EVALUATION OF PEDESTRIANS' GAZE BEHAVIOR WHEN CROSSING THE ROAD USING EYE-TRACKING TECHNOLOGY: IMPLICATIONS FOR AUTONOMOUS VEHICLE LED COMMUNICATION INTERFACE

Symbat Zhanguzhinova*, Emese Mako

Department of Transport Infrastructure and Water Resources Engineering, Szechenyi Istvan University, Gyor, Hungary

*E-mail of corresponding author: symbat.zhanguzhinova@gmail.com

Symbat Zhanguzhinova 0000-0002-0013-9163, Emese Mako 0000-0003-2412-2806

Resume

Since autonomous vehicles (AV) are in the testing process, it is an open question of how pedestrians will communicate with self-driving cars. Nowadays, explicit communication pattern is the main way of pedestrian-driver interaction, however, AV may use implicit communication when making crossing decisions. This study aims to analyze pedestrians' gaze behavior when crossing the road using an eye camera and find the most applicable location for the LED interface on AVs. 10 pedestrian crossings in Gyor, Hungary were analyzed using the synchronized eye-tracking (ET) technology and regular video cameras for combined data processing. The data were analyzed using digital image processing techniques and statistical methods to identify where pedestrians looked and whether a pedestrian-driver interaction was captured during the crossing maneuver.

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1 Introduction

One of the biggest obstacles to global health and development is still traffic-related deaths and injuries. Approximately 310,000 pedestrian deaths occurred on roads globally in 2018, making up 23% of all fatalities from traffic incidents [1]. Researchers have worked to better understand pedestrian behavior and decision-making processes to prevent pedestrians from injury. For instance, Gruden [2] used video footage and a micro-simulation model to assess pedestrian movement in a limited location in recent research. This made it possible to evaluate how well the simulation tool estimated pedestrian safety by comparing real-world pedestrian behavior with a simulated setting. In a virtual reality study by Soares et al. [3], pedestrians made crossing decisions based on visual cues (vehicle speed and distance) rather than auditory cues (engine noise or silence). This suggests that communication strategies for automated vehicles should prioritize visual signals for pedestrian safety.

More vehicles on the road without a driver are predicted throughout the next ten years. Mixed traffic will be composed of both human-driven and AVs [4]. As these vehicles become an integral part of our daily lives, it is evident that they will have to interact with humans in various dynamic scenarios. One crucial aspect that demands immediate attention is the need for clear communication patterns between AVs and pedestrians.

Conventional vehicles rely on non-verbal cues, such as hand signals, eye contact, and body language, to communicate intentions, ensuring a smooth flow of traffic. However, with AVs lacking human characteristics, one must find alternative ways to convey their intentions to pedestrians, cyclists, and other road users [5]. In recent times, there has been a surge in testing different external human-machine interfaces (eHMI) worldwide, aiming to enhance the interaction efficiency between AVs and road users. These eHMI designs enable fully AVs to signal their intention to yield to pedestrians. By minimizing uncertainty about AVs' intentions and fostering pedestrians' initial trust and understanding, these interfaces play a crucial role in facilitating effective communication with pedestrians [6-7]. For instance, a pedestrian who is staring out the front window all the time could be trying to get a driver's attention. More significantly, fixation patterns in various car parts can influence how AVs are designed. Researchers suggested equipping eHMIs with the ability to display AVs' purpose to boost interaction efficiency in the absence of human drivers in AVs. In the context of AVs and eHMI, LEDs are often used as a means of communication between the vehicle and pedestrians or other road users. They can be used to display signals or messages, indicating the vehicle's intentions, such as stopping, yielding, or indicating a turn. To determine the most effective LED interface and its optimal location for facilitating communication between the pedestrians and AVs, an ET experiment was conducted with pedestrians. The objective was to identify the LED interface that would enhance pedestrians' perception and comprehension of AV intentions. Additionally, the study advances the understanding of gender-specific gaze behavior by investigating whether there is a significant difference between males and females in their visual attention during the act of crossing a zebra crosswalk. This exploration adds a valuable dimension to the research, offering insights into potential variations in how different genders interact with the LED interfaces in vehicular environments.

1.1 Eye-tracking technology

With the ability to precisely analyze a subject's perception and behavior during the task execution, the ET technology is an invaluable tool for user testing. The ET is extensively utilized for various assessments in both real-world and virtual environments. It has shown particular value in studying human behavior in the contexts of aviation and motorized transportation [8].

By monitoring eye movements, it becomes feasible to obtain measurable data regarding the distribution of gaze, enabling insights into human perception and cognition [9]. The camera, integrated into lightweight glasses, allows for precise and unobtrusive recording of participants' eye movements as they encountered different AVs. This technology facilitates the collection of accurate and valuable data on pedestrians' visual attention patterns and aided in understanding the effectiveness of communication between the AVs and pedestrians.

Researchers often study eye movements in different fields in terms of fixations (pauses over interesting portions of information) and saccades (fast movements between fixations). Fixation or gaze durations, saccadic velocities, saccadic amplitudes, and numerous transition-based characteristics between fixations and/or regions of interest are examples of common analytical metrics [10]. This can provide information on what pedestrians find attractive and what cues they need to decide whether to cross the street. In a naturalistic study by Zhao et al. (2023) [11], the ET showed that pedestrians fixated more frequently on nearby lanes and approaching vehicles when making crossing decisions. Notably, pedestrians focused on different vehicle components depending on distance. These findings can inform pedestrian behaviour models and guide the design of pedestrian-friendly information displays on autonomous vehicles. When analyzing the eye tracking data to understand attention, two significant factors come into play. Firstly, the number of times attention is focused on specific locations within a particular area of the visual field is crucial. This reflects the frequency of fixations on specific points, indicating the intensity of the search strategy employed by the individual. Secondly, the dwell time, which represents the total duration of these fixations, plays a vital role. Longer dwell times indicate a higher level of attention directed towards a specific location, highlighting its significance in the visual field. By considering both the number of fixations and the dwell time, valuable insights into how individuals perceive and process visual information, aiding in the comprehension of human perception and cognition can be gained [12]. The study of Lévêque et al. [13] examined how both internal (e.g. age) and external (e.g. road environment) factors influence pedestrians' visual attention during the crossings and highlights the need for further research in this area, particularly regarding the impact of autonomous vehicles on pedestrian gaze patterns.

2 Methodology

2.1 Procedure

A diverse group of 278 pedestrians (172 males and 106 females) aged between 18 and 65 years were recruited for the study. Participants were selected randomly at various pedestrian crossings and road intersections in an urban area of Gyor city, Hungary.

The experiment conducted at zebra crosswalks focuses on pedestrian behavior, visibility, and safety aspects, as it involves direct interactions between the pedestrians and vehicles to accurately assess communication effectiveness. The zebra crossings also offer opportunities to study driver behavior concerning yielding to pedestrians.

The study used the Pupil Labs Core, shown in Figure 1, a wearable ET device with high-definition cameras, to detect visual, manual and cognitive distractions [14]. This head-mounted device contained binocular spectacles with two infrared cameras and a wide-angle Red-Green-Blue (RGB) panorama camera. It was chosen above competitors like the SMI ETG 2.6 and Tobii Pro spectacles 2 due to its greater accuracy [15].

To capture the crossing maneuvers from multiple

Figure 1 *Pupil Core headset [16]*

Figure 2 *One-point calibration gaze*

Figure 3 *Capturing pedestrian attention: ET glasses in use*

Figure 4 *Example of the zebra crossings*

angles, conventional video cameras were positioned on tripods on both sides of the road. This setup allowed for simultaneous recording of the pedestrian's actions and behavior of both road users: drivers and pedestrians.

Upon fitting the eye tracker to each participant, a one-point calibration was performed initially. The calibration process was then reviewed and repeated as needed to ensure precise measurements. Additionally, calibration checkpoints, shown in Figure 2, were incorporated throughout the walks, serving to verify the tracking accuracy after the completion of each walk.

Figure 4 depicts the pedestrian crossing employed

Figure 5 *Pedestrian gaze locations*

Figure 6 *Gaze overlay video showing the Pupil core eye tracker data superimposed on a marked crossing scenario, green circles represent fixations, while red lines indicate saccades*

in the experiment. This crossing utilizes white stripes painted on a slightly green pavement to ensure clear visibility for drivers approaching from both directions, thereby conferring upon pedestrians the right-of-way when crossing the two-way road.

In the experiment, participants were instructed to cross the zebra crossing while wearing the ET glasses to have a clear vision of the interaction between pedestrians and vehicles. Figure 3 shows the example of a pedestrian mounted with ET glasses. Crossing movements without any interaction were excluded from the analysis.

Figure 5 shows the focus on four specific directions of pedestrian gaze:

1) Not looking left/right
   Instances where pedestrians do not fixate on the left/right side (the direction from which vehicles were approaching) before crossing the zebra crossing were identified through the ET data analysis.
2) Road surface area between the approaching car and the zebra crossing
   When an approaching vehicle was in proximity.
3) Car hood
   When pedestrians' attention fixates on the car hood (the front part of a motor vehicle).
4) Windshield
   Potential visual communication between the pedestrian and the driver.

2.2 Input in excel

The data was organized within a Microsoft Excel spreadsheet using a table format. This table consisted of 10 rows, each representing a pedestrian crossing location of Gyor city. Additionally, the table included 4 columns to capture pedestrian gaze behavior. These columns categorized gaze direction based on the side of the road and the specific target of their gaze as mentioned above: Not looking left/right, Car hood, Road surface, and Windshield.

The videos were switched to black-and-white mode to enhance the visibility of eye calibration during the analysis.

Figure 6 presents a gaze overlay video analyzed using the pupil core eye tracker data. This video depicts a marked pedestrian crossing scenario. The green circles on the overlay visualize fixations, which represent moments where a participant's gaze remained focused on a specific area of interest. Conversely, the red lines indicate saccades, which are rapid eye movements transitioning between fixation points. By analyzing these fixations and saccades, it is possible to gain insights into the visual attention patterns of participants when interacting with the upcoming vehicle scenario.

2.3 Analyses

The video analysis encompassed ten locations within the Gyor city, where pedestrians' gaze behavior

***Table 1** Chi-Square Test*

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	6.907[a]	3	.075
Likelihood Ratio	7.059	3	.070
Linear-by-Linear Association	6.657	1	.010
No of Valid Cases	278		

***Table 2** Chi-Squared Test: area of interest and gender Crosstabulation*

			Gender		Total
			Male	Female	
Area of interest	Not looking left/right	Count	24	24	48
		Expected Count	29.7	18.3	48.0
		% within area of interest	50.0	50.0	100.0
		% within gender	14.0	22.6	17.3
		Adjusted Residual	-1.9	1.9	
	Car hood	Count	60	41	101
		Expected Count	62.5	38.5	101.0
		% within area of interest	59.4	40.6	100.0
		% within gender	34.9	38.7	36.3
		Adjusted Residual	-.6	.6	
	Road surface	Count	54	30	84
		Expected Count	52.0	32.0	84.0
		% within area of interest	64.3	35.7	100.0
		% within gender	31.4	28.3	30.2
		Adjusted Residual	.5	-.5	
	Windshield	Count	34	11	45
		Expected Count	27.8	17.2	45.0
		% within area of interest	75.6	24.4	100.0
		% within gender	19.8	10.4	16.2
		Adjusted Residual	2.1	-2.1	
Total		Count	172	106	278
		Expected Count	172.0	106.0	278.0
		% within area of interest	61.9	38.1	100.0
		% within gender	100.0	100.0	100.0

was studied using Python programming language. The primary objective was to estimate and compare the gaze behavior across these different locations. In addition to estimating the gaze behavior and comparing locations, the analysis identified the best location for the LED interface on an AVs in the future. This study determined the optimal interface of the LED interface to capture pedestrians' attention.

2.4 Association between the gender and gaze preferences

To determine whether there is a significant association between the gender (categorical) and the preference for looking, a chi-squared test was used. The chi-square test is a test of association between these two variables. The ratio of male to female respondents was the same whether they were looking at the hood, windshield, or the road surface, not looking, or looking elsewhere. In Table 1, the Pearson chi-square shows that the asymptotic significance result is 0.075 and, as it is less than 0.05, there is no association and there is evidence to suggest that there are significant differences between the gender and preferences for where people look.

Table 2 shows the total number of male and female responses. There were 61.9% of males and 38.1% of females.

As can be seen, overall, 17.3% of pedestrians did not look to the side, but in terms of gender 22.6% of females did not look to the side. As the adjusted residuals are almost equal to 1.96, it can be said that females are significantly less attentive when crossing the road. It turns out that it is the opposite for males that negative residuals say that 14% are significantly less than 17.3%.

Looking at the bonnet, there are no differences because the adjusted residuals are either below negative 1.96 or above 1.96, so there is no deviation, which means that 34.9% is not statistically different from 36.3%, the overall value, and 38.7% is not different from the overall value.

For the road surface it can also be seen that there is no deviation. Finally, the windshield results show that males had 19.8% of them looking at the windshield, while females had 10.4%, which is significantly less than the total of 16.2%. The adjusted residual is above than 1.96 and regarding females it gives - 2.1, which is below than negative 1.96.

3 Results

The experiment encompassed observations at ten locations within the Gyor city. Prior to the data collection, pedestrians were provided with instructions on proper zebra crossing techniques and the specific timing for their crossings. During the experiment, participants wore Pupil core eye tracking glasses, and an one-point calibration was conducted to ensure accurate interpretation and recording of the gaze data.

However, it is worth noting that the study encountered instances of the missing data. Participants were excluded from the analysis in such cases. The exclusion criteria were applied to scenarios where all the fixations were present during transitions between the video scenarios, and no fixations were present during the actual crossing scenarios themselves. Additionally, scenarios where participants did not encounter any vehicles and, as a result, did not face any traffic interactions were also discarded from the analysis. The exclusion of these scenarios was necessary to maintain data integrity and ensure that the analysis focused on relevant and informative gaze behavior during the zebra crossings in the presence of vehicles. The analyses were done on the data of the remaining 278 participants.

A heat map was used to visualize the distribution and intensity of pedestrian gaze patterns across the crossing area. This approach facilitated the communication of locations that received the most attention (higher number) and those that received less visual focus (lower number) from pedestrians during their crossing. Figure 7 depicts the frequency of gaze fixations:

- Higher number (0.03) indicates a higher density of gaze fixations in that specific area of the image, a place where many pedestrians looked.
- Lower numbers (0.02 and 0.01) represent areas with lower densities of gaze fixations, showing some attention but with fewer fixations compared to the location with the highest number.

A heatmap in Figure 7 created from the single participant's eye-tracking data was used to show the locations of gaze concentration seen during the pedestrian engagement with the crossing scenario. Figure 7a shows the highest Region of Interest (ROI) as a car hood. This is where pedestrians directed their gaze more often than any other part of the crossing scenario. Right after the car hood, the data revealed another critical area of interest: the road surface between the car and the pedestrian crossing, shown in Figure 7b. This is because pedestrians can use their peripheral vision to detect a vehicle when looking at the road surface.

The graph in Figure 8 highlights the importance of considering vehicle speed when studying the pedestrian interactions, as it influences how pedestrians allocate their attention in these crucial situations. The presented data reveals a notable predilection among pedestrians for focusing on the car hood. This observed phenomenon prompts an exploration of the potential influence of vehicular speed as a determining factor for the heightened focus on the car hood in these contexts (4,7,10). Notably, in locations where the windshield surpasses other regions of interest in elevation, the diminished time required for pedestrian road-crossing due to higher vehicle speeds may elucidate a propensity for clearer interaction with the driver.

a)

b)

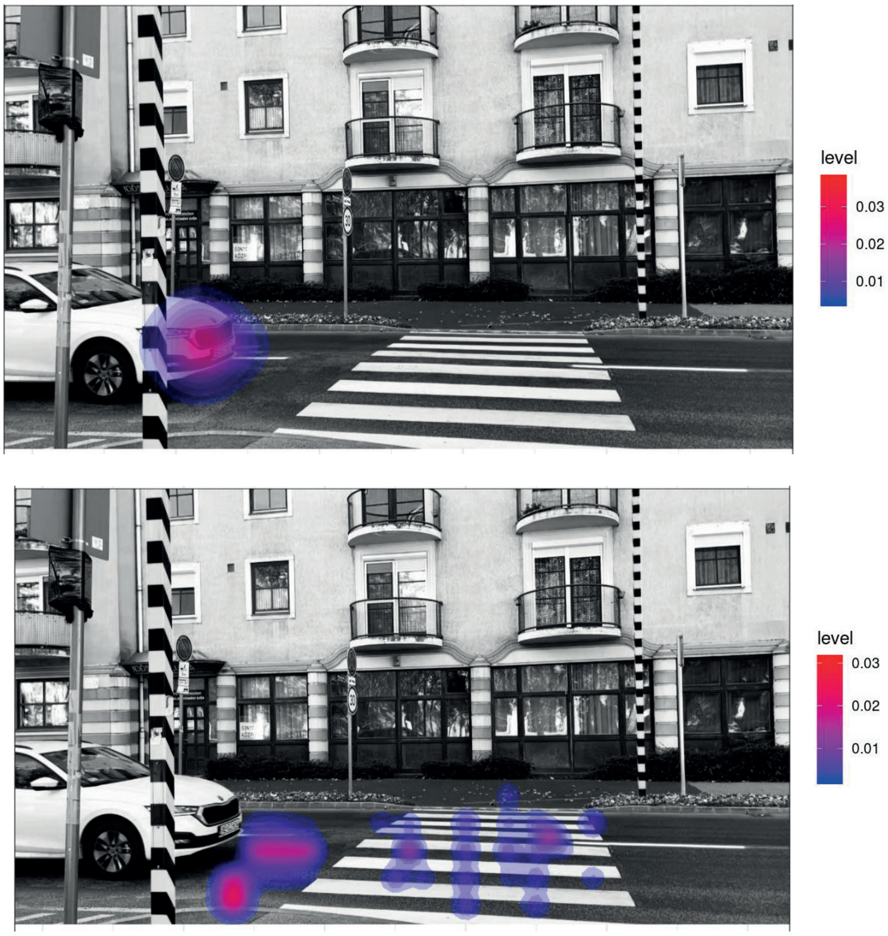

Figure 7 *Heatmap Visualization: Gaze Data from a Single Participant; a) car hood ROI, b) road surface ROI*

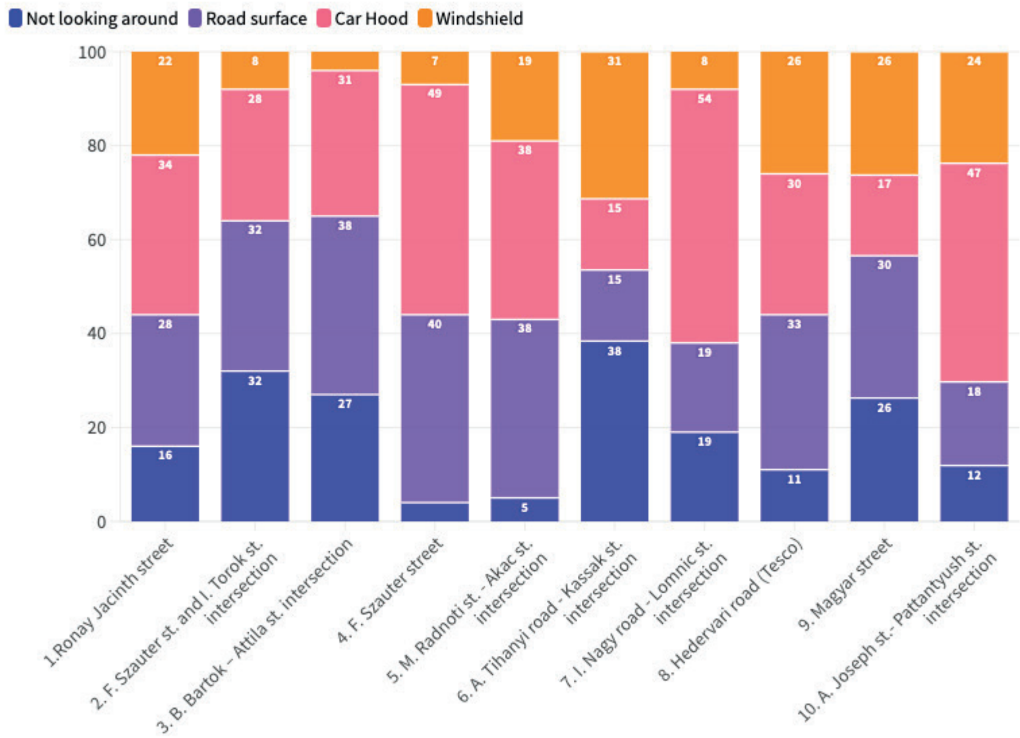

Figure 8 *Gaze behavior regarding 10 locations in Gyor city*

The Chi-Square test revealed a statistically significant association ($p = 0.075$) between the gender and pedestrians' gaze behavior when crossing the road. While there was no significant difference in the overall proportion of males and females not looking to the side, females did exhibit slightly less attentiveness (22.6% vs. 17.3 %). However, in the specific location, such a windshield, there is a significant difference emerged. Males (19.8%) were more likely than females (10.4%) to look at the windshield while crossing the road ($p < 0.05$).

4 Conclusion

The research on pedestrian gaze behavior during the road crossings in diverse locations within the Gyor city offers insightful contributions to the field of sustainable mobility and human vehicle interactions. The study's comprehensive analysis of pedestrians' visual attention patterns, and their interactions with vehicles, provides valuable evidence for decision-making in urban planning and the integration of AV technology.

Previous studies on LED interfaces in vehicles have explored various locations within the car without a targeted understanding of pedestrian behavior. By incorporating the ET technology, this research delves into the fundamental aspect of human attention, providing valuable insights into the visual focal points of individuals during a critical and safety-sensitive activity such as crossing the road. The findings reveal a consistent trend where pedestrians direct significant attention to the car hood during the road crossings from both the left and right sides. Strategically placing the LED interfaces or communication signals on car hoods of AVs can facilitate effective communication with pedestrians, promoting safer and more sustainable interactions in urban environments. The data also supports the idea that placing LED projectors in front of the vehicle, particularly near the registration plate, could be another effective location for communication with pedestrians. By projecting the relevant signals or messages onto the road surface in front of the vehicle, the AVs can establish a clear and visible means of communication, further enhancing pedestrian awareness and safety.

Following the completion of calculations, a borderline significant association is suggested between the gender and gaze behaviour at road crossings. While overall gaze behaviour was not significantly different, females tended to look less to the side than men. Interestingly, males fixated more on the windscreen than females, suggesting a possible gender difference in where the pedestrians focus their attention when crossing the roads.

The implications of this research extend to sustainable urban planning, optimized traffic management, and the responsible deployment of the AV technology.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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