Enhancing Cyclist Safety in the EU: A Study on Lateral Overtaking Distance Across Seven Scenarios Using Lab and Crowdsourced Methods

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Abstract

Cyclists face significant risks from vehicles that overtake too closely. Through crowdsourcing (N = 200) and driving simulator (N = 20) experiments, this study examines driver behaviour in seven scenarios: laser projection, road sign, road marking, car projection, centre line and side line markings (baseline), cycle lane and no road markings. Crowdsourced participants consistently underestimated overtaking distances, particularly at wider gaps, despite feeling safer with greater distances. The simulation results showed that drivers maintained an average passing distance of 3.4 m when not constrained by traffic, exceeding the 1.5 m law of the European Union. However, interventions varied in effectiveness: while laser projection was preferred, it did not significantly increase passing distance. In contrast, a dedicated cycle lane and a solid centreline led to the greatest improvements. These findings highlight the discrepancies between perceived and actual safety and provide insight for policy interventions to enhance cyclist protection in the EU.

CCS Concepts

• **Human-centered computing** → *Laboratory experiments*; *User studies*; • **Computing methodologies** → *Crowdsourcing*.

Keywords

Cyclist Safety, Driver Behaviour, Overtaking Distance, Simulation, Crowdsourcing, Human Factors, Vulnerable Road Users

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1 Introduction

Cycling has historically served as a vital mode of transport, particularly in countries such as the Netherlands, where a deliberate shift from car-centric to bike-centred urban design has significantly improved quality of life [13, 41]. This transformation has reduced the environmental and spatial footprint of cars, making urban areas more liveable for citizens [47]. The Netherlands is a successful example of behavioural change, illustrating the potential for similar transformations in other countries such as Germany and Denmark [43]. Despite these advances, cyclists continue to face substantial risks of being involved in accidents, and in the Netherlands 25% of traffic deaths are cyclists [18, 50]. This poses a challenge to the wider adoption of cycling as a sustainable transport mode. An notable exception is Seville, Spain, where 13 years of infrastructure investment have led to the halving of the risk related to cycling (defined as the yearly ratio between the total number of collisions of bicycles with vehicles and the total number of bicycle trips) [34]. The European Union (EU) aims to reduce cycling deaths by 55% by the end of 2030 [53].

In recent years, the urgency to reduce the carbon footprint [12] and alleviate urban traffic congestion has further elevated the importance of cycling. Since the COVID-19 pandemic, there has been a notable increase in bicycle usage and purchase [14], accompanied by an increase in cycling-related deaths in the EU, accounting for 10% of all road deaths [33]. EU reports highlight that many of these accidents occur on straight roads, accounting for 66% of the total fatalities [49]. Studies have shown that drivers fail to or choose not to change lanes safely to overtake cyclists [22, 30, 59]. Additional hazards arise on narrower roads, exacerbating the risks for cyclists [49, 56]. Other factors contributing to the lack of reduction in general road fatalities include the use of mobile phones while driving. Montuori et al. demonstrated in a survey-based cross-sectional study that 69% of participants admitted to using their phones while driving [36]. In particular, distractions for cyclists caused by phone use, especially when cyclists text, significantly increases the risk [29]. The findings indicate that attention issues contribute to bicycle-car collisions [29, 45]. Habibovic & Davidsson [28] and Bazilinskyy et al. [5] attempted to investigate the causes of crashes between cars and cyclists at intersections, and other studies focused on the open road [31, 52].

Effective communication between drivers, motorcyclists, and vulnerable road users (VRUs), such as cyclists and pedestrians, is essential to ensure everyone's safety on the roads. This is particularly critical as cycling continues to gain prominence as a sustainable transportation option. Recent studies highlight the importance of communication using external Human–Machine Interfaces (eHMIs), particularly for interaction between automated vehicles (AVs) and VRUs [4, 8, 11]. Granville et al. also emphasise the need for equitable road sharing [27]. However, few studies have focused on cyclists. The integration of technology and improved road infrastructure has significant potential to improve this communication and, consequently, cyclist safety [16]. As demonstrated by Walker et al.,

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factors such as cyclist clothing do not significantly influence driver behaviour [59]. Notable exceptions exist: for example, when a cyclist is dressed as a police officer, drivers behave more cautiously, adjust their speed, and pay more attention. Al-Taie further highlighted the complexity of driver-cyclist interaction, indicating the importance of well-designed communication between the cyclist and the driver [1].

Previous research has documented persistent risks for cyclists, particularly in overtaking scenarios where drivers often underestimate safe passing distances [23, 58]. While studies have examined isolated factors such as driver distractions [36] and infrastructure impacts [32], there remains a lack of systematic research on how different infrastructural or technological interventions influence actual compliance with safe overtaking distances, such as the widely promoted 1.5-meter rule. Few studies have directly compared emerging interventions such as laser and car projections with conventional infrastructure within a unified framework. Moreover, the effectiveness of these measures across diverse EU contexts, each with varying cycling cultures and road norms, remains underexplored. By integrating crowdsourced perceptual assessments with controlled laboratory simulations, this study addresses these gaps, offering a robust evaluation of driver-cyclist communication technologies and infrastructure solutions. The findings aim to inform policy initiatives that target safer overtaking practices and support the strategic goals of the EU to reduce cycling fatalities.

1.1 Aim of Study

Cycling-related accidents are increasing, highlighting the need to better understand driver behaviour and its impact on cyclist safety, especially within the EU, where cycling cultures and infrastructure vary widely. Although interest in cycling safety is growing, key gaps remain in understanding driver-cyclist interactions. Communication technologies like light projection [24, 57] remain underexplored, and systematic comparisons of interventions—such as dedicated cycling paths, alternative road markings [51], or unprotected cycling paths [55]—are still lacking. Traditional methods such as observational studies and laboratory experiments may not fully reflect real-world EU dynamics. Building on previous work, this study focusses on overtaking scenarios to evaluate how communication technologies and infrastructure influence driver behaviour. The aim is to identify scalable safety measures using both experimental and simulation-based methodologies. The findings are intended to inform policies such as the mandatory 1.5-metre overtaking distance [17] and to support safer and more sustainable cycling infrastructure in Europe. To address these goals, the study explores the following three research questions:

- RQ1: How do different technologies, such as road infrastructure or human-machine interface (HMI), influence driver behaviour in maintaining the mandatory 1.5-meter overtaking distance from cyclists in the EU?
- RQ2: What are the most effective technological interventions to improve driver-cyclist communication among the currently available interaction concepts today?
- RQ3: How do results from crowdsourced studies compare to findings from controlled laboratory experiments, particularly in evaluating driver-cyclist communication technologies?

2 Method

Crowdsourcing is becoming a popular method for collecting data from diverse participants in a time- and cost-effective manner, particularly in transportation studies. However, the results of crowdsourced studies may need validation through controlled laboratory experiments to ensure reliability and applicability, as demonstrated by Bazilinskyy et al. [10]. This study employs a dual methodology to leverage the strengths of both approaches: crowdsourcing provides broad, diverse perceptual data through controlled video stimuli, while the laboratory simulation offers active driving behaviour data under controlled but interactive conditions. Using videos in the crowdsourced study ensures standardised exposure for all participants, whereas the simulator allows for detailed measurement of how interventions influence overtaking behaviour in real time. This complementary design enables a more robust and comprehensive understanding of the effectiveness of driver-cyclist safety interventions.

Participants in this study were selected from the 27 EU countries (United Kingdom not included), as the research aligns with the ongoing efforts of the EU to reduce road accidents, particularly those involving VRUs, such as cyclists. The decision to focus on the EU was also motivated by the existing cycling infrastructure of the region, which, although more developed than in many other parts of the world, still faces significant safety challenges. Furthermore, choosing the EU provided a better opportunity to reach participants for the simulator experiment, allowing the results from both crowdsourcing and simulator tests to be compared and analysed together. Furthermore, to ensure meaningful comparisons between the two methodologies, the selection criteria required participants to be 18 years or older and have a valid driving licence. This approach allowed for a balanced evaluation of how drivers from diverse backgrounds responded to different scenarios in both study formats. The study was approved by the Ethics Review Board of Eindhoven University of Technology and the participants gave their informed consent for the use of their data.

2.1 Scenarios

Unity version 2022.1.23f1 (https://unity.com) was used to design seven scenarios in Table 1 that aims to analyse various technologies and road infrastructure solutions to enhance driver awareness during overtaking manoeuvres. The seven scenarios were selected to represent a balanced mix of real-world interventions: three based on emerging technologies (e.g., laser projection and car projections), three grounded in conventional infrastructure (e.g., road markings), and one baseline condition with no markings. This design enabled a direct comparison between advanced, low-cost, and default environments. Road markings were prioritised over vertical signage due to their higher visual salience from the driver's perspective, particularly in urban settings where roadside signs may be obscured by visual clutter [20].

The city environment and the vehicle model were taken from the coupled simulator [6]. Each scenario focused on a specific intervention to assist drivers during overtaking. The seven selected scenarios took place in a 30 km/h zone, with the car travelling at a constant speed of 30 km/h (±1 km/h) and the cyclist moving steadily at an average speed of 17 km/h varying between 12.5 and 26.5 km/h [25].

Table 1: Scenarios and view from the driver's perspective as shown to participants. Images were taken at 8.2 s during simulation.

Laser projection: A system mounted on the bicycle handlebar that projects the safe passing distance from the bicycle onto the road similar to a solution used in London, UK [24, 54].

Vertical signage: Signs placed on the roadside to remind drivers of the 1.5-metre minimum overtaking distance rule [21].

Road markings: Markings proposed by the Danish Cyclist Association to inform drivers of the 1.5-metre minimum overtaking distance rule[51].

Car projection: A system that provides the driver with visual cues to indicate the appropriate distance for overtaking [2, 54].

Centre line and side-line markings: Markings on the road (baseline) .

Unprotected cycling path: A scenario simulating a cycling path without any physical barriers separating it from vehicular traffic [44, 46].

No road markings: No specific road markings or signage [48].

View from the driver's perspective: Participants viewed all scenarios from this angle.

The cyclist was animated using the Male Cyclist Animated model from Code This Lab S.r.l. (https://assetstore.unity.com/packages/3d/characters/humanoids/male-cyclist-animated-220508). The scenarios did not include oncoming traffic to ensure that participants could focus on the distance between the car and the cyclist while overtaking. In addition, the scenarios did not include any other road users, such as pedestrians.

2.2 Data Analysis

Paired sample t-tests and one-way repeated measures analysis of variance (ANOVA) were performed to determine significant differences between scenarios, revealing patterns in driver-cyclist communication and overtaking distances [5, 37]. The results were considered significant at p $p < .001$, unless otherwise stated. All ANOVA and t-test results can be found in the supplementary material (see Section 7). In the laboratory experiment, additional metrics such as perceived lateral distance and stress responses were examined to verify alignment with the trends observed in crowdsourced data.

3 Crowdsourced Experiment

3.1 Method

Participants in the crowdsourced experiment were recruited through the Appen platform (https://www.appen.com). After joining the job, they answered demographic questions. Factors such as obtaining a driver's licence in countries with strong cycling cultures (e.g., the Netherlands, Belgium and Denmark) versus countries with less emphasis on cycling safety (e.g., Italy) were considered. The questions were based on the questionnaire in Bazilinskyy et al. [9]. The participants were compensated at a rate of 0.50 USD in total for their participation. See Section 7 for the materials used in the experiment.

The participants were shown videos of one scenario at a time, presented in random order. Each of the seven scenarios was tested with three different lateral overtaking distances: 0.8 m, 1.6 m, and 2.4 m from the cyclist, resulting in a total of 21 tests. The 1.6 m distance was used as a control to align with the EU's minimum legal overtaking distance of 1.5 m, making it harder for participants to guess the purpose of the study. The other two distances were chosen by increasing and decreasing the control distance by 0.8 m, creating a noticeable variation while ensuring that the shortest distance was close enough to feel risky but not excessively unsafe.

During each trial, participants were asked to *"PRESS and HOLD F́key when you experience any discomfort with the overtaking scenario. Release it when you feel comfortable again*" [7, 35, 38]. This input served as a method for capturing participants' responses rather than reflecting direct behaviour. Performance scores were computed for each scenario by calculating the percentage of participants who pressed the key during the 100-ms periods, scaled from 0 to 100. After the video, the participants responded to two questions shown with sliders. The first asked:*"The space between the car and the bicycle during the overtaking manoeuvre was adequate"*. Responses were given on a 5-point Likert scale ranging from "Strongly disagree" to "Strongly agree". The second question was *"Estimate the lateral distance between the car and the bicycle during the overtaking manoeuvre. The distance between the car and the bicycle was approximately"*. The slider ranged from 0.5 to 2.5 m.

At the end of the experiment, participants were polled to respond to three statements on the 5-point Likert scale ranging from "Strongly disagree" to "Strongly agree": (1) *After experiencing the videos in the experiment, I will change my attitude towards maintaining a safe overtaking distance from cyclists.*, (3) *I felt safe while overtaking the cyclist in the videos.*, (3) *Based on my experience, I support the introduction of the technology used in the scenarios on real roads.*. On the next page, they were asked to indicate the most preferred scenario as *Which scenario was most helpful in choosing the overtaking distance from cyclists?* and provide feedback on the level of stress during the experiment *I experienced a high level of stress during all scenarios.* (5-point Likert scale ranging from "Strongly disagree" to "Strongly agree").

3.2 Results

A total of 200 participants joined, 71 participants were filtered because 67 of them completed the study in under 900 s, 3 used the same IP, one used the same worker code, and two people did not have a valid worker ID. A total of 120 (52 female and 68 male) persons participated in the crowdsourced experiment. The average age of the participants was 34.54 years (SD = 10.01), and the average year of obtaining a driving licence was 21.49 years (SD = 6.13). The participants came from Italy (n = 35), Portugal (n = 14), Hungary (n = 13), France (n = 12), Spain (n = 10), Germany (n = 8), Poland (n = 7), Romania (n = 6), the Netherlands (n = 6), Belgium (n = 3), Greece (n = 2), Croatia (n = 2), Denmark (n = 1) and Ireland (n = 1). Given the focus on the EU context, we aimed to cover all of the EU, but participation from some of the member states, such as certain Baltic and Central European countries (e.g., Estonia and Austria), was not achieved. Background questions indicated that participants perceived the average EU overtaking distance rule as 1.88 m (SD = 1.82), which implies that, in general, the governments of the EU countries did not inform on such rules correctly.

The participants demonstrated behaviour aligned with the distance of the overtaking manoeuvre, which appears to be influenced by their level of discomfort, as shown in Figure 1. The 1€ filter [15] was applied to the data in this graph and other plots (frequency = 120, mincutoff = 0.1, beta = 0.1). Closer overtaking distances, such as 0.8 m, elicited the highest keypress, indicating the most discomfort. The overtaking distance of 2.4 m produced the lowest keypress, suggesting a greater sense of safety and comfort. The results of the t-test revealed significant differences between distances, particularly between 0.8 and 1.6 m and between 0.8 and 2.4 m. These findings highlight that participants could clearly distinguish between the levels of safety at varying distances of overtaking.

Additionally, the shape of the curves provides valuable information on participants' behaviour. The curve for 0.8 metres has the steepest gradient and the highest peak, suggesting increased discomfort and urgency at this distance. In contrast, the flatter and narrower curve for 2.4 m indicates that discomfort was both lower in magnitude and shorter in duration. All curves peak around the same time (~14.5 s), which reflects a specific moment in the overtaking manoeuvre that participants consistently identified as critical. This specific moment was when the car was side-to-side with the

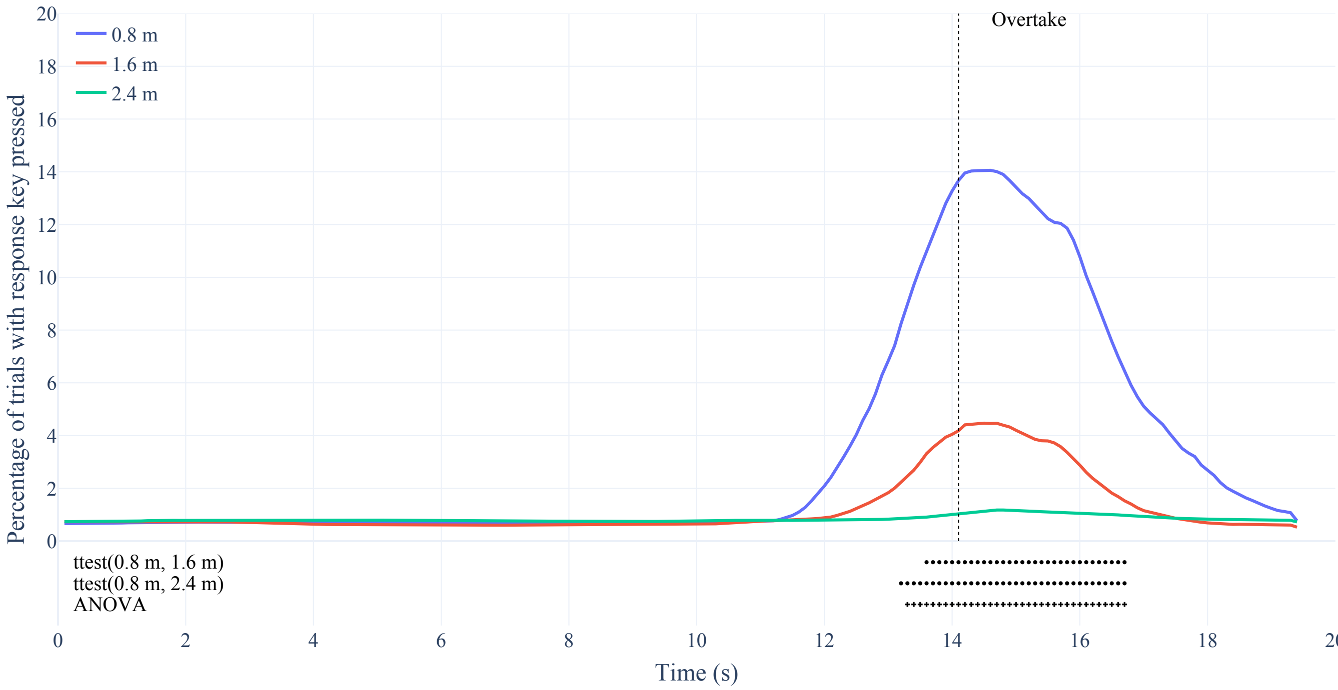

Figure 1: Mean discomfort level in the crowdsourced experiment for the three distances. The vertical line represents the overtaking moment. The circles at the bottom show significant differences, p < 0.001.

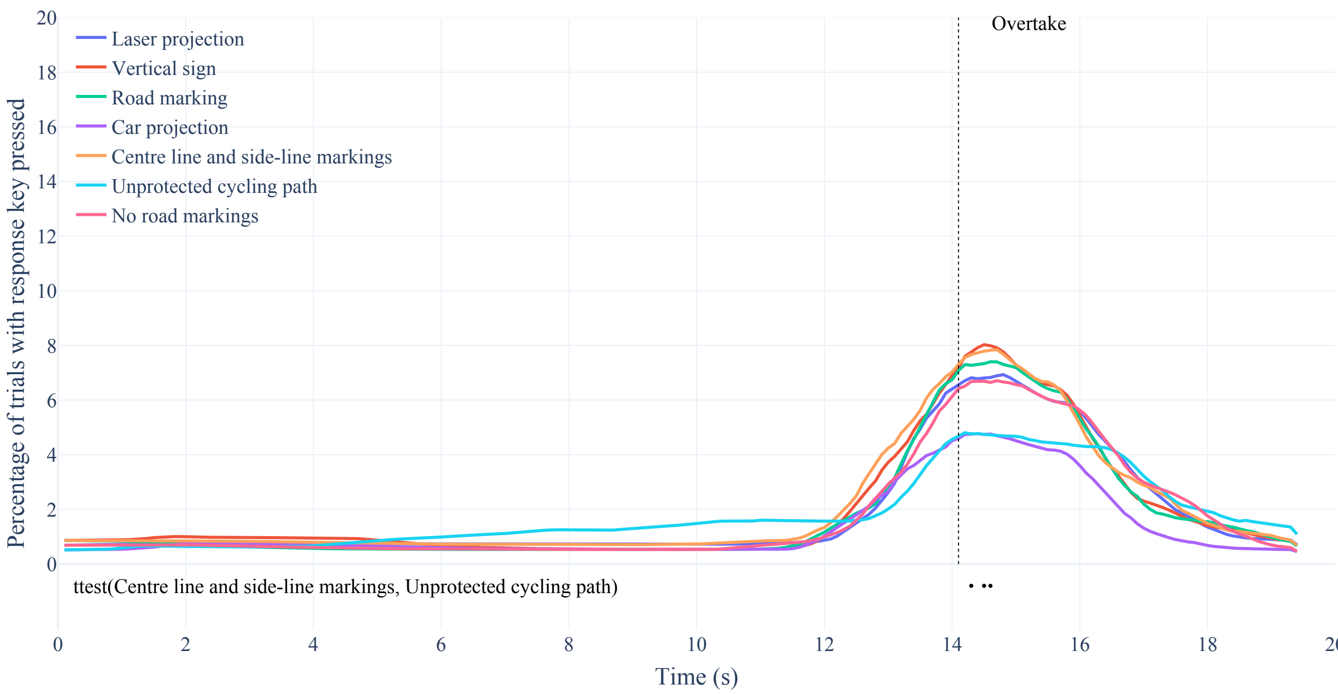

Figure 2: Mean discomfort level in the crowdsourced experiment for the seven scenarios. The vertical line represents the overtaking moment. The circles at the bottom show significant differences, p < 0.001.

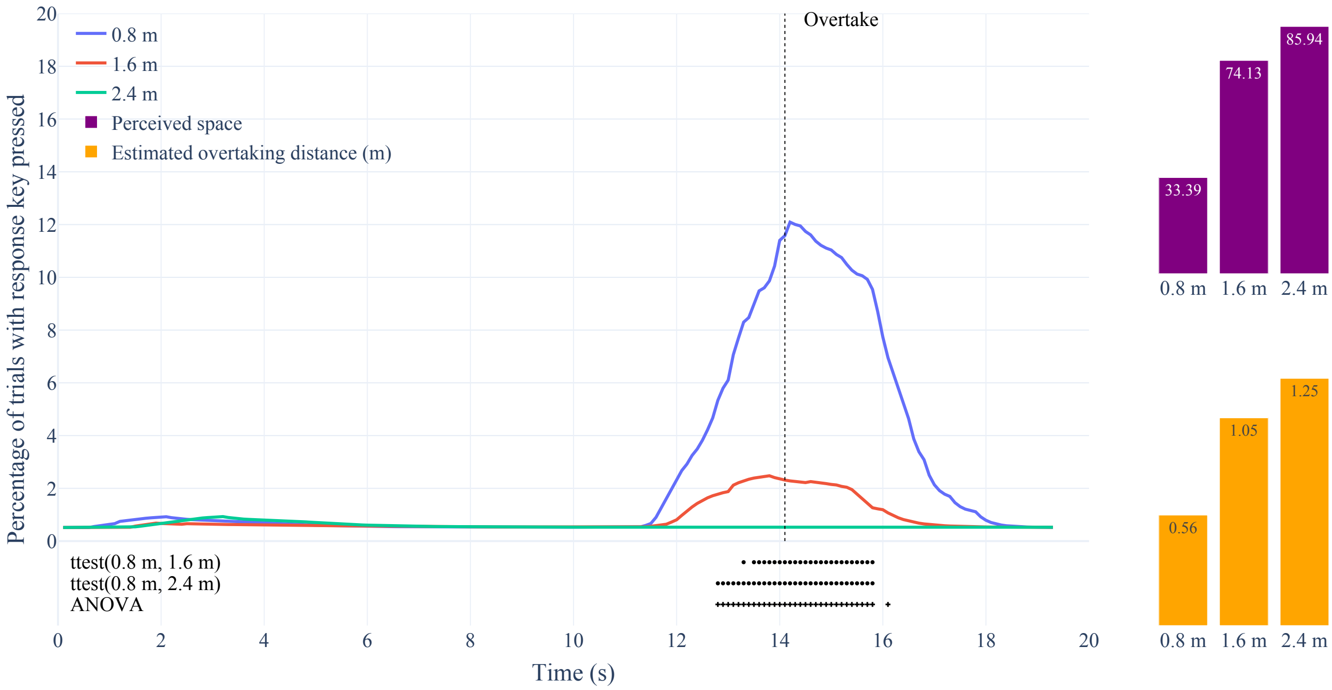

Figure 3: Participants' discomfort responses and post-stimulus questionnaire results for the perceived adequate overtaking distance and the estimated lateral distance for the *Car projection*. The purple bars represent the adequate overtaking distance reported by participants, while the orange bars show the estimated lateral distance of the overtaking manoeuvre. The vertical line represents the overtaking moment. The circles at the bottom show significant differences, p < 0.001.

cyclist. The results of the t-test highlight significant differences between the scenarios, particularly in the duration of the reported discomfort.

A time-sliced t-test analysis further revealed statistically significant differences in participant reactions at specific moments during the simulation. Notably, from time slices 135–166 for the 0.8 m vs 1.6 m comparison, and from 131–166 for the 0.8 m vs 2.4 m comparison, the p-values were consistently below $p < 0.001$. The ANOVA results supported this trend, showing significant variation in the same time window from 131–168. These localised patterns of discomfort highlight that participants could clearly distinguish between the perceived safety of different overtaking distances.

On average, participants reported feeling discomfort for a longer period when the overtaking distance was 0.8 m, compared to distances of 1.6 and 2.4 m. The shorter duration of discomfort reported for the 2.4 m condition suggests that larger overtaking distances contribute to a greater sense of safety and reduced stress.

The results confirm that closer overtaking distances increase discomfort, whereas larger distances improve safety perceptions. The statistical significance of these findings, as demonstrated by the t-test, validates the reliability of the observed trends. These results underscore the importance of maintaining safe overtaking distances to minimise discomfort and ensure cyclist safety.

Figure 2 highlights the levels of discomfort reported by participants during overtaking scenarios in seven conditions. The results indicate that the participants felt more comfortable in scenarios where some form of communication was provided, particularly with the *Car projection*. Interestingly, participants also appeared to feel relatively at ease in scenarios that involved an *Unprotected cycling path*. The t-tests revealed statistically significant differences between the *Centre line and side-line markings* and *Unprotected cycling path* scenarios, particularly from time slices $t = 142–145$ where $p < 0.001$. These results indicate that the *Unprotected cycling path* condition elicited a distinctly different discomfort response compared to the *Centre line and side-line markings* (baseline), despite similarities in visual setup.

The levels of discomfort varied between different scenarios, with some interventions leading to a more sustained perception of safety, while others resulted in momentary spikes in discomfort. The *Unprotected cycling path* and the *Car projection* showed a more uniform distribution of discomfort reports over time, suggesting that participants did not experience a specific moment of increased discomfort, but rather a more stable perception of safety or unease.

Interestingly, the *Laser projection* did not perform as effectively as the *Car projection*, with participants reporting levels of discomfort similar to those of other solutions rather than demonstrating a clear improvement. Furthermore, the *Vertical signage* and the *Road markings* resulted in momentary increases in discomfort, suggesting that participants felt uneasy at specific points in the overtaking process. The absence of road markings showed results similar to the *Centre line and side-line markings* (baseline), indicating that the

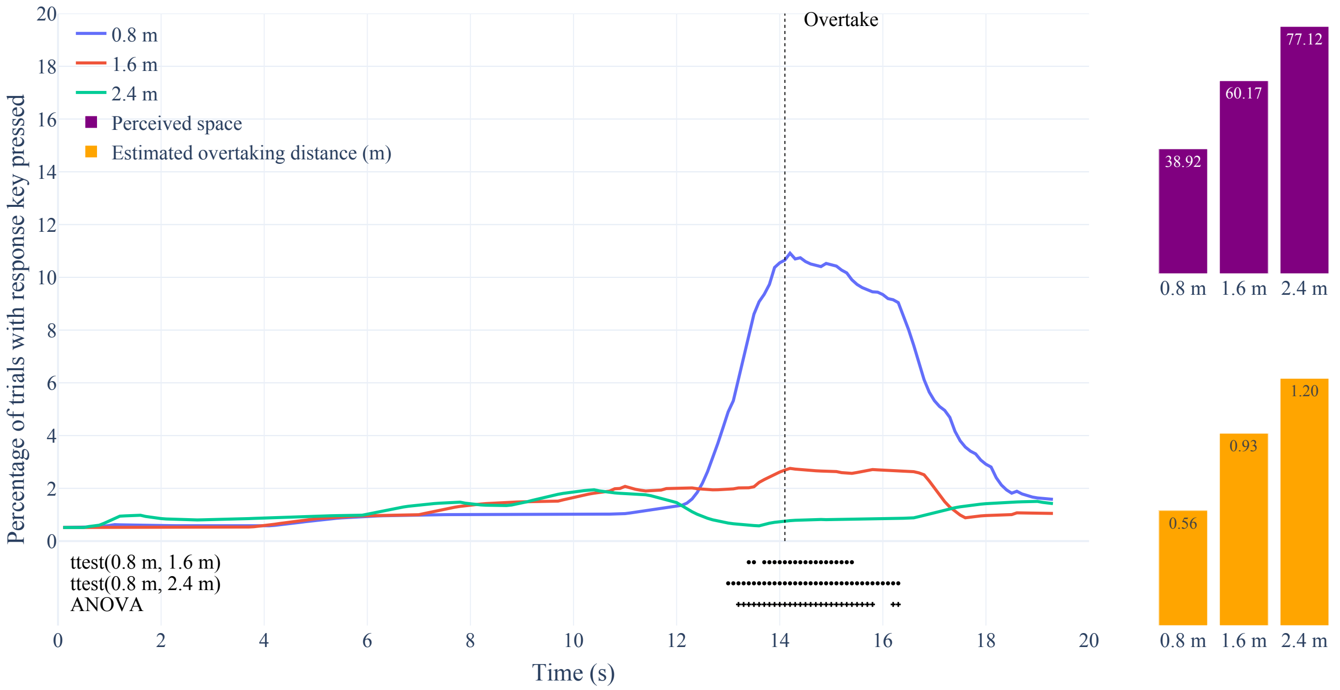

Figure 4: Participants' discomfort responses and post-stimulus questionnaire results for the perceived adequate overtaking distance and the estimated lateral distance for the *Unprotected cycling path*. The purple bars represent the adequate overtaking distance reported by participants, while the orange bars show the estimated lateral distance of the overtaking manoeuvre. The vertical line represents the overtaking moment. The circle at the bottom show significant differences, p < 0.001.

lack of additional visual guidance did not provide substantial safety improvements.

These findings highlight the importance of further investigating technological interventions, particularly *Car projection*, which demonstrated more consistent results in promoting a sense of safety for both drivers and cyclists. Given its potential to improve driver awareness during overtaking manoeuvres, this approach deserves further examination as a possible alternative to traditional infrastructure-based solutions.

Figure 3 provides information on results related to the *Car projection*. The results of the t-test highlight differences between specific scenarios, reinforcing the interpretation that overtaking distance influences perceived discomfort. Both the ANOVA and the t-test consistently showed statistically significant differences during the overtaking moment, specifically across time slices $t = 127–170$ where $p < 0.001$. This overlap between tests confirms that participants experienced heightened discomfort when overtaking distance was reduced, particularly under the *Car projection* condition. These statistical patterns, robust across both measures, reflect meaningful differences in participant responses. Specifically, the trial with the 0.8 m distance recorded the highest keypress rate, suggesting that participants experienced the greatest discomfort or felt the least safe. The trial with the 2.4 m distance showed the lowest keypress rate, reflecting increased comfort and perception of safer overtaking conditions. The range of keypress data in the trial with the 1.6 m distance fell in between, with moderate keypress rates, reflecting a gradual improvement in perceived safety.

Participants generally felt safer and more comfortable with longer overtaking distances. However, they consistently underestimated the actual gap. This trend suggests a misalignment between perception and reality in driver behaviour. The results confirm that shorter overtaking distances lead to significantly higher discomfort, while larger gaps were associated with a greater sense of adequacy and safety.

When comparing the *Car projection* with the *Unprotected cycling path*, the results reveal a misalignment between perceived comfort and actual overtaking distance. See Section 7 for additional visualisations and analysis. Although participants reported feeling more comfortable with the *Unprotected cycling path*, they were unable to achieve adequate overtaking distances or high safety ratings. This contrast underscores the importance of designing interventions that balance subjective perceptions with measurable safety outcomes.

Figure 4 compares the discomfort responses and spatial estimates under the *Unprotected cycling path* condition. Although this condition showed a general trend of increasing comfort and distance perception with wider overtaking margins, participants' estimated overtaking distances remained lower than the actual values. This reinforces the idea that perceived safety does not always align with objective spatial behaviour. The ANOVA revealed statistically significant differences during the overtaking moment, particularly between time slices $t = 131–157$ and $t = 161–162$, all with $p < 0.001$. These results reflect a consistent pattern of discomfort responses at closer distances, which further supports the sensitivity of participants to lateral proximity.

The *Car projection* demonstrated its effectiveness in improving overtaking behaviour, particularly at greater distances, as evidenced by lower keypress rates, higher perceived space, and better adequacy scores in the trial with the 2.4 m distance. Although the t-test comparing *Centre line and side-line markings* (baseline) and *Car projection* scenarios did not reveal statistically significant differences, the ANOVA results identified a short sequence of significant moments between time slices $t = 124–128$ (e.g., $p < 0.001$ at $t = 127, 128$), suggesting a localised but meaningful perceptual effect. These findings cautiously support the potential of the *Car projection* as a promising communication tool to enhance driver-cyclist interactions.

Participants were asked to choose the most helpful interaction to maintain the overtaking distance. The scenarios were chosen in this order: *Car projection* (n = 38), *Laser projection* (n = 36), *Unprotected cycling path* (n = 22), *Road markings* (n = 19) and *Vertical signage* (n = 1). These preferences align with keypress data, which indicated lower levels of discomfort in such scenarios.

4 Laboratory Experiment

4.1 Method

The setup, consisting of a screen, a gaming steering wheel, and paddles for speed control, was used to evaluate the scenarios more thoroughly, focusing on whether they contributed to improving the lateral overtaking distance rather than assessing distance perception. Participants could freely control the car's steering with the wheel and adjust the speed using the pedals, allowing for a detailed analysis of their actions while overtaking the cyclist. The speed of the car and the lateral distance from the cyclist were recorded every 0.1 s [23, 58]. In addition, the coordinates of the car, time, speed, and the closest distance between the bicycle and the car box colliders were also recorded.

The tests were carried out in a controlled environment. The light level was kept the same, and the shades were closed during the experiment. There was no noise during the experiment. To closely mimic a real driving experience, the participants used a 27-inch screen set-up equipped with a steering wheel, accelerator, and braking pedals (see Figure 5). To run the simulation, a Microsoft Surface Book 2 with Intel I7, 8GB of RAM, and a dedicated graphics card, Nvidia 1050ti, was used. In this setup, the cyclist maintained a constant speed of 17 km/h along a set path, while the car's speed was controlled by the participant, allowing variations in speed and lateral distance.

The laboratory experiment was conducted by first providing participants with information about the project and requiring them to complete a demographic survey, which included questions on driving experience and familiarity with cycling safety. Like in the crowdsourced experiment, the survey structure and questions used were based on the questionnaire in Bazilinskyy et al. [9]. They were then asked to read the instructions. Before the first actual trial, the participants were given a demonstration in which only the car and the city environment were used without the cyclist to allow the participants to practice. Participants were allowed as much time as

Figure 5: Experimental setup used during the laboratory experiment. Participants controlled a vehicle using a gaming steering wheel and paddles for speed adjustments with the simulation on a monitor.

needed until they felt confident driving the car. See Section 7 for the materials used in the laboratory experiment.

The scenarios were randomised. After each scenario, participants were required to answer two questions based on the survey: (1) *After the simulation, to what extent do you agree with the following statement: The space between the car and the bicycle during the overtaking manoeuvre was adequate* and (2) *Could you estimate the lateral distance between the car and the bicycle during the overtaking manoeuvre. Give your answer in meters. The distance between the car and the bicycle was approximately.....*Participants at the end of the study were asked to express their preferences for the scenario *Which of the seven scenarios, featuring various technologies such as road markings or laser projections, was the most helpful in accurately determining the distance between the car and the cyclist?* They could select only one of the seven scenarios.

The laboratory study included 20 participants (7 female and 13 male), with a mean age of 21.0 years (SD = 3.0) and an average driving licence holding period of 2.0 years (SD = 2.3). Participants were primarily recruited through personal networks at the Eindhoven University of Technology. Participants were recruited from ten EU countries: Estonia (n = 4), the Netherlands (n = 4), Bulgaria (n = 3), Italy (n = 2), Poland (n = 2) and one participant each from Spain, Germany, Romania, Latvia, and Cyprus. This distribution provided a diverse, yet younger and less experienced, driver sample compared to the crowdsourced group.

4.2 Results

The results of the laboratory experiment showed that there was a variation across the different scenarios. The results of this experiment provide support for what can be observed in the crowdsourced experiment. The first insight from the general result showed that participants demonstrated difficulty in accurately estimating the lateral overtaking distance, with an average estimation error of 1.63 m across all scenarios, based on the difference between the estimated and actual overtaking distances.

The distance between the car and the cyclist was also observed to be on average high compared to expectation, regardless of the scenario. The average overtaking distance was 3.40 m. This is likely due to the absence of incoming traffic as suggested by the participant comments, which made the participants feel comfortable taking a greater distance than required by regulations.

Figure 6 presents the recorded overtaking distances in different scenarios, illustrating how the mean distance varies over time in the scenarios. Although scenarios such as the *Laser projection* demonstrated the highest recorded overtaking distances, there is significant variation between scenarios. The *Unprotected cycling path*, which participants in the crowdsourced experiment associated with high comfort and high perceived adequacy Figure 2, also resulted in shorter overtaking distances, reinforcing its limitations Figure 6. The results of the t-test indicated that there were no statistically significant differences between conditions, highlighting the need for more research to better understand the relationship between perceived safety and actual driver behaviour in overtaking situations.

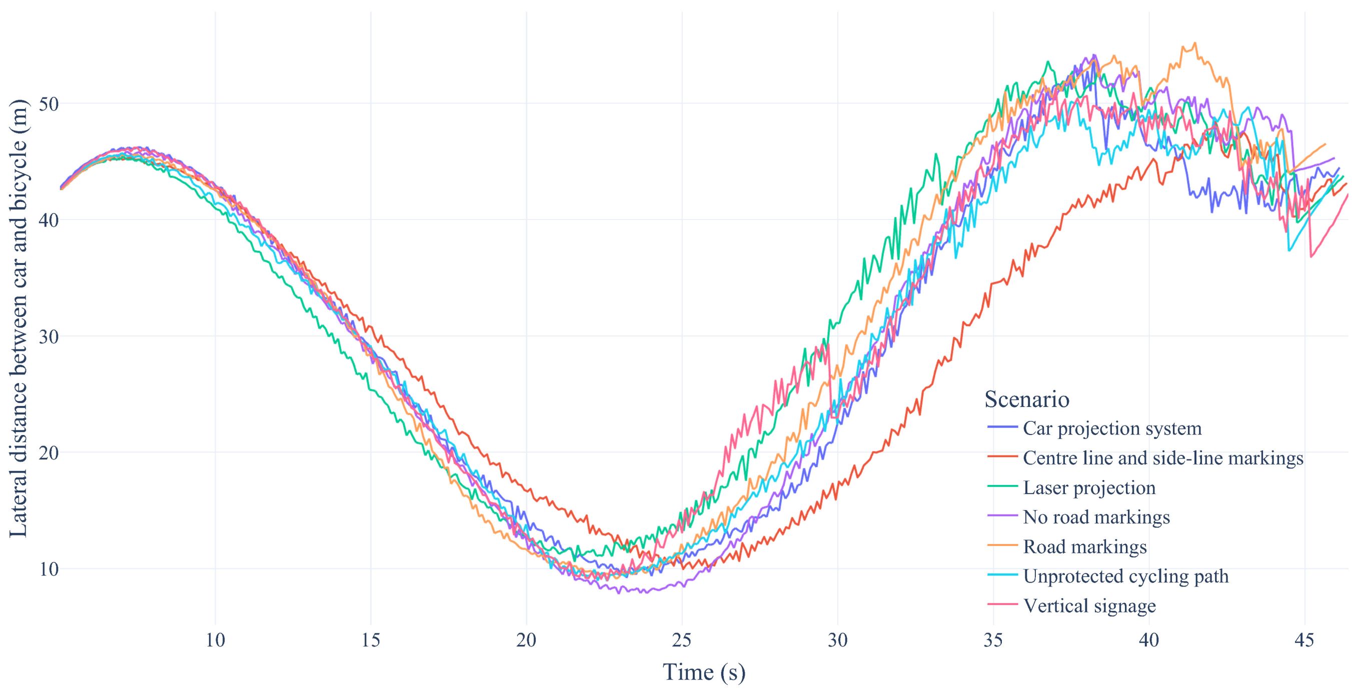

Figure 6: Lateral distance between car and bicycle across scenarios. Data are shown from the 5th second.

Participants were polled to indicate their most preferred interaction concept. The scenarios preferred by the participants did not always correspond to those that maintained the highest overtaking distances. The *Unprotected cycling path* received the highest number of participant votes, with 10 in total. This was followed by the *Laser projection* with 5 votes, the *Car projection* with 3 votes, and the *Road marking* with 2 votes. The remaining options did not receive any votes. However, Figure 6 shows that the *Unprotected cycling path* did not result in the highest overtaking distances, as other conditions, such as the *Laser projection*, led to greater actual clearance. This discrepancy between perceived safety and actual driver behaviour suggests that the participants' sense of security does not necessarily align with objective overtaking behaviour, which warrants further investigation.

5 Discussion

This study examined seven interventions aimed at increasing the lateral overtaking distance for cyclist safety in the EU. Crowdsourced (N = 120) and laboratory (N = 20) experiments evaluated technologies and infrastructure-based solutions. While *Laser projection* and *Car projection* were preferred, they were not always the most effective in measured results. The results highlight a gap between perceived comfort and actual overtaking distances, which underlines the need to align driver perception with real safety (RQ1). Previous studies have shown that drivers often underestimate the distance they leave when overtaking cyclists, particularly when they perceive the road to be wide or the cyclist to be predictable [58]. This misalignment suggests that effective HMI or infrastructure interventions must not only influence behaviour but also enhance spatial awareness during overtaking.

Car projection emerged as the most effective, increasing overtaking distance and reducing discomfort through intuitive visual cues. *Laser projection* was the most preferred, valued for its clarity. Similarly, automotive projection systems offer real-time feedback, reducing stress and improving decision making [19]. Advanced technologies were favoured, but simpler interventions, such as *Vertical signage* and *Road markings*, performed comparably in measured behaviour. Although less preferred, *Vertical signage* achieved similar results in terms of measured overtaking distances, highlighting its potential as a lower-cost alternative [21]. *Road markings* showed moderate effectiveness, providing further support for their applicability in resource-constrained settings. Interestingly, the *Unprotected cycling path* was rated as comfortable, but resulted in the smallest overtaking distances, exposing a misalignment between subjective comfort and actual safety (RQ2) [40].

The behavioural results confirm that drivers often misjudge safe passing distances [26], reinforcing the need for interventions that improve spatial awareness. Technologies such as *Bicycle projection* and *Car projection* help reduce uncertainty, but the diversity of responses indicates that no single intervention is universally effective. Context-specific solutions are likely to be needed to account for environmental and cultural variation.

The combination of crowdsourcing and simulation provided complementary insights (RQ3). Crowdsourcing enabled broad participation across the EU but was limited by its use of pre-recorded videos. The controlled study, although lacking traffic complexity, offered real-time behavioural data. The laboratory simulation showed greater overtaking distances, probably due to the absence of oncoming traffic or distractions. This difference underscores the importance of validating the findings in real-world settings to ensure broader applicability.

These findings have practical implications for both infrastructure and HMI design, and they also offer important directions for policy intervention. The demonstrated effectiveness of low-cost road markings suggests that policymakers could prioritise implementing and maintaining such markings as a cost-effective safety measure, particularly given that *Road markings* are more likely to capture driver attention than roadside signs, which can be obscured or overlooked. Furthermore, promising results for *Car projection* systems highlight the potential of regulatory bodies to encourage or mandate integration of real-time overtaking cues into vehicle safety standards. A combined approach, leveraging both infrastructure and in-vehicle technologies, can offer the most comprehensive strategy to improve cyclist safety by better aligning driver perception with actual risk.

Building on these insights, the role of adaptive, context-aware solutions emerges as a key design direction. These systems can dynamically respond to changing traffic patterns, environmental conditions, and regional or cultural variations in road use and driver behaviour. For example, adaptive projections or road markings could modify their colour, intensity, or messaging based on factors such as oncoming traffic, weather conditions, or the presence of vulnerable road users or obstacles such as construction sites.

To guide future design efforts, several critical considerations must be addressed when implementing adaptive visual solutions for driver support. Usability and safety must remain paramount: visual cues must be intuitive, easily understood, and minimally distracting under varying lighting and driving conditions. Designers must also consider the complexity of the system, as it can affect the development, maintenance, and long-term reliability factors that influence user trust and adoption. Finally, scalability is essential to ensure that these solutions can be effectively deployed across various urban and rural environments, taking into account different infrastructure capabilities and cultural contexts.

Recognising these factors, future cycling safety interventions can be developed to be flexible, context sensitive, and responsive to evolving environmental and cultural factors, helping policymakers and designers collaborate to reduce risk to cyclists more effectively.

5.1 Limitations and Future Work

While this study provides valuable information, several limitations must be acknowledged. Although this study focused on drivers, future work should explore how these interventions affect cyclists' perceived safety. A more immersive simulator, such as the one in Petermeijer et al. [42], or the use of VR headsets could better replicate real-world driving [8]. Furthermore, conducting tests in live traffic would improve the ecological validity by capturing more natural driver behaviour. The current simulation lacked dynamic elements, such as pedestrians and opposing traffic, which can influence decisions. The crowdsourced approach offered broad perspectives but relied on subjective interpretations of 2D video, potentially limiting realism. The sample size was also small compared to similar studies (e.g., Onkhar et al. [37] and Bazilinskyy et al. [5] with 2000 participants each), suggesting that future work should scale up, ideally across all EU member states. The selected overtaking distances (0.8 m, 1.6 m, 2.4 m) could be expanded to a continuous range to gain richer behavioural insights [3]. Similarly, while seven interventions were tested, future research should assess whether they represent the entire design space or if additional concepts should be explored. Regional and infrastructural differences across the European Economic Area (EEA) and beyond may influence effectiveness, especially since the current scenario reflected a US-style layout. Future work should also consider other VRUs, such as scooter riders, who face similar risks. Lastly, although participants had driver's licences, a further detailed analysis of the driving experience, particularly among the crowdsourced population, could clarify its impact on overtaking behaviour. Real-world studies, integration with connected vehicles, and the development of real-time feedback systems can provide deeper insights and improve cyclist-driver communication. In addition, eye-tracking data was collected during the crowdsourced study using WebGazer [39], and future analyses could use this to explore the visual attention of participants and its relation to perceived safety.

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7 Supplementary Material

Supplementary material containing anonymous questionnaire data, simulator code, and videos used in the experiment is available at: http://doi.org/10.4121/ef92ee06-87c6-4bdb-980f-37cc4f687785. The maintained version of the code is available at https://github.com/gip58/cyclist-distance-crowdsourced.

References

[1] Ammar Al-Taie, Yasmeen Abdrabou, Shaun Alexander Macdonald, Frank Pollick, and Stephen Anthony Brewster. 2023. Keep it Real: Investigating Driver-Cyclist Interaction in Real-World Traffic. , Article 769 (2023), 15 pages. https://doi.org/10.1145/3544548.3581049

[2] Liebram Alena. 2019. Continental enhances intelligent glass control. https://www.continental.com/en/press/press-releases/2019-07-25-intelligent-glass-control

[3] Pavlo Bazilinskyy, Dimitra Dodou, and J. C. F. De Winter. 2020. External human-machine interfaces: Which of 729 colors is best for signaling 'Please (do not) cross'?. In *Proceedings of IEEE International Conference on Systems, Man, and Cybernetics (SMC)*. IEEE, Toronto, Canada, 3721–3728. https://doi.org/10.1109/SMC42975.2020.9282998

[4] Pavlo Bazilinskyy, Dimitra Dodou, and J. C. F. De Winter. 2022. Crowdsourced assessment of 227 text-based eHMIs for a crossing scenario. In *Proceedings of International Conference on Applied Human Factors and Ergonomics (AHFE)*. New York, USA. https://doi.org/10.54941/ahfe1002444

[5] Pavlo Bazilinskyy, Dimitra Dodou, Y. B. Eisma, W . V. Vlakveld, and J. C. F. De Winter. 2022. Blinded windows and empty driver seats: the effects of automated vehicle characteristics on cyclist decision-making. *IET Intelligent Transportation Systems* 17 (2022), 72–84. https://doi.org/10.1049/itr2.12235

[6] Pavlo Bazilinskyy, Lars Kooijman, Dimitra Dodou, and J. C. F. De Winter. 2020. Coupled simulator for research on the interaction between pedestrians and (automated) vehicles. In *Proceedings of Driving Simulation Conference (DSC)*. Antibes, France.

[7] Pavlo Bazilinskyy, Lars Kooijman, Dimitra Dodou, and J. C. F. De Winter. 2021. How should external Human-Machine Interfaces behave? Examining the effects of colour, position, message, activation distance, vehicle yielding, and visual distraction among 1,434 participants. *Applied Ergonomics* 95 (2021), 103450. https://doi.org/10.1016/j.apergo.2021.103450

[8] Pavlo Bazilinskyy, Lars Kooijman, K. P. T. Mallant, V. E. R. Roosens, M. D. L. M. Middelweerd, Dodou Dimitra Overbeek, L. D., and J. C. F. De Winter. 2022. Get out of the way! Examining eHMIs in critical driver-pedestrian encounters in a coupled simulator. In *Proceedings of International ACM Conference on Automotive User Interfaces and Interactive Vehicular Applications (AutoUI)*. Seoul, South Korea. https://doi.org/10.1145/3543174.3546849

[9] Pavlo Bazilinskyy, Miltos Kyriakidis, and Joost de Winter. 2015. An International Crowdsourcing Study into People's Statements on Fully Automated Driving. *Procedia Manufacturing* 3 (2015), 2534–2542. https://doi.org/10.1016/j.promfg.2015.07.540 6th International Conference on Applied Human Factors and Ergonomics (AHFE 2015) and the Affiliated Conferences, AHFE 2015.

[10] Pavlo Bazilinskyy, Roberto Merino-Martınez, Elif Özcan, Dimitra Dodou, and J. C. F. De Winter. 2023. Exterior sounds for electric and automated vehicles: Loud is effective. *Applied Acoustics* 214 (2023), 109673. https://doi.org/10.1016/j.apacoust.2023.109673

[11] Siri Hegna Berge, Marjan Hagenzieker, Haneen Farah, and Joost de Winter. 2022. do cyclists need hmis in future automated traffic? an interview study. *Transportation Research Part F: Traffic Psychology and Behaviour* 84 (Jan. 2022), 33–52. https://doi.org/10.1016/j.trf.2021.11.013

[12] Christian Brand, Evi Dons, Esther Anaya-Boig, et al. 2020. the climate change mitigation effects of active travel. *Research Square* PREPRINT (Version 1) (July 2020), 1–30. https://doi.org/10.21203/rs.3.rs-39219/v1

[13] Matthew Bruno, Henk-Jan Dekker, and Letícia Lindenberg Lemos. 2021. Mobility protests in the Netherlands of the 1970s: Activism, innovation, and transitions. *Environmental Innovation and Societal Transitions* 40 (Sept. 2021), 521–535. https://doi.org/10.1016/j.eist.2021.10.001

[14] Ralph Buehler and John Pucher. 2022. cycling through the covid-19 pandemic to a more sustainable transport future: evidence from case studies of 14 large bicycle-friendly cities in europe and north america. *Sustainability* 14, 12 (2022), 1–32. https://doi.org/10.3390/su14127293

[15] Géry Casiez, Nicolas Roussel, and Daniel Vogel. 2012. The 1€ filter: A simple speed-based low-pass filter for noisy input in interactive systems. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, 2527–2530. https://doi.org/10.1145/2207676.2208639

[16] Christine Chaloupka-Risser and Elisabeth Füssl. 2017. The importance of communication between cyclists and other traffic participants and its potential in reducing traffic safety-critical events. *Transactions on Transport Sciences* 8, 1 (2017), 24–30. https://doi.org/10.5507/tots.2017.004

[17] Deirdre CLUNE. 2017. Parliamentary question | minimum lateral clearance distance when passing cyclists | E-002358/2017 | European Parliament. https://www.europarl.europa.eu/doceo/document/E-8-2017-002358_EN.html

[18] European Commission. 2016. 2015 road safety statistics: what is behind the figures? https://ec.europa.eu/commission/presscorner/detail/en/memo_16_864

[19] Continental AG. 2019. Virtual a-pillar: continental improves vehicle safety with invisible pillars. https://www.continental.com/en-us/press/press-releases/continental-enhances-driver-safety-by-eliminating-forward-blind-spots/. Accessed: 2025-04-07.

[20] Marco Costa, Leonardo Bonetti, Valeria Vignali, Claudio Lantieri, and Andrea Simone. 2018. The role of peripheral vision in vertical road sign identification and discrimination. *Ergonomics* 61 (2018), 1619 – 1634. https://doi.org/10.1080/00140139.2018.1508756

[21] Alastair Dalton. 2022. *Drivers passing dangerously close to cyclists nearly halved in pilot project.* National World Publishing Ltd. https://www.scotsman.com/news/transport/drivers-passing-dangerously-close-to-cyclists-nearly-halved-in-pilot-project-3555536

[22] Marco Dozza, Ron Schindler, Giulio Bianchi-Piccinini, and Johan Karlsson. 2016. How do drivers overtake cyclists? *Accident Analysis and Prevention* 88 (March 2016), 29–36. https://doi.org/10.1016/j.aap.2015.12.008

[23] Marco Dozza and Joakim Werneke. 2014. Introducing naturalistic cycling data: What factors influence bicyclists' safety in the real world? *Transportation Research Part F: Traffic Psychology and Behaviour* 24 (2014), 83–91. https://doi.org/10.1016/j.trf.2014.03.001

[24] Simon Driver and Elliott Ross. 2015. *Blaze laserlights.* Transport for London. https://tfl.gov.uk/modes/cycling/santander-cycles/blaze-laserlights#on-this-page-2

[25] Jenny Eriksson, Åsa Forsman, Anna Niska, Susanne Gustafsson, and Gunilla Sörensen. 2019. An analysis of cyclists' speed at combined pedestrian and cycle paths. *Traffic Injury Prevention* 20 (2019), 56–61. https://doi.org/10.1080/15389588.2019.1658083 2018 International Cycling Safety Conference (ICSC).

[26] Donald A. Gordon and Truman M. Mast. 1970. Drivers' judgments in overtaking and passing. *Human Factors* 12, 3 (1970), 341–346. https://doi.org/10.1177/001872087001200310 arXiv:https://doi.org/10.1177/001872087001200310 PMID: 5483808.

[27] Sue Granville, Fiona Rait, Mike Barber, and Andra Laird. 2001. Sharing road space: Drivers and cyclists as equal road users. *2001* 1 (2001), 1–98. https://webarchive.nrscotland.gov.uk/3000/https://www.gov.scot/resource/doc/156597/0042065.pdf

[28] Azra Habibovic and Johan Davidsson. 2011. Requirements of a system to reduce car-to-vulnerable road user crashes in urban intersections. *Accident Analysis & Prevention* 43, 4 (July 2011), 1570–1580. https://doi.org/10.1016/j.aap.2011.03.019

[29] Kang Jiang, Zhiwei Yang, Zhongxiang Feng, N. N. Sze, Zhenhua Yu, Zhipeng Huang, and Jiajia Chen. 2021. Effects of using mobile phones while cycling: a study from the perspectives of manipulation and visual strategies. *Transportation Research Part F: Traffic Psychology and Behaviour* 83 (Nov. 2021), 291–303. https://doi.org/10.1016/j.trf.2021.10.010

[30] Jordanka Kovaceva, Gustav Nero, Jonas Bärgman, and Marco Dozza. 2019. Drivers overtaking cyclists in the real-world: Evidence from a naturalistic driving study. *Safety Science* 119 (Nov. 2019), 199–206. https://doi.org/10.1016/j.ssci.2018.08.022

[31] Magdalena Lindman, Sofia Jonsson, Lotta Jakobsson, Tobias Lasse Karlsson, Dave Gustafson, and Anna Fredriksson. 2015. Cyclists Interacting with Passenger Cars; A Study of Real World Crashes. In *2015 IRCOBI Conference Proceedings*. Lyon, France, 9–11. https://api.semanticscholar.org/CorpusID:112407468

[32] Miguel Loyola, John D Nelson, Geoffrey Clifton, and David Levinson. 2023. the influence of cycle lanes on road users' perception of road space. *Urban, Planning and Transport Research* 11, 1 (Dec. 2023), 2195894. https://doi.org/10.1080/21650020.2023.2195894 Publisher: Routledge, _eprint: https://doi.org/10.1080/21650020.2023.2195894.

[33] Ingrid van Schagen Marjolein Boele-Vos. 2024. european commission (2024). road safety thematic report – cyclists. european road safety observatory. brussels, european commission, directorate general for transport. https://transport.ec.europa.eu/system/files/2024-03/ERSO-TR-Cyclists-20240305.pdf

[34] R. Marqués and V. Hernández-Herrador. 2017. On the effect of networks of cycle-tracks on the risk of cycling. the case of Seville. *Accident Analysis & Prevention* 102 (2017), 181–190. https://doi.org/10.1016/j.aap.2017.03.004

[35] C. S. Mok, Pavlo Bazilinskyy, and J. C. F. De Winter. 2022. Stopping by looking: A driver-pedestrian interaction study in a coupled simulator using head-mounted displays with eye-tracking. *Applied Ergonomics* 105 (2022), 103825. https://doi.org/10.1016/j.apergo.2022.103825

[36] Paolo Montuori, Pasquale Sarnacchiaro, Raffaele Nubi, Donatella Di Ruocco, Alessandro Belpiede, Antonia Sacco, Elvira De Rosa, and Maria Triassi. 2021. The use of mobile phone while driving: Behavior and determinant analysis in one of the largest metropolitan areas of Italy. *Accident Analysis & Prevention* 157 (July 2021), 106161. https://doi.org/10.1016/j.aap.2021.106161

[37] Vishal Onkhar, Pavlo Bazilinskyy, Dimitra Dodou, and J. C. F. De Winter. 2022. The effect of drivers' eye contact on pedestrians' perceived safety. *Transportation Research Part F: Traffic Psychology and Behaviour* 84 (2022), 194–210. https://doi.org/10.1016/j.trf.2021.10.017

[38] Max Oudshoorn, J. C. F. De Winter, Pavlo Bazilinskyy, and Dimitra Dodou. 2021. Bio-inspired intent communication for automated vehicles. *Transportation Research Part F: Traffic Psychology and Behaviour* 80 (2021), 127–140. https://doi.org/10.1016/j.trf.2021.03.021

[39] Alexandra Papoutsaki, Patsorn Sangkloy, James Laskey, Nediyana Daskalova, Jeff Huang, and James Hays. 2016. Webgazer: scalable webcam eye tracking using user interactions. In *Proceedings of the Twenty-Fifth International Joint Conference on Artificial Intelligence (IJCAI'16)*. AAAI Press, New York, New York, USA, 3839–3845.

[40] John Parkin and Ciaran Meyers. 2010. The effect of cycle lanes on the proximity between motor traffic and cycle traffic. *Accident Analysis & Prevention* 42, 1 (2010), 159–165. https://doi.org/10.1016/j.aap.2009.07.018

[41] Robert Perot. 2023. From bikes to cars and back again: How Dutch cities became cycling cities. *Vassar College Digital Library* 1 (2023), 1–60. https://digitallibrary.vassar.edu/collections/institutional-repository/a7ce4b7d-2ed2-4f57-9b93-568666ddaf40

[42] S. M. Petermeijer, Pavlo Bazilinskyy, Klaus Bengler, and J. C. F. De Winter. 2017. Take-over again: Investigating multimodal and directional TORs to get the driver back into the loop. *Applied Ergonomics* 62 (2017), 204–215. https://doi.org/10.1016/j.apergo.2017.02.023

[43] John Pucher and Ralph Buehler. 2008. Making Cycling Irresistible: Lessons from The Netherlands, Denmark and Germany. , 495–528 pages. https://doi.org/10.1080/01441640701806612

[44] Sara Rivera Olsson and Erik Elldér. 2023. Are bicycle streets cyclist-friendly? micro-environmental factors for improving perceived safety when cycling in mixed traffic. *Accident Analysis & Prevention* 184 (May 2023), 107007. https://doi.org/10.1016/j.aap.2023.107007

[45] Mikko Räsänen and Heikki Summala. 1998. Attention and expectation problems in bicycle–car collisions: An in-depth study. *Accident Analysis & Prevention* 30, 5 (Sept. 1998), 657–666. https://doi.org/10.1016/S0001-4575(98)00007-4

[46] Gernot Sauter. 2021. (7) making cycling safer: cyclists also need pavement markings | linkedin. https://www.linkedin.com/pulse/making-cycling-safer-cyclists-also-need-pavement-markings-sauter/

[47] Francesco Scorza and Giovanni Fortunato. 2021. cyclable cities: building feasible scenario through urban space morphology assessment. *Journal of Urban Planning and Development* 147, 4 (Dec. 2021), 05021039. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000713 Publisher: American Society of Civil Engineers.

[48] Stella C. Shackel and John Parkin. 2014. Influence of road markings, lane widths and driver behaviour on proximity and speed of vehicles overtaking cyclists. *Accident Analysis & Prevention* 73 (Dec. 2014), 100–108. https://doi.org/10.1016/j.aap.2014.08.015

[49] Freya Slootmans. 2023. european commission (2023) facts and figures cyclists. european road safety observatory. brussels, european commission, directorate general for transport. https://road-safety.transport.ec.europa.eu/document/download/e916d096-cdae-4979-8700-0c81db3fbde6_en?filename=ff_cyclists_20230213.pdf

[50] SWOV. 2023. Fietsers. https://swov.nl/nl/factsheet/fietsers

[51] The Local Denmark. 2022. Danish cyclists want new markings to remind motorists to keep distance. https://www.thelocal.dk/20220915/danish-cyclists-want-new-markings-to-remind-motorists-to-keep-distance

[52] Libby Thomas, Krista Nordback, and Rebecca L. Sanders. 2019. Bicyclist Crash Types on National, State, and Local Levels: A New Look. *Transportation Research Record* 2673 (2019), 664 – 676. https://api.semanticscholar.org/CorpusID:181689938

[53] European Union. 2024. european declaration on cycling. http://data.europa.eu/eli/C/2024/2377/oj/eng

[54] Volvo. 2014. Volvo cars and poc to demonstrate life-saving wearable cycling tech concept at international ces 2015. https://www.media.volvocars.com/us/en-us/media/pressreleases/155565/volvo-cars-and-poc-to-demonstrate-life-saving-wearable-cycling-tech-concept-at-international-ces-201

[55] Rul von Stülpnagel, Rafael Hologa, and Nils Riach. 2022. Cars overtaking cyclists on different urban road types – Expectations about passing safety are not aligned with observed passing distances. https://api.semanticscholar.org/CorpusID:250632612

[56] Rul von Stülpnagel, Rafael Hologa, and Nils Riach. 2022. Cars overtaking cyclists on different urban road types – expectations about passing safety are not aligned with observed passing distances. *Transportation Research Part F: Traffic Psychology and Behaviour* 89 (Aug. 2022), 334–346. https://doi.org/10.1016/j.trf.2022.07.005

[57] Dick Waard, Frank Westerhuis, Carola Engbers, Rosemary Dubbeldam, and Hans Rietman. 2021. Enlightening cyclists: an evaluation study of a bicycle light communication system aimed to support older cyclists in traffic interactions. *International Journal of Human Factors and Ergonomics* 8 (01 2021), 1. https://doi.org/10.1504/IJHFE.2021.10040965

[58] Ian Walker. 2007. Drivers overtaking bicyclists: Objective data on the effects of riding position, helmet use, vehicle type and apparent gender. *Accident Analysis & Prevention* 39, 2 (2007), 417–425. https://doi.org/10.1016/j.aap.2006.08.010

[59] Ian Walker, Ian Garrard, and Felicity Jowitt. 2014. The influence of a bicycle commuter's appearance on drivers' overtaking proximities: an on-road test of bicyclist stereotypes, high-visibility clothing and safety aids in the United Kingdom. *Accident Analysis & Prevention* 64 (2014), 69–77. https://doi.org/10.1016/j.aap.2013.11.007