Preliminary Comparative Analysis of E-Scooter and Pedestrian Speed Perception in a VR Environment*

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Abstract
This study explores the speed perception of electric scooters (e-scooters) compared to pedestrians in a virtual environment, based on the hypothesis that e-scooters are perceived as slower due to the absence of walking-related movements, such as arm swings. Participants compared a pedestrian moving at 1.3 m/s and an e-scooter traveling at 1.0–1.6 m/s. Results suggest that, despite individual differences, e-scooters tend to be perceived as slower. Future research will increase the number of participants and trials and simulate real-world scenarios to validate our assumption quantitatively.

Keywords
e-scooters, pedestrians, speed perception, virtual environment

1. Introduction

Personal Mobility Vehicles (PMVs) are small transportation devices designed for short-distance travel, and they are expected to contribute to easing traffic congestion, reducing CO2 emissions, and addressing the "last mile" problem. Among them, e-scooters have rapidly gained popularity as an efficient means of transportation in urban areas [1, 2, 3].

However, with the increasing prevalence of e-scooters, concerns about their safety have also risen [1, 4, 5]. For instance, in some cities in Europe and the United States, stricter regulations have been implemented due to concerns over traffic accidents and safety, with an increasing number of cases where e-scooters are prohibited from riding on sidewalks [1].

In contrast, in Japan, since July 1, 2023, e-scooters are allowed to travel on sidewalks because their maximum speed does not exceed 6 km/h [6]. However, during the period when sidewalk riding was prohibited, from 2020 to Jan. 2023, 76 accidents involving e-scooters were reported, 8 of which involved pedestrians [7]. As the number of e-scooters on sidewalks increases, there are concerns about a rise in accidents involving pedestrians, and indeed, an increase in such accidents has been reported overseas [8, 5].

The causes of accidents involving e-scooters include factors related to the scooters themselves, such as their small tires, which make them more susceptible to tipping over or colliding with obstacles like bumps and debris [5, 9]. The speed difference between e-scooters and pedestrians on sidewalks is also a factor. Since e-scooters travel faster than pedestrians, the risk of collisions increases, especially on narrow or crowded sidewalks [10, 11].

This study focuses on pedestrians' perception of e-scooter speeds and aims to test the hypothesis that pedestrians are prone to misjudging the speed of e-scooters. A virtual environment will be used to conduct an experiment evaluating speed perception errors. In this experiment, we will measure how pedestrians perceive the speed of other pedestrians and e-scooters around them and analyze the accuracy of their perception.

2. Related Research

In addition to the studies mentioned above, research on behavioral prediction tasks has also been conducted. A behavioral prediction task involves predicting the time it takes for a moving object to reappear, which temporarily disappears due to occlusion or other factors. Battaglini et al. conducted a study using images of bicycles and motorcycles, demonstrating that when the moving speed is low, the symbolic meaning of the objects (for example, a motorcycle being perceived as faster than a bicycle) significantly influences the prediction of the object's movement [12].

Furthermore, numerous studies have investigated personal mobility vehicles (PMVs) and e-scooters. Paudel et al. explored collisions between e-scooters and pedestrians in a virtual environment, revealing that the risk of pedestrians sustaining head injuries sharply increases when the speed of the e-scooter is between 10 and 15 km/h [13]. Additionally, the research by Hishikawa et al. conducted a questionnaire survey on the appearance of PMVs and pedestrian risk perception, reporting that

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the appearance of a PMV influences how pedestrians perceive risk [14].

In contrast, this study focuses not on subjective risk perception but on speed perception. It aims to evaluate how the perception of speed changes when pedestrians and e-scooters approach within a virtual environment.

3. Experiment

The following experiment was conducted using a virtual environment to evaluate how participants perceive the speed of approaching e-scooters and pedestrians and whether there is a difference in perceived speed.

In the experiment, participants wore a head-mounted display (Meta Quest 3, 72Hz refresh rate, resolution 3616×1952 pixels, field of view: horizontal 110 degrees, vertical 96 degrees) and observed e-scooters and pedestrians approaching in the virtual environment, then evaluated their speed. Figure 1 1 shows the experimental setup in the virtual environment. Participants stood at a designated standing point in the virtual environment and were instructed to focus on a fixation point 8.5 meters ahead and 1.7 meters above the ground throughout the experiment.

Participants observed two scenarios: a pedestrian approaching (left side in Figure 2) and a person on an e-scooter approaching (right side in Figure 2). They were asked to report which of the two felt faster. To prevent speed judgment based on the time taken to appear and approach, the pedestrian and the e-scooter appeared randomly at distances of 5m, 6m, or 7m from the participant. They disappeared once they approached within less than 1 meter. The second stimulus was presented three seconds after the first. This constituted one trial. The walking speed for the pedestrian was set at the average walking speed of an adult male, 1.3 m/s [15], while the speed of the e-scooter was set at 1.1, 1.2, 1.3, 1.4, and 1.5 m/s. The presentation order of the pedestrian and scooter, as well as the speeds, were counterbalanced. The experiment was conducted under two conditions: the approaching object came from the front (0 degrees) or 30 degrees outside the participant's field of view.

The virtual environment was created using Unity (2023.2.20f1). For the male model, [16] was used, and for the e-scooter model, [17] was utilized. Additionally, to simulate the natural movements of a person riding an e-scooter, the pitch and yaw angles of the head were randomly varied.

The experiment followed this process: First, the participants were explained the experiment, and verbal consent to participate was obtained. Then, the participants put on the HMD, and the experiment began. For each angle condition, five trials were conducted for each of the five-speed conditions of the e-scooter, totaling 25 trials.

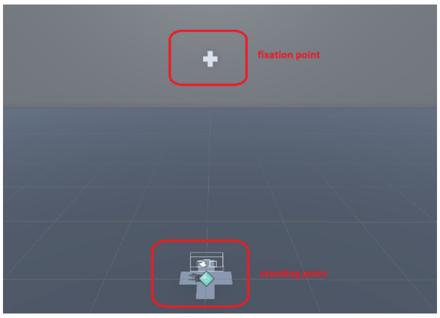

Figure 1: Experimental environment.

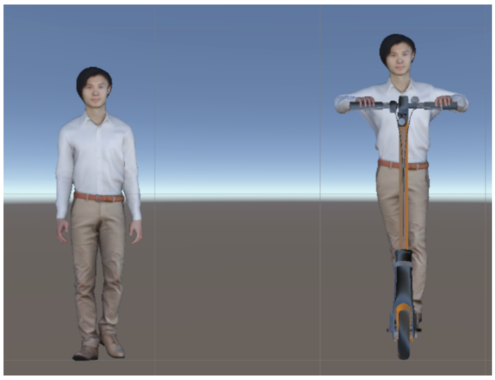

Figure 2: Pedestrian and E-scooter in VR environment.

Participants were allowed to take a break every five trials if they wished. The experiment included 9 participants (eight males and one female, with a mean age of 22.1 years and a standard deviation of 1.07 years), all of whom had normal vision.

4. Results

Figures 3 and 4 present the experiment results. Each figure shows the results for the approach angles of 0 and 30 degrees, respectively. The horizontal axis represents the speed of the e-scooter (1.1–1.5 m/s). In contrast, the vertical axis shows the average proportion (with standard deviation) of participants who judged that "the e-scooter is faster" compared to a pedestrian walking at 1.3 m/s. The curve indicates the logistic curve fitted to the data.

The results show that, for both the 0-degree and 30-degree conditions, the proportion of participants judging the e-scooter as faster increased as the scooter's speed increased. This suggests that participants were generally able to perceive the approaching speeds accurately. Specifically, focusing on the scooter speed of 1.3 m/s, the average proportion of responses indicating "the e-scooter

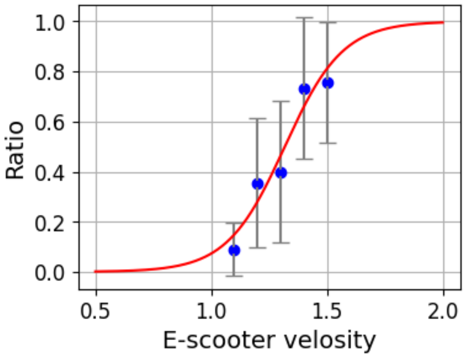

Figure 3: Averaged results (0 degrees).

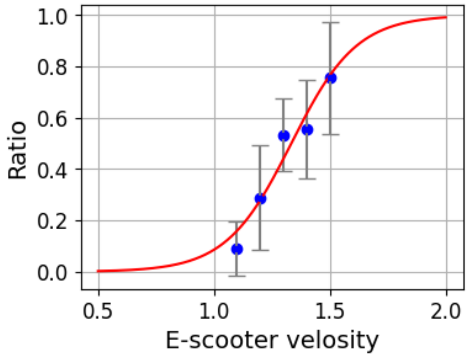

Figure 4: Averaged results (30 degrees).

is faster" was 0.4 under the 0-degree condition, whereas it was 0.533 under the 30-degree condition. This suggests that the e-scooter might be perceived as slower under the 0-degree condition.

Next, the point of subjective equality (PSE), where the choice ratio reaches 0.5, was calculated based on the logistic curve fitting. The PSE for the 0-degree condition was 1.317 m/s, and for the 30-degree condition, it was 1.334 m/s. Both values were slightly higher than 1.3 m/s. These results suggest that the e-scooter's speed tends to be perceived as slower, aligning with the initial hypothesis.

Next, based on the results shown in Figures 3 and 4, we found that none of the conditions yielded response ratios close to 0 or 1. This suggested that the speed range for the e-scooter might not have been sufficient for accurate logistic curve fitting. Therefore, the speed conditions were extended to cover a range of 1.0–1.5 m/s, with increments of 0.1 m/s, resulting in seven conditions. An additional experiment was conducted with eight participants, with five trials for each speed condition. Furthermore, due to the large standard deviations and variability in participant results, the data for each participant were summarized separately. Figures 5–8 present the results for two participants (1 and 2) out of the eight, whose results exhibited contrasting tendencies.

In the results for Participant 1 (Figures 5 and 6), when comparing the pedestrian moving at 1.3 m/s with the e-scooter, the proportion of responses indicating "the e-scooter is faster" was 0.4 in both trials. The points of subjective equality (PSE) were 1.326 m/s and 1.316 m/s, respectively, indicating that the e-scooter tended to be perceived as slower than the pedestrian.

Conversely, for Participant 2 (Figures 7 and 8), the proportion of responses indicating "the e-scooter is faster" was 0.6 in both trials. The PSE values were 1.275 m/s and 1.240 m/s, showing a tendency for Participant 2 to perceive the e-scooter as faster than the pedestrian.

Finally, Tables 1 and 2 present the PSE and the difference thresholds calculated based on the logistic curve fitting results for each condition. The results show that, although the magnitude of the differences varies, the PSEs are higher under the 0-degree conditions, whereas the difference thresholds are larger under the 30-degree conditions.

Table 1
Difference threshold (5 conditions)

	0 degrees	30 degrees
Difference threshold	0.137	0.155

Table 2
PSE and Difference thresholds (7 conditions)

	PSE		Diff. thresholds	
participant	0 deg.	30 deg.	0 deg.	30 deg.
1	1.326	1.316	0.052	0.073
2	1.275	1.240	0.055	0.129
3	1.231	1.226	0.128	0.167
4	1.343	1.475	0.100	0.113
5	1.361	1.315	0.111	0.093
6	1.450	1.354	0.070	0.049
7	1.400	1.584	0.145	0.336
8	1.364	1.230	0.136	0.236

5. Discussions

This study evaluated how participants perceive the approaching speeds of e-scooters and pedestrians in a virtual environment. When comparing a pedestrian walking at 1.3 m/s with an e-scooter, the proportion of responses indicating that "the e-scooter is faster" was below 0.5 in most cases. Similarly, the points of subjective equality (PSE) were above 1.3 m/s for most participants. These results suggest that, despite individual differences, e-scooters tend to be perceived as slower than they are.

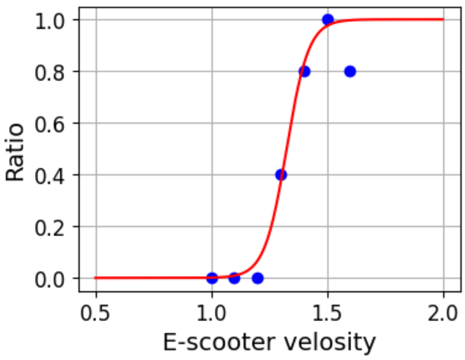

Figure 5: Participant 1 results (0 degrees).

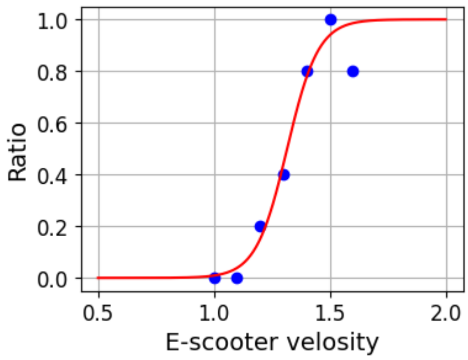

Figure 6: Participant 1 results (30 degrees).

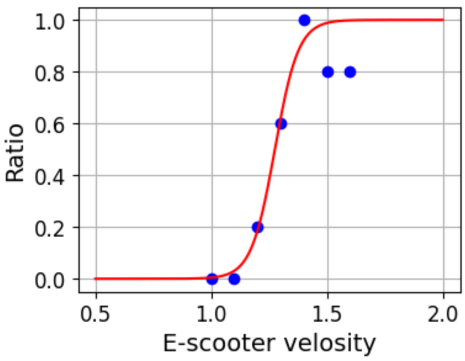

Figure 7: Participant 2 results (0 degrees).

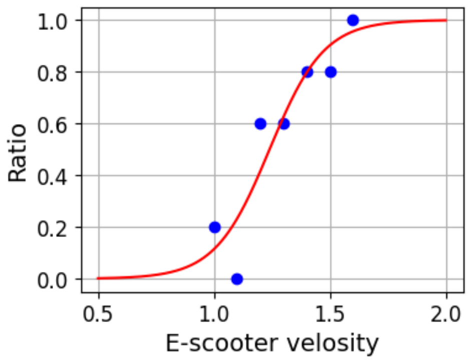

Figure 8: Participant 2 results (30 degrees).

One possible reason for this perceptual difference is the absence of large bodily movements, such as arm swings or leg motions, typically accompanying walking. Although statistical testing has not yet been conducted, the additional experimental results showed higher PSE values under the 0-degree condition (six out of eight participants). This suggests that central vision (0 degrees), which is more sensitive to fine movements, may be more influenced by the absence of arm swings and other walking-related motions. In contrast, Hassan et al., although not investigating approaching objects, conducted experiments on speed perception of moving light points and reported that speeds tend to be perceived as slower in peripheral vision [18]. These findings indicate that multiple factors may interact to influence speed perception, and future experiments will aim to investigate these effects further.

Regarding the relationship between approach angle and difference threshold, Tables 1 and 2 show that the difference threshold was larger under the 30-degree condition than the 0-degree condition. This may be because, under the 30-degree condition, participants relied on peripheral vision, which likely resulted in lower speed perception accuracy than in the 0-degree condition.

6. Conclusions

This study conducted a speed perception experiment in a virtual environment based on the hypothesis that e-scooters are perceived as slower than pedestrians due to the absence of bodily movements associated with walking, such as arm swings and leg motions. In the experiment, participants observed a pedestrian approaching at 1.3 m/s and an e-scooter approaching at speeds ranging from 1.0 to 1.6 m/s, and they were asked to report which felt faster. Although the results showed large individual differences, they suggest that e-scooters tend to be perceived as slower.

We plan to expand the experiment by increasing the number of participants and trials to assess the differences in speed perception further. Additionally, we aim to conduct experiments in more realistic scenarios to simulate real conditions better and validate these findings.

Acknowledgments

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