, and collecting quantitative and qualitative data (see Figure 1).

3 Study Design

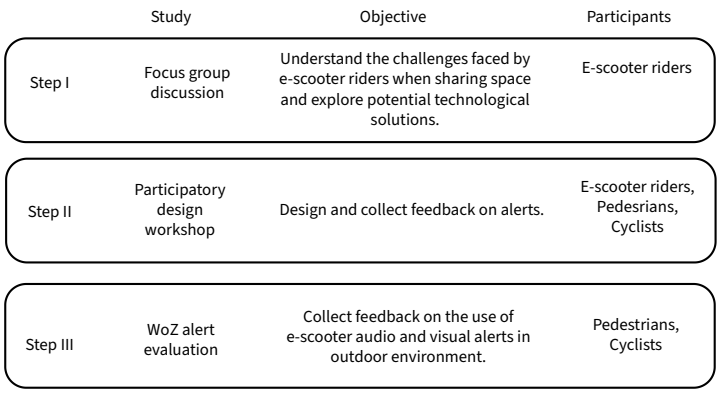


Fig. 1. The study design.

3.1 Step I - Focus Group Discussion

Designing future products, services, and systems that are accepted by individuals and society is often complex. The primary challenge lies in identifying the most critical problems to address and developing effective solutions [11, 34]. To address this challenge and ground our design process in real-world user experiences, we began with a focus group discussion. This initial step aimed to explore the challenges e-scooter riders face when interacting with other road users in shared spaces, and to gather ideas for potential solutions.

3.1.1 Study Design. We adopted a qualitative, scenario-based approach to facilitate open-ended exploration of rider experiences. Three commonly encountered road-sharing scenarios involving e-scooters were used to guide the discussion (see Appendix A). This approach allowed participants to reflect on past experiences and consider new possibilities for improving e-scooter interactions through design. The study served as an ideation step for our next steps.

3.1.2 Participants. A total of eight participants (five males and three females) were recruited via a flyer distributed in the community and on social media platforms. Their ages ranged from 23 and 51

years ($M = 33.7, SD = 9.6$). We included both frequent and occasional e-scooter riders to ensure a diversity of perspectives. Interested participants were sent an information sheet and consent form via email, and all provided informed consent prior to the session.

3.1.3 Procedure. The focus group session was held in a meeting room and the session lasted approximately 1.5 hours. The main researcher facilitated the discussion beginning with an introduction to the study goals. Participants were then introduced themselves and described their e-scooter usage frequency. Each of the three scenarios was presented one at a time, prompting participants to share challenges they had experienced or anticipated in similar situations. They were encouraged to propose potential solutions and reflect on the feasibility of those solutions. To support the discussion, participants used sticky notes and create affinity diagrams, organising their ideas. Figure 2 illustrates the workflow for the focus group discussion. The session was audio-recorded and later transcribed. To enhance the reliability and validity of the findings, member checking was conducted [35]. The transcript was shared with participants for their review to ensure the accuracy of the recorded information.

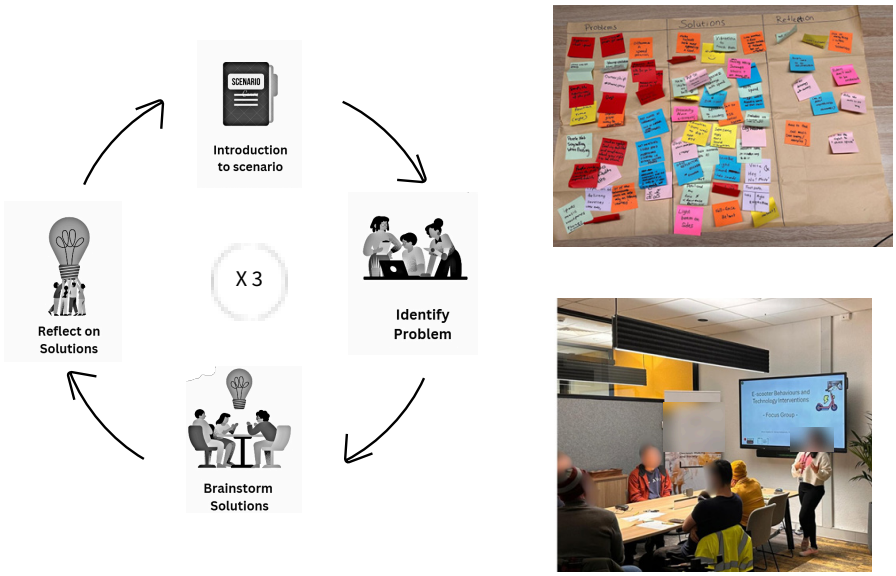


Fig. 2. Workflow for focus group discussion and participant engagement in the session

3.2 Step I - Findings

The focus group discussion revealed a range of challenges associated with e-scooter use in shared spaces, highlighting issues related distracted pedestrians, unpredictable movements and limitations in being visible. In response, a variety of solution directions were proposed, spanning regulatory measures, infrastructure adaptations, and technology-driven interventions. The findings are summarised in Table 1.

The participants identified several recurring problems faced by e-scooter riders. The issues were categorised into the following themes:

Table 1. Summary of focus group findings

	Category	Details
Challenges	Distracted pedestrians	Pedestrians walking in the middle of the path. Pedestrians distracted by headphones or phones. Aggression to step out of way. Misjudge e-scooter movement and step in the way. Groups blocking shared ways.
	Unpredictable movements	Children and elderly people and making unpredictable movements. Dogs on leashes create sudden obstacles.
	Practices of some rental users	Some rental users' irresponsible and unsafe riding practices affect public acceptance.
	Being visible to others	E-scooter lights hart to notice. Pedestrians often ignore bell alert. Loud honks startle pedestrians and cyclists.
	Communicating turns	Lack of left/right indicators. Releasing handle to hand-signal turns causes instability.
Solutions	Proximity alerts	Augmented glasses or audio warning overriding music on headphones. Display phone notification if e-scooters in proximity.
	Enhance visibility	Adding reflective stickers or side blinkers to e-scooter. Embedding light to helmet; Implement lighting systems that change brightness and colour dynamically.
	Improve notifications	Adding cool continuous music. Make the 'ding' bell different to bicycle bell. Add voice alerts.
	Adaptive infrastructure	Dedicated lanes for e-scooters avoiding other encounters.
	Enforce responsible behaviour	Enforce fines for violating rules. Restrict trip start if safety measures are not met. Use signage and social media campaigns.

- **Distracted pedestrians:** Participants frequently described situations where pedestrians, engrossed in mobile phones or wearing headphones, failed to notice approaching e-scooters. One participant noted, *"They might not hear any e-scooter approaching, especially from behind when walking with headphones."* Another participant agreed it saying *"Headphones and phones- a serious problem. They don't hear the bell signal, they don't hear anything, walking middle of the path. They don't see you unless if you stop and tap on the shoulder or something."* These observations highlight the limitations of relying on passive human attention in shared spaces. While distraction is usually framed as an individual responsibility, our participants instead viewed it as an environmental condition that e-scooter riders must constantly adapt to.
- **Unpredictable movements:** Erratic movements of pedestrians, particularly children, elderly individuals, and those walking dogs, were seen as hazards. Participants highlighted scenarios where dogs on leashes created unexpected obstacles, increasing the risk of accidents.
- **Practices of some rental users:**Participants raised concerns about rule violations, which they often observed among rental riders- such as riding on footpaths, failing to wear helmets and disregarding safety protocols. These behaviours were noted as a frequent cause of conflicts with other road users. One participant said *"people on commercial hire, they are the ones on*

the footpath. The other thing with commercial hire is nobody wears helmets." Beyond safety risks, participants highlighted the issue of reduced public acceptance of e-scooters in shared spaces. They mentioned that the irresponsible behaviour of some rental riders unfairly shaped negative perceptions of all e-scooter users, including those who follow the rules.

- **Being visible to others:** Participants expressed concerns about e-scooters being inconspicuous. One problem is their low visibility in low-light conditions, because the rear lighting located at the bottom of the e-scooter is inadequate. As one participant explained, *"[It is] just a tiny little light that is on the back of the scooter. You don't even see it."* This highlights a mismatch between standard lighting features and the visibility needs of riders navigating shared environments in dim settings. The positioning and minimal brightness of such lights were perceived as insufficient for ensuring that other road users could detect the rider in time.

  Another key challenge reported was the difficulty of effectively notifying others of an e-scooter's presence. While bells were the most common signalling tool, participants noted that these were often ignored or failed to respond to. In response, riders described relying on verbal communication to alert others. As one participant explained, *" If someone starts getting in my way, it's like "no, don't get in my way. Stay where you are. I'm coming through." [But] I'm not going to have a whole conversation doing that. I'm just gonna say, " Stop. Don't move." By the time they've frozen, I've got past them."* This illustrates different strategies riders adopt in shared spaces to inform their presence. Moreover, participants reported experimenting with louder signals, such as honks, to capture attention. While these were occasionally effective, riders acknowledged the risks associated with sudden loud sounds, as these can startle other road users, leading to unpredictable reactions.
- **Communicating turns:** Participants highlighted the difficulty of safely signalling turns, as e-scooters lack left/right indicators. One participant described a situation where a cyclist complained about not signalling, stating, *"A cyclist [once] complained me that I didn't signal when I was turning, because they were riding too close. I came to a turn, and made it. I can't signal."* Unlike cyclists, who use hand signals, e-scooter riders face challenges when attempting to signal turns using hands. Differences in vehicle design and manoeuvrability can be reasons this. Releasing one hand to signal often disrupts the balance of the e-scooter and increases the risk of losing control. One participant said *"I don't take my hands off the handlebars. It's not balance. I put my leg out to signal. If you are gonna go left, you put the left leg out."* These examples illustrate how e-scooter riders develop signalling strategies through lived experience. Even though e-scooters are often classified similar to bicycles, their structural and operational differences should be noted.

The solutions discussed included:

- **Proximity alerts:** To improve situational awareness in shared spaces, participants proposed several technology-driven interventions aimed at better notifying distracted pedestrians of an approaching e-scooter. A key concern was pedestrians wearing headphones who are unable to hear conventional auditory signals. One solution involved the use of augmented glasses to deliver visual alerts when an e-scooter is nearby—leveraging visual modalities when auditory channels are blocked. Another suggestion focused on designing a universal e-scooter alert sound that could interrupt ongoing audio on personal devices. The idea was to integrate this alert into headphone systems, allowing critical safety signals to override media playback.

  However, participants also expressed concerns about the intrusiveness of such solutions. Some noted that people use headphones to intentionally disconnect from their surroundings,

and forcing interruptions could negatively affect user experience and personal autonomy. This highlights a tension between safety and perceived overreach in attention-grabbing design.
For pedestrians distracted by mobile phones, another proposal involved triggering proximity-based notifications directly on their screens. Participants noted that while people may fail to notice electric vehicles due to their silent operation, they typically become aware of traditional motor vehicles through engine noise. Since e-scooters, like electric cars, do not produce such auditory cues, mobile phone notifications were seen as a practical alternative for restoring awareness among pedestrians.

- **Enhanced visibility:** Participants proposed several strategies to improve the visibility of e-scooters in low-light conditions. Suggested measures included attaching reflective stickers and side-mounted blinkers to the e-scooter, as well as incorporating lights on helmets to increase rider visibility. Some participants reported already employing these methods in their daily commutes, indicating both perceived effectiveness and feasibility.
  Beyond static lighting solutions, participants expressed interest in more responsive visibility systems. One idea involved adaptive lighting that could dynamically adjust brightness, flash rate, or colour based on environmental conditions or the proximity of other road users. Such systems were seen as more noticeable than conventional constant-beam lights and better suited for drawing attention in complex or crowded environments.
  The need for customizable brightness levels was also highlighted. One participant described manually modifying the brightness of their strobe light in response to feedback from others: *"I've been using a strobe light and had complaints it's too bright. You either put it low enough they can't see it properly, or leave it too bright. What I do now is, put the hand in on running path."* This anecdote illustrates the lack of fine-grained control in current lighting systems and the trade-off users face between visibility and social acceptability. The insights suggest an opportunity for intelligent lighting features that balance user control, environmental sensitivity, and social context to improve safety and communication in shared spaces.
- **Improved notifications:** Given the difficulty pedestrians face in detecting the presence of e-scooters in the absence of engine noise, participants emphasised the need for more distinctive and effective sound alerts. Several participants suggested that the traditional bell, taken from bicycle design, is insufficient and lacks both functional impact and aesthetic appeal. One participant proposed designing a unique, branded sound for e-scooters, stating: *"Can we add a cool noise to e-scooters? For example, cars now make a sexy noise. Ferrari noise—now they're making an amazing sound. BMW and Teslas have their special music—new symphony. I think instead of a 'ding'—it's a bit old school."*
  These responses reflect a desire for audio signals that are not only functional but also modern, identifiable, and appealing—comparable to the intentional audio branding used in electric vehicles. The suggestion points to a broader opportunity for sonic design in micromobility systems that enhances recognition and fosters a distinct identity for e-scooters in traffic environments.
  Beyond rethinking the standard bell, participants shared experiences with other forms of auditory signalling. Some experimented with louder honks to capture attention in crowded or distracted pedestrian zones. However, they acknowledged that these sounds, while effective, can also startle pedestrians. As one participant noted, *"I tried a honk too. A little bigger honk. It scares people even more."* Others adopted more ambient strategies, such as playing music aloud through portable speakers. One rider shared, *"I wear a little Bluetooth speaker on my shoulder, playing music while I am riding. People hear it from miles away. They turn their head, see me, and move from the way."*

These improvised solutions highlight the limitations of current e-scooter alert systems and the lengths to which riders go to ensure their presence is acknowledged in shared spaces. They also underscore the need for context-sensitive, non-intrusive, and socially acceptable audio signalling options that strike a balance between noticeability and comfort for nearby road users. From a design perspective, these findings suggest that multifunctional, user-configurable alert systems—capable of adapting to the environment and user preference—may be critical in addressing the communication gap between e-scooter riders and others in public spaces.

- **Adaptive infrastructure:** Participants emphasised the need for dedicated infrastructure for e-scooter riders, specifically the development of separate lanes to reduce conflict with other road users. They noted that current shared environments often force e-scooters to navigate among pedestrians, cyclists, and motor vehicles—each with different speeds, behaviours, and levels of awareness. This mismatch in travel modes was seen as a major source of safety concerns.

  The proposed solution of building dedicated e-scooter lanes was seen as a way to reduce exposure to unpredictable obstacles and mitigate the need for constant speed adjustment or evasive manoeuvres. Participants believed that purpose-built infrastructure could support more predictable movement patterns, improve rider confidence, and reduce friction with other road users. These findings reinforce the importance of urban planning and infrastructure adaptability as key components of micromobility integration, complementing vehicle-level design solutions.
- **Enforcing responsible behaviour:** To promote safer riding practices, participants proposed a range of rule enforcement and awareness strategies. A common recommendation was the stricter enforcement of fines for rule violations, such as riding on footpaths or neglecting helmet use as a deterrent to unsafe behaviour.

  Participants also suggested implementing technological restrictions that prevent a ride from starting unless key safety requirements are met. For example, they proposed systems that verify helmet use before activation, detect if the ride involves tandem (double) riding, and assess whether the rider may be under the influence. These measures reflect a recognition that platform-based interventions can complement formal regulation by embedding safety incentives directly into the user experience and creating checkpoints that promote accountability at the moment of use.

  In addition to the regulations, participants highlighted the importance of public education and social norms in shaping responsible behaviour. They suggested interventions including clear signage in shared spaces and targeted social media campaigns to raise awareness about proper e-scooter use. These insights underscore the importance of combining policy-level enforcement with proactive communication strategies.

3.3 Step II - Participatory Design Workshop

To ensure the participatory design workshop addresses a solution with both practical relevance and disciplinary alignment, we grounded our topic selection in the themes identified during the earlier focus group discussion. Participants highlighted three key factors influencing e-scooter safety: device-level features, policy frameworks, and road infrastructure—mirroring the categorisation proposed by Mehranfar and Jones [32]. While policy and infrastructure improvements are essential, they typically require long term systemic changes and fall within the remit of urban planners and transport authorities. As HCI researchers, our expertise is better suited to intervening at the device level, where user-centred design can be rapidly prototyped, evaluated, and refined.

Among the device-level suggestions, automated alert systems emerged as a promising direction. Observational studies have shown that e-scooter riders employ a wide range of strategies to alert others in shared spaces, including ringing bells, verbal cues, hand gestures, or simply waiting without taking explicit action [26]. This variability suggests a lack of consistent signalling behaviour, which may reduce the effectiveness of manual methods in preventing conflicts with pedestrians and other road users.

Rather than assuming automation is inherently more reliable, we approached automated alerts as a complementary mechanism intended to support and enhance existing rider behaviours. Automated alerts may help mitigate inconsistencies by providing a baseline level of signaling in situations where manual alerts are unavailable, delayed, or socially awkward to initiate. We recognize, however, that automated systems come with their own challenges, including the risks of false positives (unnecessary alerts) and false negatives (missed detections), both of which can have safety implications and must be addressed through careful design and evaluation.

Given these considerations, we selected automated audio and visual alerts as the focus of our participatory design workshop. This allowed us to collaboratively explore how such systems could supplement rider actions, improve situational awareness for nearby pedestrians and cyclists, and ensure social acceptability in shared public spaces.

Building on this rationale, our proposed solution involves detecting the presence of nearby pedestrians or cyclists and automatically emitting a warning signal to increase awareness and reduce the likelihood of conflict. The primary objective of this study was to explore the design and perceived effectiveness of such automated alerts through a participatory approach, rather than to develop or evaluate the underlying detection technology. This section presents the second phase of our study—the participatory design workshop—where we collaborated with stakeholders to co-design and refine audio and visual alert prototypes tailored for shared mobility contexts.

3.3.1 Initial Alert Generation. Prior to the design workshop, the research team generated a set of alerts inspired by the focus group discussion and existing literature. According to previous research, audio alerts for vehicles should be noticeable, inoffensive, and minimise unnecessary environmental noise. For instance, Walton et al. [51] demonstrated that alert sounds comprising pure tones with frequency content in the $800Hz$ to $1kHz$ range, along with amplitude modulation or impulsive characteristics, achieved an optimal balance between detectability and annoyance. We extracted sounds used in their study, and additional sounds were designed to maintain similar acoustic properties.

In response to insights from the focus group, we developed a set of prototype sound alerts for further exploration in the participatory design workshop. Focus group participants expressed that they use verbal communication to alert others; accordingly, we created five spoken warning messages—two in a female voice and three in a male voice. To create verbal warnings (spoken messages), we utilised the Speakatoo AI voice generator[1]. Additionally, participants indicated a preference for bell sounds that differ from the conventional bicycle bell. Based on this, we synthesized five distinct bell sounds by processing audio samples from the Freesound database[2] using a custom Python script. A further theme that emerged was an interest in "cool" continuous sounds that could maintain presence without requiring active user input. To reflect this, we created five continuous sounds, also synthesized from Freesound audio samples. All sound alerts and corresponding Python scripts are available in our project repository[3]. These alerts served as the

[1] https://www.speakatoo.com/tts/start
[2] https://freesound.org/
[3] https://github.com/HiruniNuwanthika/User-Perception-Evaluation-Escooter-Alerts.git

foundation for the design workshop, where participants provided feedback for refinement and evaluated their effectiveness.

3.3.2 Participants. In line with the participatory design principles that emphasise the involvement of both direct and indirect stakeholders [9, 16], we recruited e-scooter riders, pedestrians, and cyclists to contribute to the design process. This inclusive approach enabled us to align the design of e-scooter alerts with the values, and concerns of these affected groups. Our goal was to identify alert designs that improve the visibility of e-scooters presence for pedestrians and cyclists while avoiding any embarrassment for riders.

The participant group included three e-scooter riders aged between 30 and 51 years (M = 33.7, SD = 9.6), three pedestrians aged between 27 and 36 years,(M= 30.3, SD = 4.9), and three cyclists aged between 28 and 43 years (M = 34.6, SD = 7.6). The recruitment was carried out through a flyer displayed on social media.

3.3.3 Procedure. The participatory design workshop was structured to enable participants to experience, evaluate, and provide feedback on a range of audio and visual alert prototypes. To simulate a realistic experience, alerts were demonstrated using a Bluetooth speaker and bike lights mounted on an e-scooter.

The session began with the moderator presenting five voice alerts that were played sequentially. After all five alerts were demonstrated, participants engaged in a group discussion and subsequently completed a feedback form capturing their individual reflections. This same structure was followed for the remaining alert types: five bell sounds, five continuous sounds, and two visual alerts (i.e.,a flashing light and a speed-based colour-changing light). Each set of alerts was played individually, followed by a discussion session and feedback form.

Discussions were facilitated by the lead researcher and guided by five key criteria: visibility, safety, communication, distraction, and acceptance. Participants were invited to share their impressions, raise concerns, and suggest improvements. The alerts were replayed on request during the discussion to support participant reflection and comparison across different options. All discussions were audio-recorded with participant consent for later analysis.

The goal of this session was to identify the most promising alert option from each category for inclusion in the next phase of our study- outdoor evaluation. To support this, participants were provided with an online voting form at the end of the workshop. The form included audio and video clips of each demonstrated alert, enabling participants to replay the designs before voting. For each alert category—voice, bell, continuous sound, and visual—participants were asked to select the one option they believed would be most effective in shared road scenarios. Figure 3 illustrates the structure and flow of the workshop activities.

3.4 Step II - Findings

To inform the next phase of our study, one alert from each category was selected for outdoor evaluation based on participant votes collected at the end of the workshop. While the voting results guided the selection process, this section presents findings from the feedback forms completed during the workshop, which offer deeper insight into participants' perceptions of each alert type.

3.4.1 Feedback Form Responses. The responses for feedback forms on alert types from design workshop participants revealed clear patterns in the acceptance and perceived effectiveness of the demonstrated alert designs. As seen in Figure 4, bell alert emerged as the most consistently accepted option ($mean = 4.6$, $std = 0.5$) . Participants found it less distracting while being highly communicative, improving safety, and providing strong visibility. In contrast, the continuous sound alert was the least accepted ($mean = 1.6$, $std = 0.7$). It was rated as highly distracting with lower

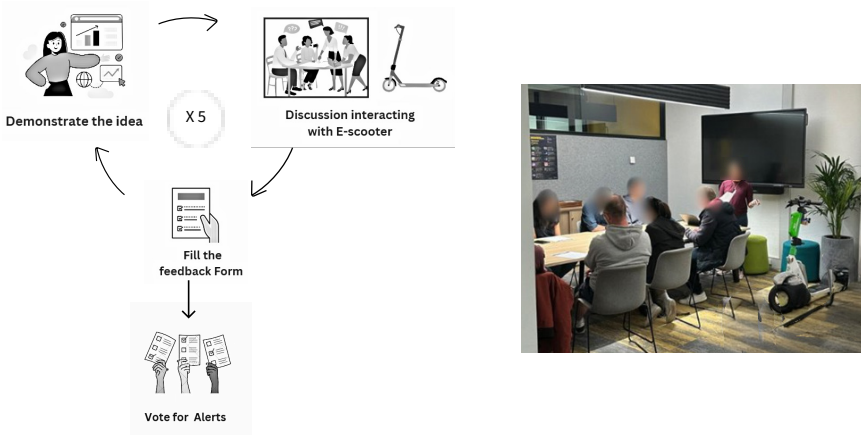


Fig. 3. Workflow for design workshop and participant engagement in the session

communication effectiveness, though participants acknowledged its moderate impact on safety and visibility. Voice commands were relatively well-received, balancing moderate distraction with high communication effectiveness ($mean = 3.7$, $std = 1.3$). Participants perceived them as offering notable safety improvements and rated their visibility as moderate. The flashing light alert generated mixed feedback; while participants appreciated its high visibility and potential to enhance safety, they noted moderate levels of distraction and communication ($mean = 4.0$, $std = 0.7$). Finally, the colour changing light received varied opinions, with scores for visibility spanning a broad range and differing perspectives on its distraction, communication, and overall acceptance ($mean = 1.8$, $std = 1.1$).

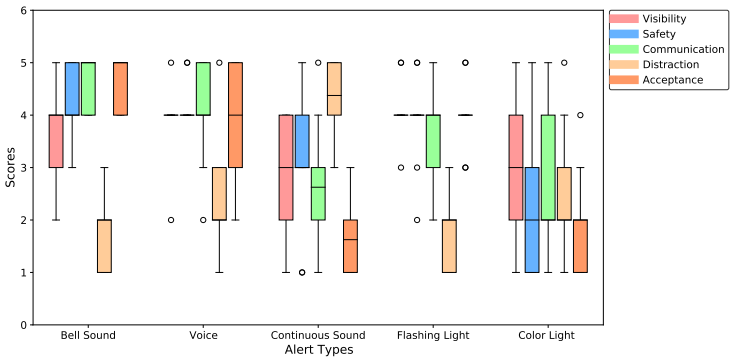


Fig. 4. Workshop Results - Visibility, Safety, Communication, Distraction, Acceptance ratings of alert types

3.4.2 Discussions. Beyond votes, discussions provided additional insights into the nuances of the alerts. One key debate centred around whether all e-scooters should automatically emit alerts. Pedestrians expressed concerns that widespread implementation of audio alerts could be annoying and startling. In contrast, e-scooter riders argued that some form of notification is better than nothing, stressing the importance of making their presence known in shared spaces.

Regarding voice alerts, participants debated on the message delivered and its accent, with one pedestrian stating, *"I personally like it to be in commanding nature. Otherwise I might not give much*

attention". They also suggested using a female voice, as higher frequencies are more likely to cut through noisy, crowded environments. Concerns about language barriers and the cognitive load required to comprehend voice alerts were also raised. For bell sounds, some preferred a sound distinct from the typical bicycle bell to help uniquely identify e-scooters, while others advocated for a familiar sound shared by both bikes and e-scooters for consistency. Participants showed interest in the option of a steady light that automatically converts to a flashing light when a pedestrian or cyclist is detected. However, they highlighted its limitations during daytime visibility. This led to the suggestion of combining audio and visual alerts. One participant proposed, *"What if we combine both- the light flashes when it detects people, with that we have the audio feature as well. When flashing light turns to stead light, no sound. Instead of having a continuous sound, only when it is flashing. It is universal and cater to diverse sensory perceptions."* These discussions emphasise the importance of designing alerts that improve visibility without causing annoyance.

3.5 Step III - Wizard of Oz Evaluation

The final step of the study aimed to evaluate the effectiveness of the selected audio and visual alerts in a real-world environment using a WoZ approach. This evaluation focused on how pedestrians and cyclists perceived different alert types in naturalistic road-sharing encounters with an e-scooter.

3.5.1 Participants. A total of 20 participants were recruited, consisting of 10 pedestrians (aged between 25 and 55 years; M = 34.1, SD = 9.2) and 10 cyclists (aged between 25 and 58 years; M = 35.5, SD = 11.5). Recruitment was conducted via social media and flyer displayed in community.

3.5.2 Study Design. To reduce complexity and limit external influences, each scenario involved one participant (pedestrian or cyclist) interacting with a single e-scooter rider. This aligns with prior studies, such as Liu et al. [29], which evaluated pedestrian-oriented forewarning systems using a similar one-on-one setup.

The study employed a within-subjects design in which each participant experienced five different alert conditions under two encounter directions: approaching and overtaking, resulting in 10 rounds per participant. The five alert conditions were: voice alert (Female voice: "Attention! e-scooter approaching"), bell alert (short synthesized chime), continuous sound (looped low-pitch motor sound), flashing light (white LED strobe), baseline setting (no alert).

The direction of encounters was counterbalanced across rounds to avoid directional bias. Specifically, participants with odd-numbered IDs began with an approaching scenario, while those with even-numbered IDs began with an overtaking scenario. This ensured an even distribution of encounter direction across the participant pool. The order of alert types, however, remained consistent for all participants to maintain procedural clarity and reduce cognitive load during repeated exposures.

3.5.3 Apparatus and Environment. The study took place on a straight, $0.9km$ long and $5m$ wide shared-use path located in a moderately trafficked area of an urban campus. The route is designated exclusively for pedestrian and cycling traffic, with no motor vehicle access, providing a safe and controlled environment for the evaluation. The path had consistent lighting and clear visibility during daytime hours (between 10:00 am and 4:00 pm). Road noise from nearby streets was moderate, and occasional background pedestrian activity introduced naturalistic elements without excessive distraction. No evaluations were conducted during low-light or nighttime conditions.

Alerts were delivered through a Bluetooth speaker and a light mounted on the e-scooter. Audio and visual stimuli were triggered remotely by a researcher (the "wizard") using a smartphone, creating the illusion that the alerts were automatically activated based on the e-scooter's proximity

to the participant. Participants wore Tobii Pro Glasses 3 eye-tracker[4] to record eye movements, while the e-scooter rider wore a chest-mounted GoPro camera to capture participants' behavioural interactions from the rider's perspective. The study setup is illustrated in Figure 5.

3.5.4 Procedure. Each session began with a short briefing to the participant. Then they were assisted in wearing eye-tracking glasses and calibration. It is followed by an acclimation period to ensure participant comfort. Next, verbal consent was obtained. Once participants were ready, they proceeded to walk or cycle along the predefined route while a researcher followed on the e-scooter, simulating real road-sharing conditions.

Participants experienced 10 encounters in total—five with the e-scooter approaching from the front and five from behind. Each encounter featured a different alert condition, with all participants experiencing the same fixed sequence of alerts. At the end of each round, participants completed a brief Likert-scale questionnaire evaluating the alert they experienced in terms of visibility, safety, communication, distraction, and overall acceptability. A short follow-up interview was also conducted after all rounds to gather more detailed qualitative feedback.

3.5.5 Data Collection and Analysis. Three types of data were collected during the evaluation phase: eye-tracking data, questionnaire responses, and video recordings. Each was analysed using an appropriate method to determine insights into participant attention, perception, and behavioural response to the e-scooter alerts.

Questionnaire Analysis: Participant feedback collected through 5-point Likert scale questionnaires after each encounter was analysed using statistical analysis methods. Descriptive statistics were computed to identify trends in perceived visibility, safety, communication, distraction, and overall acceptability across the different alert types. Where appropriate, inferential statistics were used to determine whether differences between alert types were statistically significant.

Gaze Data Analysis: As prior research has shown that gaze metrics can reveal participants' engagement [46], cognitive processing [33], and attentional focus [30, 33], we analysed three gaze-related indicators: fixation count, fixation duration, and gaze dispersion. Raw eye-tracking data were exported from Tobii Pro Lab and filtered to include only 'fixation' events. For each participant and encounter, we identified a 6-second time window (3 seconds before and after the moment of encounter), based on manual timestamp annotations from video footage. The extracted gaze data within these windows were used for quantitative comparison across alert types. All data processing scripts are available in our project repository[5].

Video Analysis: To complement the quantitative findings, we conducted a thematic analysis [5] of the video recordings to identify and interpret recurring behavioural patterns of participants exposed to e-scooter alerts. As demonstrated in previous studies, thematic analysis is well-suited for uncovering interaction dynamics in mobility-related contexts [26, 31]. Two researchers collaboratively reviewed video footage from four randomly selected participants (two pedestrians and two cyclists). Coding of each encounter focused on observable behaviours such as head turns, changes in navigational path, and communicative gestures in response to the alert. Glance behaviour was not coded due to the use of eye-tracking glasses, which limited the visibility of subtle gaze shifts in the video footage. The initial coding phase informed the development of a preliminary codebook, which served as a guide for analysing the remaining videos. The codebook was iteratively refined throughout the analysis process to incorporate new observations and emerging themes.

[4] https://www.tobii.com/products/eye-trackers/wearables/tobii-pro-glasses-3
[5] https://github.com/HiruniNuwanthika/User-Perception-Evaluation-Escooter-Alerts.git

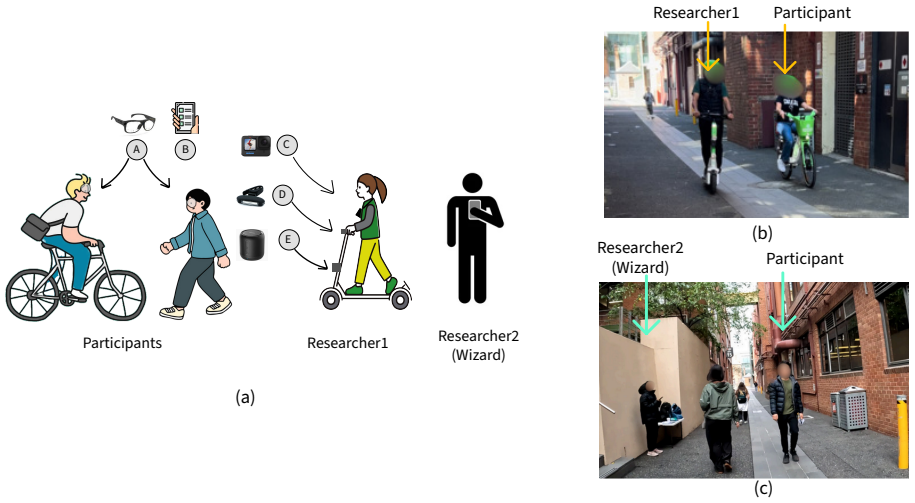


Fig. 5. (a) Participant equipped with (A) Tobii Pro 3 Glasses and accessed an (B) online questionnaire. The researcher wearing a (C) GoPro camera, rides en e-scooter equipped with a (D) flashing bike light and a (E) Bluetooth speaker.
(b) Overtaking scenario with the e-scooter rider and cyclist; the wizard is positioned outside the view.
(c) Approaching scenario with the pedestrian and e-scooter rider; the wizard is visible, while the e-scooter rider is outside the frame.

3.6 Step III -Findings

3.6.1 Questionnaire. To analyse the differences in visibility, safety, communication, distraction, and acceptance scores across different alert types, we performed Friedman test. In cases with significant difference, Dunn's post-hoc test with Bonferroni correction was performed to determine groups that differed significantly. Table 2 shows significance of alerts, indicating significant pairs with for tick (✓) and dash (–) otherwise. (Statistical significance was considered at $p < 0.05$).

Table 2. Significance comparison of alert types versus baseline for pedestrians and cyclists

Alert Types	Visibility		Safety		Communication		Distract		Acceptance	
	Pedestrian	Cyclist	Pedestrian	Cyclist	Pedestrian	Cyclist	Pedestrian	Cyclist	Pedestrian	Cyclist
Baseline-Voice	✓	✓	✓	✓	✓	✓	–	✓	✓	✓
Baseline-Bell	✓	✓	✓	✓	✓	✓	–	✓	✓	✓
Baseline-Light	–	–	–	–	–	–	–	–	–	–
Baseline-Continuous	–	–	–	–	–	–	–	–	–	–

The results indicate that the light alert and continuous sound alert did not exhibit significant differences from the baseline setting across any measured aspect. In contrast, the voice alert and bell alert showed notable impacts on visibility, safety, communication, and acceptance for both pedestrians and cyclists. While pedestrians did not report a significant increase in distraction when exposed to either the voice or bell alert compared to the baseline, cyclists found both alerts to be more distracting. Overall, the findings suggest that incorporating voice or bell alerts can meaningfully enhance perception and user experience, whereas adding light or continuous sound alerts does not significantly alter the experience relative to the baseline.

Further, we calculated the Chi-square statistics to explore if there is a significant difference between the scores given by pedestrians and cyclists for these different alerts (p-values are shown in Table 3). Pedestrians and cyclists perceive the distractibility of the bell alert and voice alerts differently. Pedestrians rated those alert as less distracting than cyclists. However, cyclists rated the flashing light and voice alerts as safer than pedestrians. Figure 6 shows the score distribution.

Table 3. P-values for Chi-square test on pedestrian and cyclist scores

	Visibility	Safety	Communication	Distract	Acceptance
Baseline	0.22	0.05	0.35	0.06	0.28
Bell	0.78	0.33	0.12	**0.04**	0.53
Continuous	0.12	0.87	0.56	0.90	0.55
Flash Light	0.22	**0.04**	0.31	0.40	0.06
Voice	0.31	**0.01**	0.10	**0.02**	**0.04**

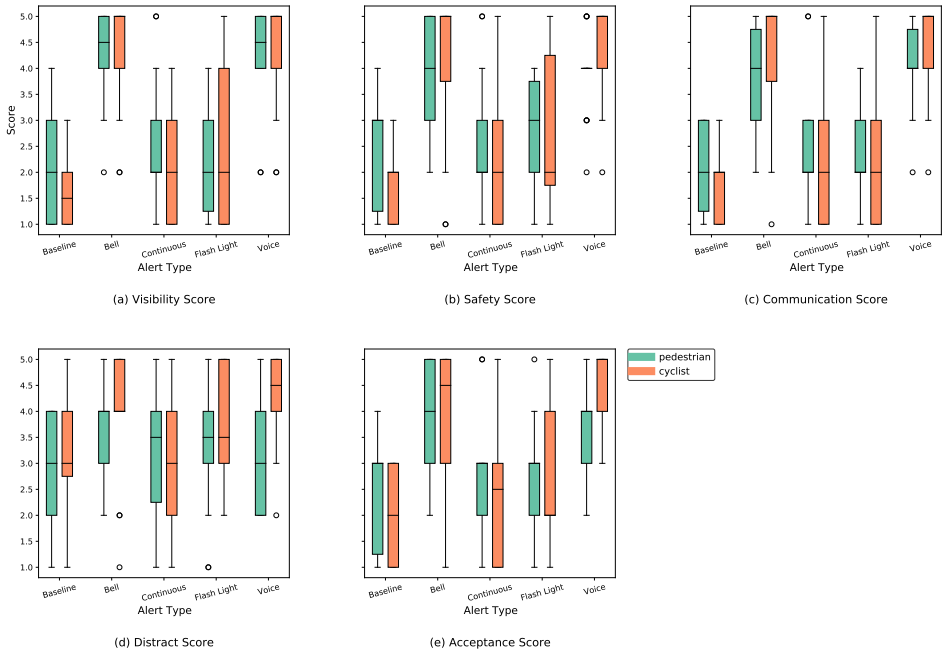


Fig. 6. Pedestrian and cyclist scores for each alert type

In our analysis, we examined the scores between the approach and overtake scenarios across alert types. Table 4 shows the pairs with significant differences when approaching and overtaking, calculated from Dunn's Test. Participants observed significant differences in the voice alert and bell alert compared to the baseline in both approaching and overtaking scenarios. However, the flashing light alert showed a significant difference from the baseline only in the approaching scenarios, with no significant effect observed in overtaking. No significant differences were found between the continuous sound alert and the baseline in either approaching or overtaking scenarios. Overall, voice and bell alerts show effectiveness in both interaction scenarios, while flashing light alert appear to be situationally effective.

Table 4. Significance comparison of alert types versus baseline for approach and overtake scenarios

Alert Types	Visibility		Safety		Communication		Distract		Acceptance	
	Approach	Overtake	Approach	Overtake	Approach	Overtake	Approach	Overtake	Approach	Overtake
Baseline-Voice	✓	✓	✓	✓	✓	✓	–	–	✓	✓
Baseline-Bell	✓	✓	✓	✓	✓	✓	–	–	✓	✓
Baseline-Light	✓	✓	✓	–	✓	–	–	–	✓	–
Baseline-Continuous	–	–	–	–	–	–	–	–	–	–

We then conducted Chi-square test to determine whether there were significant differences in scores between the approaching and overtaking scenarios (see Table 5 containing p-values). While no significant differences were observed between approaching and overtaking scenarios for the baseline setting, bell alert, continuous sound alert, or voice alert, a notable difference was identified for the flashing light alert. Specifically, the overtaking scenario elicited a higher frequency of negative responses across aspects such as visibility, safety, communication, and acceptance compared to the approaching scenario. The score distribution for each scenario is illustrated in Figure 7.

Table 5. P-values for Chi-square test on approach and overtake scores

	Visibility	Safety	Communication	Distract	Acceptance
Baseline	0.63	0.65	0.51	0.97	0.33
Bell	0.75	0.27	0.13	0.46	0.76
Continuous	0.61	0.24	0.75	0.67	0.55
Flash Light	**0.01**	**0.01**	**0.01**	0.50	**0.02**
Voice	0.29	0.77	0.06	0.53	0.33

3.6.2 Gaze Data. In this section, we discuss the results of gaze data, comparing significant differences across alert types as well as approaching and overtaking scenarios.

As fixation counts for pedestrians were normally distributed as determined by the Shapiro-Wilk test, we conducted a paired t-test. The results revealed a significant difference in fixation counts between the approach and overtake scenarios ($t - statistic = 2.59, p - value = 0.01$). In contrast, the fixation counts for cyclists were not normally distributed. Therefore, we employed the non-parametric Wilcoxon signed-rank test, which indicated no significant difference in fixation counts between the approach and overtake scenarios for cyclists ($statistic = 276.0, p - value = 0.11$). These findings are visualised in Figure 8 (a).

Figure 8 (b) illustrated the distribution of fixation counts across alert types. According to Friedman test results ($Statistic : 5.5, P - value : 0.23$), there is no significant difference in cyclists' fixation counts across the alert types. Similarly, results of the ANOVA test ($F-statistic : 0.07, P-value : 0.99$) show no statistically significant difference in pedestrians' fixation counts across the alert types.

Wilcoxon signed-rank test for cyclists fixation duration data ($statistic = 262.0, p - value = 0.07$) indicate no significant difference between approach and overtake scenarios. However, paired t-test for pedestrians' fixation duration data revealed a significant difference ($statistic = 2.44, p - value = 0.01$). The average fixation duration was higher when the e-scooter overtake pedestrians compared to when they see one approaching. These findings are visualised in Figure 9 (a). According to Friedman results there is no significant difference between the cyclists' or pedestrians' fixation duration across alert types (see Figure 9 (b)).

According to Wilcoxon signed-rank test, the average gaze dispersion of pedestrians showed a significant difference between e-scooter approaching and overtaking scenarios ($statistic =$

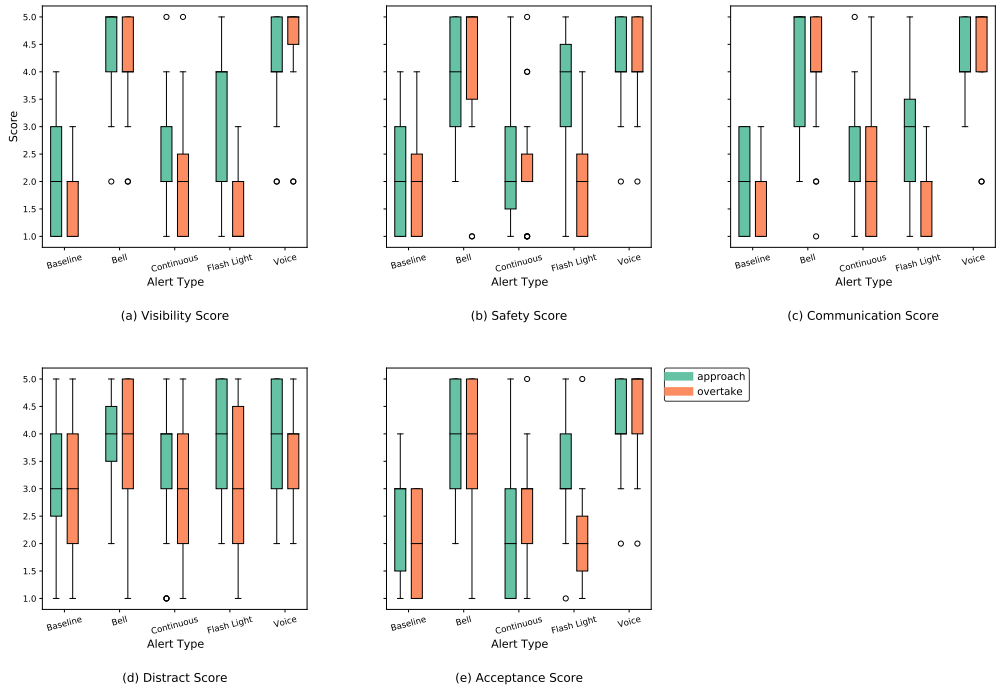


Fig. 7. Scores in approaching and overtaking scenarios for each alert type

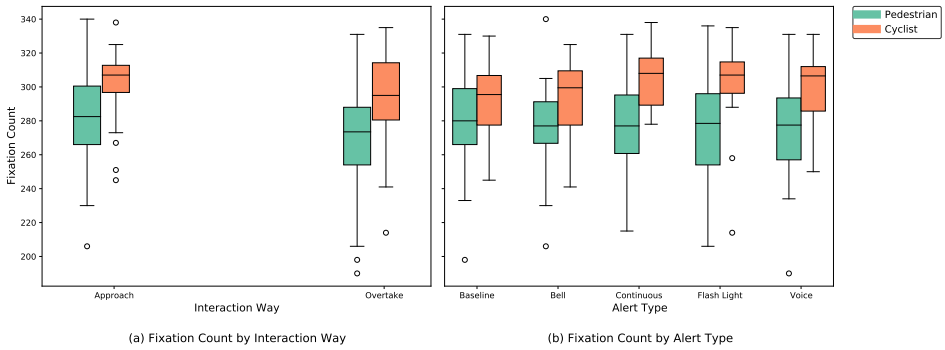
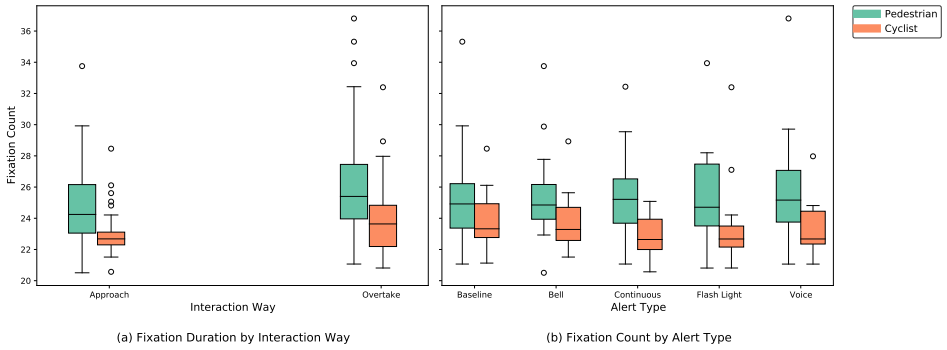


Fig. 8. Fixation Count Results.

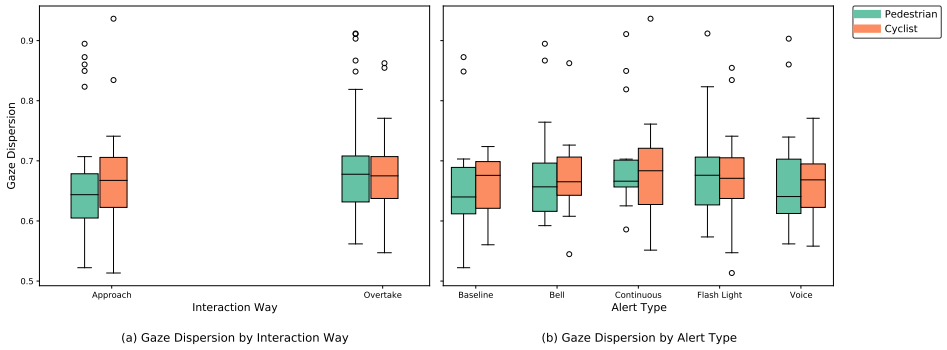
199.0, $p - value = 0.01$) with gaze dispersion being higher during the overtaking scenario. For cyclists, the results indicated no significant difference in gaze dispersion between the approaching and overtaking scenarios ($statistic = 328.0, p - value = 0.27$). These findings are presented in Figure 10 (a).

The Friedman test for cyclists and pedestrians ($p - value > 0.05$) showed no significant variation in gaze dispersion among the different alert types. The distribution of gaze dispersion values for both groups is shown in Figure 10 (b).



(a) Fixation Duration by Interaction Way (b) Fixation Count by Alert Type

Fig. 9. Fixation Duration Results.



(a) Gaze Dispersion by Interaction Way (b) Gaze Dispersion by Alert Type

Fig. 10. Gaze Dispersion Results.

3.6.3 Video Recordings. Clear avoidance responses were observed in overtaking scenarios involving cyclists when voice alert and bell alert were played. Those alerts prompted riders to create space for the e-scooter by moving thier cycle to a side or by adjusting their speed. For example, C5 adjusted her path following the voice alert and momentarily slowed her pace. Similarly, C8 responded to the bell alert by glancing over his shoulder, while veering gently to the left , allowing the e-scooter to pass. A particularly notable incident occurred with C3, who, after hearing the bell, turned her head to assess the e-scooter's position and then steered slightly to the left to give way, resulting in a near miss with the rider due to limited clearance. Figure 11 (a) shows the moment of C3's head turn and subsequent path change. In contrast, no discernible changes were visible when using continuous sound, flashing light, or in the baseline setting. Cyclists under these conditions continued riding without adjusting their speed or trajectory. In approaching encounters with cyclists, the alerts appeared to have less influence. Participants maintained forward motion and showed minimal behavioural shifts across all alert types.

Several pedestrians displayed reactive behaviours when overtaken by the e-scooter, particularly under the voice and bell alert conditions. One pedestrian, P6, turned his head quickly to the right in response to both voice alert and bell alert, then shifted closer to the edge of the path to clear space. In another example, P1 heard the voice alert and turned his head sharply looking at the e-scooter. He stepped aside while glancing behind, briefly pausing as the e-scooter passed. Figure 11 (b) highlights this moment of spatial negotiation. However, when overtaken in the control condition

or with the flashing light and continuous sound, pedestrians typically continued walking without turning their heads or altering their course.

In approaching situations involving pedestrians, overt behavioural responses were less common. Participants generally walked with their gaze forward and did not exhibit sudden movements or avoidance behaviours. However, more nuanced interactions were observed in visually busy environments, where distinguishing the e-scooter from background movement was more difficult. For example, P5, who was walking while looking at his phone, raised his head earlier when a continuous motor sound was played compared to when the flashing light was used. In the flashing light condition, he only looked up when the e-scooter was within a close distance, as shown in Figure 11 (c).



(a) (b) (c)

Fig. 11. (a) C3 turns her head left in response to the bell alert and shifts left to make space for the e-scooter. (b) P2 looks back after hearing the voice alert. (c) P5 looking at his phone, raises his head only when the e-scooter is very close during the flashing light alert.

Additionally, reactive behaviours were recorded among individuals outside the formal participant group. In several overtaking events, nearby pedestrians not enrolled in the study turned their heads to look at the e-scooter when a voice alert was played and moved aside accordingly.

4 Discussion

Our results on questionnaire responses showed that among audio alerts presented, voice and bell alerts were rated significantly higher in visibility, safety, communication, and acceptance compared to continuous sounds. This is consistent with our video observations, where both pedestrians and cyclists responded to bell and voice alerts during overtaking scenarios. These suggest that clear and familiar auditory cues are more effective in enhancing e-scooter detectability. These findings align with prior research on AVAS, which found that pedestrians respond more effectively to impulsive and recognisable sounds rather than abstract or continuous noise [52]. The high acceptability of bell alerts can be attributed to their familiarity in shared spaces, as bicycle bells are already an established communication method for road users. Similarly, voice alerts were also well received, likely because e-scooter riders manually use verbal cues to communicate their presence, as revealed in our focus group discussions. This is further supported by research on advanced driver assistance systems, which identifies voice alerts as one of the most effective forms of notification [42].

However, while low noise emissions are commonly cited as a reason why e-scooters are difficult to detect [50], our findings indicate that introducing continuous noise may not be a well-accepted

solution for improving awareness. Nonetheless, our observational data suggest that continuous sounds may still offer a subtle benefit in specific contexts. For instance, we noted that visually distracted pedestrians, such as those looking at their phones were more likely to reorient earlier when a continuous sound was present compared to a visual cue like a flashing light. While not as salient as bell or voice alerts, continuous sounds may serve as a passive awareness mechanism for users whose visual attention is otherwise occupied.

Although both pedestrians and cyclists preferred voice and bell alerts, cyclists found these alerts more distracting than pedestrians did. This suggests that users of different mobility modes may interpret and react to alerts differently. Cyclists, who rely heavily on environmental cues for navigation and situational awareness [45], may experience increased cognitive load and auditory interference, potentially impacting their ability to process surrounding traffic information efficiently. These findings resonate with studies on external human-machine interfaces (eHMIs), which note that faster-moving users like cyclists may have shorter windows for signal interpretation, making complex or layered alerts less effective [49]. This highlights the need to design e-scooter alerts that are cyclist-friendly, considering that cyclists are among the primary road users sharing space with e-scooters.

Our eye-tracking data revealed that average fixation duration was significantly higher when an e-scooter overtook pedestrians compared to when it approached them, suggesting that pedestrians paid more attention to overtaking e-scooters. This implies that perceived safety concerns may be greater in overtaking scenarios, where pedestrians feel more vulnerable to unexpected movements. These findings align with prior research showing that lower speeds are perceived as safer in overtaking scenarios, whereas slightly higher speeds are more acceptable in face-to-face interactions [6]. Additionally, the significantly higher gaze dispersion observed during overtaking scenarios further supports the notion that pedestrians allocate more attention in these interactions. This aligns with findings from a cycling study examining gaze behaviour under different road conditions, which showed that gaze dispersion increases in areas requiring more attention [53]. Unlike face-to-face encounters, where pedestrians can visually anticipate an oncoming e-scooter and adjust their path accordingly, overtaking interactions introduce greater uncertainty, particularly if the e-scooter rider does not provide an explicit warning. These findings highlights the need for more effective communication mechanisms during overtaking scenarios, ensuring that pedestrians are aware of an e-scooter's presence before it passes them.

However, these findings appear to contrast with Kazemzadeh [23], who reported that young adult e-scooter riders perceived face-to-face encounters as more unsafe than overtaking. This discrepancy highlights the importance of considering user perspective—that of the e-scooter rider versus the pedestrian or cyclist. As they explain, while cycling literature typically associates overtaking with greater discomfort due to the burden of navigation falling solely on the rider, their study showed that e-scooter riders, particularly younger users, felt more in control during overtaking scenarios, likely due to the agility of e-scooters. In contrast, face-to-face interactions required real-time negotiation with unpredictable pedestrians, reducing their sense of safety.

In our study, however, pedestrians and cyclists were the ones being overtaken, placing them in a reactive rather than proactive role. From this vantage point, both groups may experience startle effects or perceived vulnerability. Thus, while e-scooter riders may perceive overtaking as safer due to greater control, those being overtaken—regardless of their mobility mode—may interpret the same event as more risky or intrusive

Another explanation for the differing findings lies in the methodological approaches. Kazemzadeh [23] employed an online video-based survey, in which participants passively viewed pre-recorded e-scooter encounters and imagined their safety responses. While this approach enables consistent scenario presentation and broad participation, it lacks the embodied experience of being in the

moment. In contrast, our study captured real-world, in-situ interactions, where participants walked or cycled and directly encountered an e-scooter in motion. These live experiences likely evoked more authentic cognitive and emotional reactions. This methodological distinction may explain why overtaking was perceived as more threatening in our study.

Together, these findings illustrate how safety perceptions are deeply context-dependent, shaped by the interaction of user roles, encounter types, environmental conditions, and demographic factors. For instance, while e-scooter riders may feel more in control during overtaking due to their ability to manage speed and distance [23], pedestrians and cyclists in our study felt more vulnerable in these same scenarios. Moreover, factors such as path width, ambient noise, and visual clutter can amplify or mitigate these perceptions, highlighting the importance of environmental context. Future research should explore these nuances across different spatial, demographic, and infrastructural settings to ensure interventions are both effective and equitable.

This study offers several key contributions that address gaps in prior literature. First, while most previous research has relied on survey-based methods—often incorporating video clips of hypothetical scenarios, our study provides in-situ, embodied insights by examining real-world interactions between e-scooters and other road users. Second, rather than focusing solely on the perceptions of e-scooter riders, we centre the perspectives of pedestrians and cyclists, who are often the more vulnerable users in active mobility spaces. Third, we combine subjective feedback, video recordings, and eye-tracking data, enabling a richer understanding of how attentional processes correspond to perceived safety across different alert types and encounter directions. Finally, we evaluate multiple dimensions of alert design, including visibility, safety, communication, distraction, and acceptance, across distinct interaction types—offering practical design insights grounded in real user experiences. These contributions extend current knowledge by providing a multi-modal, multi-perspective, and context-sensitive understanding of how to design effective e-scooter safety alerts.

5 Implications for Design

Building on our findings, we present three design recommendations to support the design and development of effective e-scooter alerts.

5.1 Allow riders to manually control alerts instead of full automation

Our findings suggest that riders should have the ability to manually control the emission of alerts rather than relying on a fully automated system. Participants expressed concerns that automatic alerts may not always be contextually appropriate, potentially causing unnecessary distractions, in environments where alerts are not needed or could be perceived as intrusive. Providing riders with control over when and where alerts are activated allows for more situationally appropriate use, ensuring that alerts are only emitted when necessary to enhance communication. This approach is consistent with existing vehicle safety mechanisms, such as context-aware automatic braking systems in motor vehicles, which activate when needed but also allow drivers to override or disable the feature when appropriate. Similarly, an adaptive e-scooter alert system should offer manual override options, enabling riders to customize alert usage based on real-time conditions.

5.2 Adaptive continuous sound alerts with further research

Our findings indicate that participants did not prefer a continuous sound alert, possibly due to the lack of an optimal sound design. This raises the question of whether a universally recognised e-scooter sound—similar to the distinctive audio branding used by Ferrari, as mentioned in our focus group discussions—could improve acceptance and effectiveness. However, identifying such a sound requires further research to determine what acoustic characteristics make a sound both

distinctive and acceptable in shared spaces. A well-designed continuous sound must strike a balance between being noticeable without being overly disruptive, be easily identifiable as an e-scooter alert, and be distinct enough to avoid blending into background noise. Additionally, one key limitation of a fixed-volume continuous sound is that it fails to adapt to dynamic urban environments. In noisy settings, a low-volume alert may go unheard, while in quieter areas, a loud, persistent sound may become intrusive. To address this, future continuous e-scooter alerts should incorporate context-aware sound modulation, allowing the volume to adjust based on ambient noise levels. Another essential feature is speed-based sound adaptation. Adjusting the frequency or amplitude of the continuous sound wave according to speed could provide pedestrians and cyclists with an intuitive cue about an e-scooter's speed, improving their situational awareness and response time.

5.3 Design concise and clear voice commands

Our research highlights that voice commands should be concise and clear to maximize their effectiveness. Longer messages may introduce confusion or delay comprehension, making them less suitable for fast-moving environments. Simple, direct phrases that quickly convey the e-scooter's presence, intent, or direction are more easily understood by pedestrians and cyclists. Cyclists emphasised the importance of knowing which side an e-scooter will pass on during overtaking manoeuvrers. Adding a directional cue (e.g., "Passing on your left") could reduce uncertainty, allowing cyclists to adjust their movements accordingly. Given the cognitive effort required to process voice commands, unlike a simple bell or tone, there is a need for well-designed, easily recognizable voice alerts that are short and action-oriented and delivered in clear tone.

6 Limitations and Future Work

This study provides valuable insights into e-scooter alert design and perception in active mobility shared spaces. However, several limitations must be acknowledged to inform future research and practical implementation.

First, our use of WoZ methodology, where a researcher manually triggered alerts during encounters, enabled consistent testing across alert types. However, it may not fully replicate how an actual automated system would behave in real-time contexts. Differences in timing, responsiveness, and situational appropriateness could affect how alerts are perceived. Future research should validate these findings using sensor-driven, real-time alert systems to assess their effectiveness in naturalistic conditions.

Importantly, we do not assume automation is inherently superior. Instead, our approach treats automated alerts as a complementary mechanism designed to support, rather than replace, manual signalling behaviours. This is especially relevant given that prior observational work highlights inconsistency in how riders currently signal their presence. While automation can help provide a baseline layer of signalling, it also introduces new design challenges, including false positives (triggering alerts unnecessarily) and false negatives (failing to alert when needed). Both outcomes can undermine safety and user trust. Future research must investigate the accuracy, timing, and social appropriateness of automated alerts under diverse conditions to ensure they genuinely enhance, not disrupt, interactions in shared spaces.

Second, although the study was conducted outdoors and involved live interactions, it was carried out in a semi-controlled environment, limiting exposure to the full range of real-world complexity. Participants followed a defined route and were aware they would encounter an e-scooter, which may have influenced their attentiveness and behaviour. The path was relatively quiet, with low interference, and stable environmental conditions. These factors differ from typical urban settings where unpredictability—such as sudden pedestrian movement, crowding, or competing noise—can significantly influence how alerts are noticed and interpreted. To improve ecological validity,

future work should examine alert effectiveness in naturalistic, high-variability settings, including congested footpaths, shared intersections, and during varied weather or lighting conditions.

Third, participants experienced each alert type only once per encounter. While this allowed for within-subject comparisons, it may have introduced a novelty bias, where first impressions disproportionately influenced feedback. In practice, users may adapt to or become desensitized to repeated alerts. Therefore, future work should examine longitudinal effects, including user learning, habituation, and trust over time. This is particularly relevant for automated systems, which may be perceived differently after repeated use.

Fourth, while the alert conditions were selected based on a prior design workshop, the study tested only one representative alert from each category. This limited variety constrains our understanding of how design nuances might influence user responses. Future studies should expand the range of alert designs and examine how they perform under varying environmental conditions, including high-noise or low-visibility contexts. Such testing will be essential to identify optimal combinations of salience, clarity, and social acceptability for diverse user groups.

Fifth, our participant sample was relatively small and comprised of pedestrians and cyclists within a specific urban context. Although the study was designed to elicit diverse perspectives, the findings may not generalize to all populations or contexts. Larger-scale studies, involving demographically diverse groups across multiple infrastructure types would provide a stronger basis for generalizability.

Further, the order of alert presentation was not counterbalanced, which may have introduced ordering effects or bias. Participants could have been influenced by the sequence in which alerts were experienced. Future studies should employ counterbalancing techniques, such as Latin Square designs, to ensure equal distribution of conditions and minimize confounding effects.

Finally, participants were aware of being observed through eye-tracking glasses and video recordings. While these tools allowed for rich analysis of gaze and behaviour, they may have also influenced participants' natural responses. Future work could explore less obtrusive data collection methods, such as passive sensing or wearable logging, to capture more authentic behavioural patterns.

7 Conclusion

In this work, we explored the challenges of space-sharing for e-scooter riders through a focus group discussion, which identified key issues such as distracted pedestrians using phones or headphones, unpredictable movements, and difficulties in being visible to other road users. Among the suggested solutions, we chose to focus on device-based feature integration, specifically on automated audio and visual alerts to enhance e-scooter detectability. We approached automated alerts as a complementary mechanism, intended to support and enhance existing rider behaviours. Automated alerts may help mitigate inconsistencies by providing a baseline level of signalling in situations where manual alerts are unavailable, delayed, or socially awkward to initiate. We designed and refined three types of audio alerts and two types of visual alerts in a participatory design workshop involving e-scooter riders, pedestrians, and cyclists. The final evaluation was conducted in a real-world outdoor setting using a WoZ approach, enabling participants to engage directly with e-scooters emitting different alert types under natural conditions. By combining real time encounters with self reported feedback, video analysis, and eye-tracking, the study captured behavioural and perceptual responses. This multi-modal, in-situ method allowed for a nuanced understanding of how pedestrians and cyclists experience and interpret various alert designs in real world scenarios, offering insights that are often missed in controlled lab or survey-based studies. Findings from self-reported ratings indicate that voice and bell alerts received statistically significantly higher ratings compared to continuous sound and flashing lights. These results were

further supported by video evidence, where participants visibly responded to bell and voice alerts through spatial adjustments, such as moving aside or turning their heads. Additionally, cyclists rated these alerts as more distracting than pedestrians, suggesting that mode-specific preferences and attentional demands should inform alert design. Eye-tracking data revealed that pedestrians focused more on overtaking e-scooters than approaching ones, indicating greater perceived vulnerability in those encounters. To support the development of effective and non-intrusive e-scooter alerts, we provide three design recommendations based on the insights from this study - allow riders to manually control alerts instead of full automation, develop adaptive continuous sound alerts with further research, design concise and clear voice commands.

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A Scenarios in Focus Group Discussion

Scenario 1: E-scooters often share narrow paths with pedestrians and cyclists. These shared spaces are typically limited in width, which can create challenges when an e-scooter needs to approach or overtake another road user. For instance, imagine a busy morning commute where a cyclist and/or pedestrian are using a narrow path, and an e-scooter rider approach from behind. The limited space makes it difficult for the e-scooter to overtake safely. Such situations are further complicated by the speed differences between 3 modes; walking, cycling and scooting. Another example is an e-scooter rider approaching a pedestrian and/or cyclist face-to-face in a narrowed path.

Scenario 2: One of the notable characteristics of e-scooters is their quiet operation. While this can be seen as an advantage in reducing noise pollution, it poses significant safety risks. Silent riding means that pedestrians and/or cyclists might not hear an e-scooter approaching, especially from behind. For example, the e-scooter rider not ringing the bell (thinking it will distract the pedestrian) before overtaking. Another example is when a pedestrian walking with headphones on might be completely unaware of an e-scooter coming up behind them, leading to sudden reactions or even collisions. This lack of auditory warning is particularly dangerous at intersections or busy crosswalks where multiple road users converge.

Scenario 3: E-scooters can sometimes make sudden or unpredictable movements, which can surprise other road users. For instance, an e-scooter rider might need to swerve suddenly to avoid an obstacle, or they might make an unexpected turn without signalling. As per the discussions we had with cyclists, they do have (hidden) ways of hand signalling, when stopping, turning, etc. Do e-scooter riders have such signals? Another example for these unpredicted movements is that e-scooter riders move from riding to walking and wise versa. These unpredicted actions in crowded can be a hazard for pedestrians and cyclists since they are not prepared for such movements.