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Comparison of Vehicle-To-Bicyclist and Vehicle-To-Pedestrian Communication Feedback Module: A Study on Increasing Legibility, Public Acceptance and Trust

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***Abstract*— Autonomous vehicles have an existential communication challenge due to the lack of need for a human driver who can signal to vulnerable road users nearby about the intentions of the vehicle. This presents an opportunity for a vehicle to vulnerable road user communication system, such as for bicyclists. Enabling communication between bicyclists and autonomous vehicles will lead to an improvement of the bicyclists' safety in autonomous driving. If a bicyclist wants to pass the autonomous vehicle, the autonomous vehicle should provide feedback to the human about what it is about to do and what it would like the person to do. The user study presented in this paper investigated several possible options for an external display for effective nonverbal communication between an autonomous vehicle and a bicyclist. The results were compared to our recent study concerning vehicle-to-pedestrian communication. In total 208 participants were recruited for the vehicle-to-walker and vehicle-to-bicyclist feedback module studies. The results did not show significant differences between the communication modalities presented. This paper shows and discusses differences between vehicle-to-walker and vehicle-to-bicyclist feedback modules. It is plausible to use the same combination of interaction modes, symbols and text, as for the vehicle-to-pedestrian communication feedback module due to economic reasons. This study shows the necessity for more immersive environments to study vehicle to bicyclist communication needs in more detail.**

***Index Terms*— Autonomous Vehicle, Bicyclist, eHMI, Legibility, Public Acceptance, Trust**

I. Introduction

There has been a rapid evolution in the field of autonomous vehicles (AV) in recent years. A driverless vehicle must make decisions dynamically for every problem it faces while traveling to the destination. And we can anticipate that the AV will achieve complete autonomy in future years. But many questions arise regarding the accident prevention techniques adapted by the AV. Autonomous driving technologies can minimize accidents stemming from slow human reaction time and errors in judgment. Ultimately, these technologies will improve road safety and save lives.

Traffic accidents are a leading cause of death and injury in the U.S. [1], with the primary culprit being human error. In the year 2019, around 846 bicyclists were killed, among which 224 bicyclists were killed at an intersection [2]. Utilizing external displays can reduce risk concerns of cycling due to perceived insufficient safety [3]. Although there are no statistics stating how many bicyclist accidents were caused by lack of communication and miscommunication, it is likely that a considerable amount of the 30% of fatal bicyclist accidents which were attributed to "failure to yield right of way" by the National Highway Traffic Safety Administration was caused by communication problems [2], [4].

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A driverless vehicle may cause a lack of nonverbal communication where eye contact with the driver is commonly established. This is a critical point in which intent is communicated [5]. At present, the primary way to communicate intent is to use turn signals, which can indicate simple turns or lane changes; no more detailed interface is currently commercially-available. Without a possibility to communicate intent, both entities are set in a confused state whether to approach or wait for the other person to pass first.

We conducted a study to identify a visual feedback module for establishing a communication between a bicyclist and an AV, which increases most legibility, public acceptance and trust in the AV's decision. But to design a visual feedback module, we face certain challenges in the case of a bicyclist: Bicyclists travel at a higher speed, and the location of the bicyclist can be anywhere around the AV. Along with considering these challenges and designing the system, our main goal is to find which visual feedback module or combinations of feedback modules would increase most public acceptance, legibility, and trust in the autonomous vehicle's decision.

This study is an extension of our previously conducted vehicle-to-pedestrian communication feedback module study for a vehicle-to-bicyclist communication feedback module, see [6].

II. Background

The limited time vulnerable road users (VRU) have to detect and interpret a signal is significant for the consideration of the symbol, size, and photometric aspects [7]. Therefore, messages need to be simple, salient, and familiar [7], [8]. Further, signals on moving vehicles have to account for various combinations of both vehicles and VRUs [7]. An autonomous vehicle that indicates its intent to stop by displaying a message to the VRU should not unintentionally advise the VRU to cross in front of a different vehicle [7]. The designs need to scale from a single vehicle and pedestrian to crowded intersections [7].

While there are several studies to investigate an autonomous vehicle-pedestrian-feedback-module [9], [7], [8], [10] or a

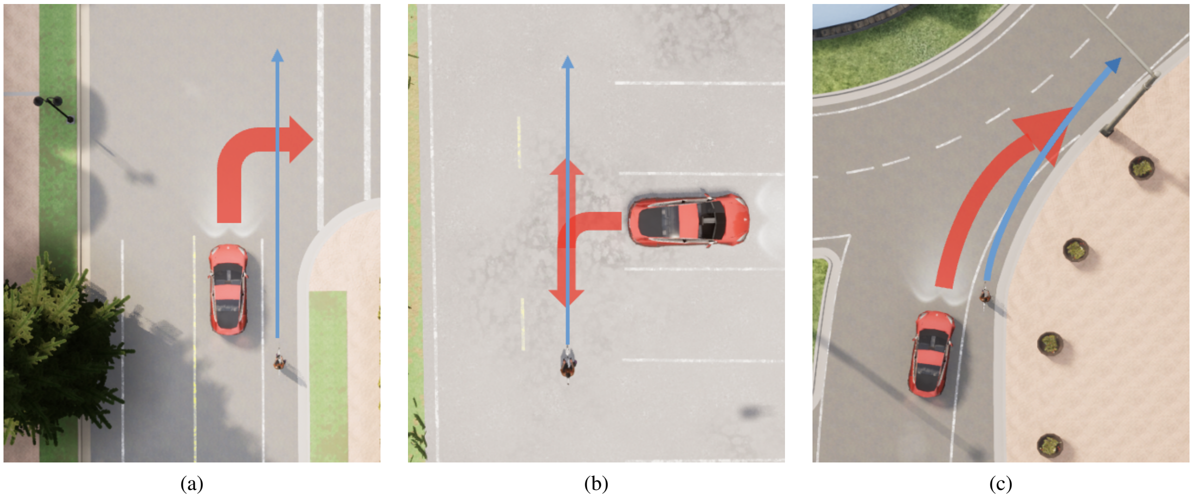


Fig. 1: Example possible collision scenarios: a) Bicyclist going straight and the AV turning right; b) The AV drives out of the parking spot; c) Bike-lane merging into the main road.

feedback module for communicating between an AV and vulnerable road users [11], we only found one previous study, which specifically investigates AV-bicyclist communication [3]. This study is limited, however, to identify a visual feedback module since most feedback modules, implemented and tested in the VR environment, are not visual or initiated by the AV. In that study, participants came up with 29 designs with visual communication. Twelve of those designs were laser projections. Most interfaces were relatively simple, such as red and green colors, simple icons, outlines of bicycles, or numbers and units representing measures, e.g., the distance between the bicyclist and the AV. For the VR study in Hou et al. [3], the visual feedback modules initiated by the AV were laser projections and a vehicle windshield display. In this paper, we expand the study by Hou et al. [3] by investigating more feedback module options via a questionnaire.

Since there is no clear indication about which feedback module would increase most the public acceptance and trust in the autonomous vehicle's decision we compare feedback module options via a questionnaire. The ideas for the different interaction modes result from literature review and brainstorming of the research group. The bike road projection and the colored car window screens are adapted from [3]. The text options "I'm resting" and "I'm about to yield" are taken from [10] and "Go ahead" is taken from [8]. The LED light options and the text "Don't pass" which is similar to the "Don't walk" option are ideas from [9]. "Safe to pass" is similar to the "Safe to cross" message mentioned in [7]. The advisory symbols "Biking" and "No biking" are similar to the cross advisory symbols in [7]. The smiley symbol originated from [12], in which the researchers used a robot's face and a waving hand to create an anthropomorphic virtual driver. The ideas for the different traffic signs and the pedestrian traffic light symbol as well as the text option "Stop" are from [13]. The idea for the zebra crossing road projection is from [14] and the go ahead road projection is from [15].

III. Method

Our prior work [6] conducted an online study with the target group pedestrians instead of bicyclists. The results of this study showed that participants preferred the combination of text and symbols as interaction modes to be displayed if the autonomous vehicle is not driving. Further, the results showed that the text interaction mode option "Safe to cross" should be used combined with the symbol interaction mode option that displays a symbol of a walking person.

A. Scenario

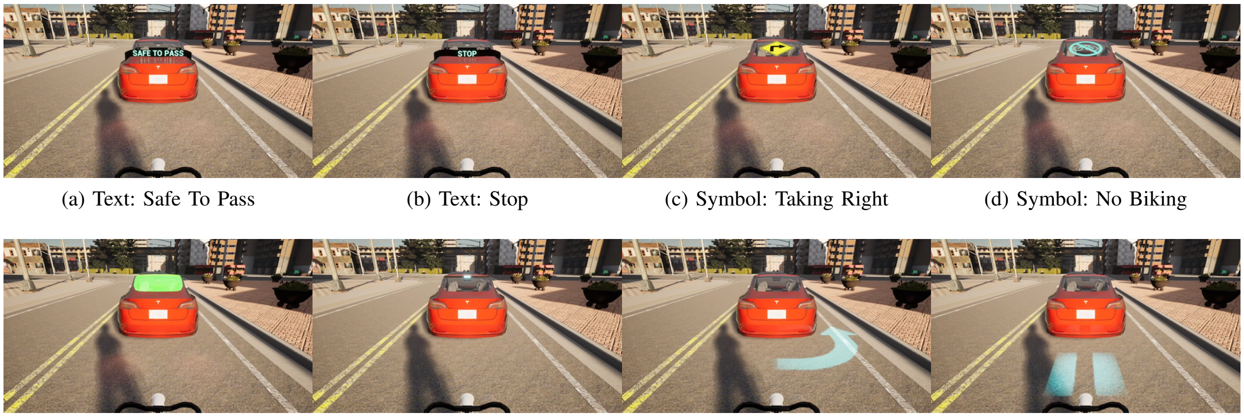
Figure 1 illustrates three example scenarios, all having a potential risk of accidents if the AV and the bicyclist do not communicate. In the first case, at an intersection, a car intends to turn right, meanwhile a bicyclist from behind the car tries to proceed straight at the same time. In the second case, a car tries to back out of a parking spot and a bicyclist is approaching perpendicular from the rear of the car. In the third case, a bike lane is merging into the main road, causing a chance of a potential crash by a car hitting the rear of a bicycle. These example scenarios demonstrate some common accident dangers to bicyclists in everyday traffic and the importance of having the possibility to communicate the vehicle's intent to avoid a potential crash.

B. Research Question

The research question is: Which visual feedback module or combinations of feedback modules increases most public acceptance, legibility, and trust in the autonomous vehicle's decision?

Legibility is important in the selection of a feedback module since the time pedestrians have to detect and interpret a signal is limited [7] and the message displayed on an AV should be intuitive and concise [16].

Public acceptance is another important aspect in the selection of a feedback module since the biggest obstacle in the mass adoption might not be technological, but public



(a) Text: Safe To Pass (b) Text: Stop (c) Symbol: Taking Right (d) Symbol: No Biking

(e) Light: Green Windows (f) Light: Static LED (g) Road Projection: Right Turn (h) Road Projection: Pause

Fig. 2: Interaction mode visualization examples.

acceptance [17], [18]. Public acceptance is essential for the extensive adoption of AVs [19].

Trust has been identified as crucial to the successful design of autonomous vehicles [20]. The American Automobile Association (AAA) reported that only one in ten U.S. drivers would trust to ride in an AV, and 28% of U.S. drivers are uncertain [20], [21].

C. Experiment Setup

The questionnaire was created using Qualtrics XM, an online survey tool. The participants were asked to watch videos of different concepts of the feedback modules, followed by corresponding questions. The simulations for the videos were created with CARLA [22], based on Unreal Engine. In Unreal Engine 4 it is possible to create and modify objects, such as vehicles and the feedback displays. We used Blender to create the feedback displays.

We designed the four sections text, symbols, lights and projections to visualize the feedback module. In Figure 2 examples of interaction mode visualizations are displayed.

We chose to frame the perspective from the point of view of the bicyclist viewing the rear of the autonomous vehicle. A real world feedback module has to be visible from 360 degrees as you can derive from the example scenarios in Figure 1. However, for simplicity and to not confuse participants with several perspectives we selected one perspective to display the different interaction modes to the participants.

D. Questionnaire

We asked the same questions as in our prior work [6], which we will reiterate in this section. We focused on making the questionnaire as simple and short as possible to answer the research question since there are many different aspects to consider for a feedback module on an AV. For the options in this questionnaire we omit current law requirements, which limit, e.g., color, flashing lights, light-up text, or projections from the vehicle [23]. Also, we ask about the general concepts and add the videos and images for illustration purposes only. That means the participant can refer to the illustration if it is unclear how a specific feedback module option could look like, but should not consider location, color or size. We decided to use the color cyan in the illustrations as much as possible to decrease the influence of color. Cyan or turquoise is a neutral color in traffic, has good visibility, and has already been used in several studies regarding an AV-pedestrian-display, e.g., in [9], [24].

The questionnaire consists of demographic related questions, questions related to the feedback module and combinations of feedback modules. Based on the participants' answers, we analyzed the most preferred, public accepted, legible and trusted visual feedback modules for autonomous vehicles.

The first section of the questionnaire is in part based on Schaefer's "Trust Perception Scale-HRI" [25] with a 5-point Likert scale for the different feedback module concepts. The following four questions were asked for each interaction mode text, symbols, lights and road projections separately.

- I believe the ___ interaction mode protects people from potential risks in the environment / looks friendly to the bicyclist / communicates clearly
- I prefer the ___ interaction mode over human-driver interaction

We added randomization to the order of displaying the interaction modes as well as the order of the specific interaction mode options to reduce bias.

Further, we asked participants to rank the interaction modes text, symbols, lights and road projections regarding preference, legibility, public acceptance and trust directly, to receive a clear answer regarding our research question:

- Please rank the interaction modes from the easiest to understand interaction mode (1) to the hardest to understand interaction mode (4) / from the interaction mode you trust the most (1) to the interaction mode you trust the least (4) / from the interaction mode you accept the most (1) to the interaction mode you accept the least (4) / in order of preference from your most preferred (1) to your least preferred (4)

The questionnaire includes questions about combinations as well to test if a combination of several feedback module concepts increases legibility, public acceptance and trust more than one single concept. This includes questions about the participant's preference about the amount of concepts, which concepts and the location of the concepts on the AV.

The questionnaire concludes with demographic questions about, e.g., age, gender, ethnicity and current level of education.

E. Participants

145 participants were recruited for the vehicle-to-bicyclist feedback module study via flyers and social media to fill out the questionnaire online. The questionnaire has a duration of about 20 to 30 minutes. The participants were allowed to skip questions. For the vehicle-to-bicyclist feedback modules study 59 participants identified as female, 59 participants identified as male, three participants identified as non-binary / third gender and the remaining 24 participants did not specify. 92 participants provided the information that they learned how to drive a car or ride a bike in the United States, while 24 participants learned how to drive a car or ride a bike in other countries (eleven in Germany, five in China, three in India, two in Japan, one in France, one in Indonesia and one in Peru). For the vehicle-to-pedestrian feedback module study we refer to [6].

IV. Results and Analysis

In this section we present the results of our study to identify a feedback module to enable an autonomous vehicle to communicate with bicyclists.

We used R to analyze the data. Since the Likert questions are ordinal, we tested for normality with the Shapiro-Wilk normality test. The result of the Shapiro-Wilk normality test achieved a p-value that is less than $p < 0.05$, so we cannot assume normality. Due to this result, we used non-parametric tests and show the results of the Likert questions with frequencies/percentages.

A. Legibility, Public Acceptance, Trust, and Preference

To answer our research question of identifying a feedback module for communicating between a pedestrian and an autonomous vehicle, we analyzed the ranking questions. Figure 3 shows a visualization of the ranking questions.

We present the raw rank-ordering data, but they are not significant. The question "Please rank the interaction modes in order of preference from your most preferred (1) to your least preferred (4)" resulted in the following average rank order: Symbol, Text, Projection, Light. The question "Please rank the interaction modes from the easiest to understand interaction mode (1) to the hardest to understand interaction mode (4)" resulted in the following average rank order: Light, Symbol, Projection, Text. The question "Please rank the interaction modes from the interaction mode you trust the most (1) to the interaction mode you trust the least (4)" resulted in the following average rank order: Symbol, Light, Text, Projection. The question "Please rank the interaction modes from the interaction mode you accept the most (1) to the interaction mode you accept the least (4)" resulted in the following average rank order: Text, Projection, Light, Symbol.

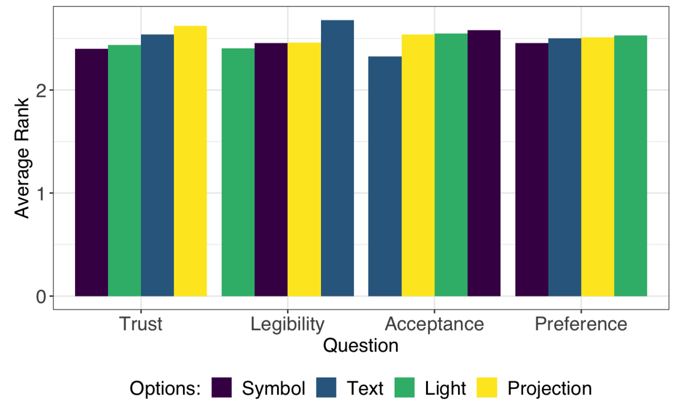


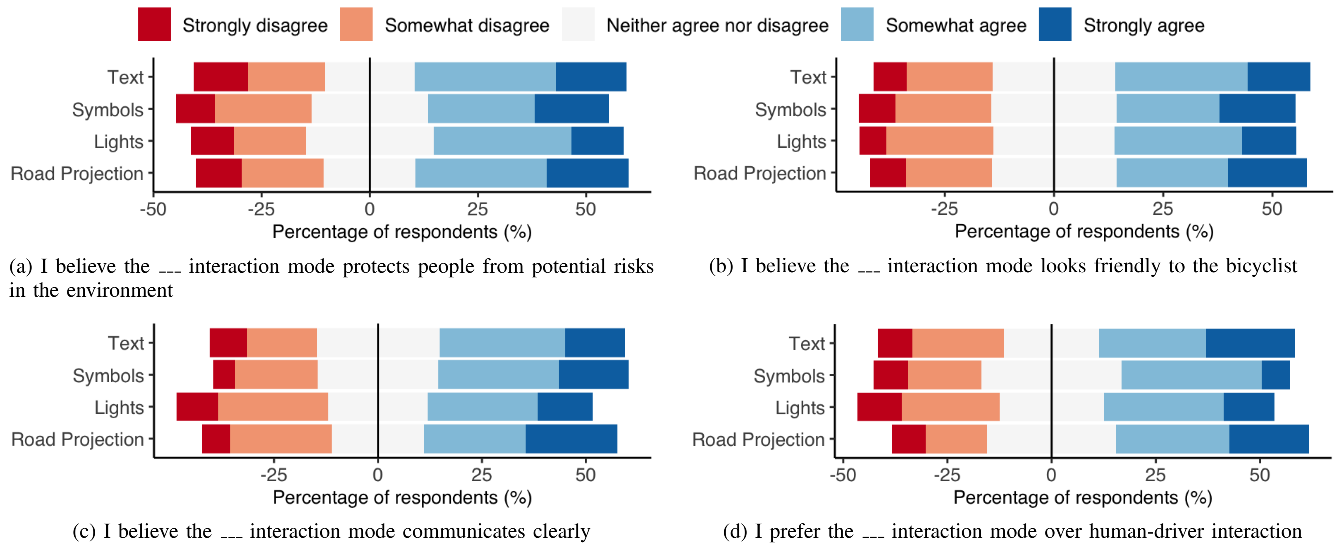
Fig. 3: The result of ranking questions regarding trust, legibility, acceptance and preference shows that there are no significant differences between the interaction mode options symbol, text, light and road projection. Significance was analyzed with the Kruskal-Wallis test.

Analysis of the Likert questions sorted by interaction modes are shown in Figure 4. Regarding the question "I believe the ___ interaction mode protects people from potential risks in the environment" participants agreed with the road projection interaction mode (49.24%), followed by the text interaction mode the most (48.89%), light interaction mode (43.94%) and symbol interaction mode (41.79%). "I believe the ___ interaction mode looks friendly to the bicyclist" led to most agreement for the text interaction mode (44.70%), followed by the road projection interaction mode (43.61%), light interaction mode (41.54%) and symbol interaction mode (40.91%). Participants believed that the interaction mode communicates clearly led to most agreement for the road projection interaction mode (46.56%), followed by the symbol interaction mode (45.80%), text interaction mode (44.70%) and light interaction mode (39.53%). Furthermore, participants preferred the interaction mode over human-driver interaction led to most agreement for the text interaction mode (46.97%), followed by the road projection interaction mode (46.32%), light interaction mode (40.91%) and symbol interaction mode (40.46%). We tested each question for significance with the Kruskal-Wallis test, which showed no significance for the different interaction modes.

Taking all results together regarding which feedback module increases most legibility, public acceptance and trust in the autonomous vehicle's decision participants did not have significant preferences towards an interaction mode.

B. Supplemental data

1) Combination of interaction modes: We checked if participants prefer to add several interaction modes to the AV. From Table I it can be concluded that the most selected



(a) I believe the ___ interaction mode protects people from potential risks in the environment

(b) I believe the ___ interaction mode looks friendly to the bicyclist

(c) I believe the ___ interaction mode communicates clearly

(d) I prefer the ___ interaction mode over human-driver interaction

Fig. 4: Assessment by participants of the questions (a), (b), (c) and (d) with a 5-point Likert scale for the four selected interaction modes text, symbols, lights and road projection. The differences between the interaction modes are not significant.

option by participants is to combine two interaction modes (41.09%).

One	Two	Three	Four	Not sure
22.48%	41.09%	23.26%	8.53%	4.65%

TABLE I: The distribution of the question results “How many interaction modes would you combine?” shows that most participants would combine two interaction modes.

When being asked the question “Which interaction modes would you combine?” the answer for two interaction mode combinations, which was selected most by participants (25.00%) is to combine the text and road projection interaction modes, followed by the text and symbol interaction modes (20.00%), and the light and road projection interaction modes (20.00%), see Figure 5. We show that participants answered with different combinations. The differences between the answers are not significant.

Since the differences between the interaction modes are not significant, we further looked at the specific interaction mode options for all four interaction mode options, see Figure 6. We conducted Mann-Whitney U tests for each of the groups to check for significance. The threshold of significance to the highest ranked option is visualized by a dashed line in Figure 6. However, most differences between the options are not significant.

V. Discussion

The results of the vehicle-to-bicyclist communication feedback module study presented in this paper regarding which feedback module increases most legibility, public acceptance and trust in the autonomous vehicle’s decision for the four selected interaction modes text, symbols, lights and road projection are not significant. In comparison, the results of our previously conducted vehicle-to-pedestrian communication feedback module study [6] showed that participants prefer symbols over text, lights and road projection and that participants prefer the combination of symbols and text as interaction modes to be displayed. This can have several reasons. Bicyclists move at a higher speed than pedestrians and the location of the bicyclist can be anywhere around the autonomous vehicle. These factors lead to a different focus when ranking interaction mode options: They have to be seen and understood more quickly. For these reasons, road projection and light interaction modes seem to gain advantage compared to symbol and text interaction modes. Since in the previously conducted vehicle-to-pedestrian communication feedback module study [6] the result was to use a combination of text and symbol interaction modes, this combination can be used for the vehicle-to-bicyclist

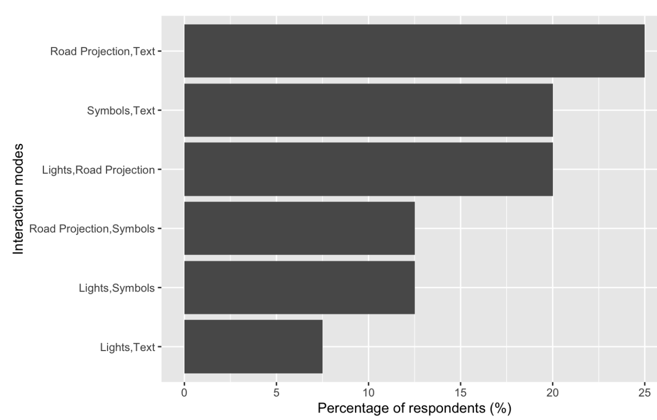
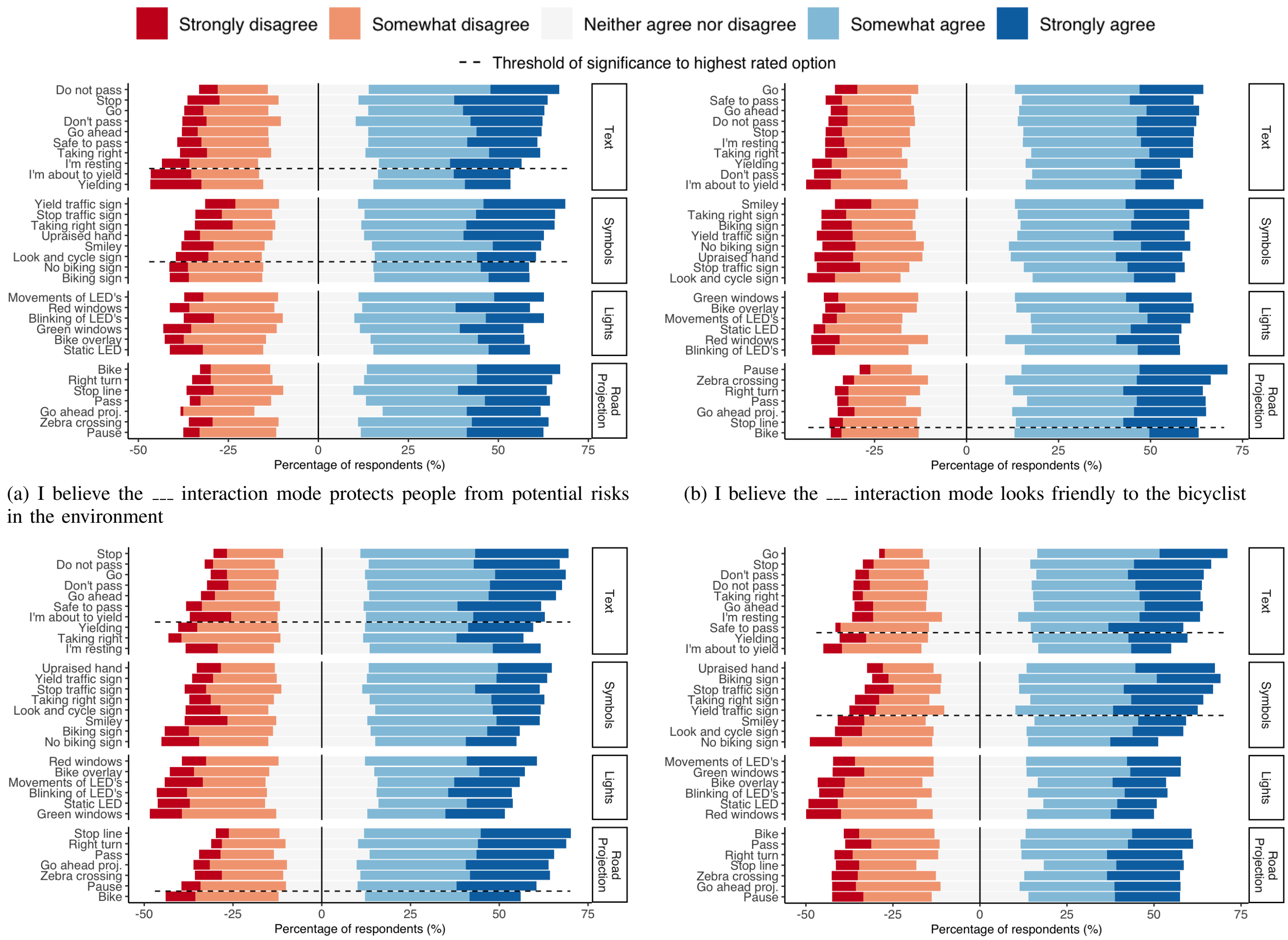


Fig. 5: The result of the question “Which interaction modes would you combine?” shows that the differences of the answers between combining two interaction modes are not significant.



(a) I believe the ___ interaction mode protects people from potential risks in the environment

(b) I believe the ___ interaction mode looks friendly to the bicyclist

(c) I believe the ___ interaction mode communicates clearly

(d) I prefer the ___ interaction mode over human-driver interaction

Fig. 6: Assessment by participants of the questions (a), (b), (c) and (d) with a 5-point Likert scale for the specific interaction modes for the bicyclist options. We conducted Mann-Whitney U tests for each of the groups to check for significance. Most differences between the options are not significant, see the threshold of significance to the highest ranked option which is visualized by a dashed line. However, tendencies are identifiable, such as selecting a very short text message.

communication feedback module as well. Applying the same feedback modules for both use cases has the advantage to limit costs for the feedback modules.

While most differences between the options for the different interaction modes in Figure 6 are not significant, tendencies are identifiable. For the text interaction mode if it is safe to pass, participants agreed with “Go” the most and if it is not safe to pass, participants agreed with “Stop” (or “Do not pass”) the most. These are very short text options, which emphasizes to consider the high speed of bicyclists when selecting interaction modes for a feedback module. From the significance tests we can conclude that we will have to follow-up investigating the majority of specific interaction mode options. Some specific interaction mode options can be omitted due to a significant difference to the highest ranked option: For the text interaction mode we will omit “I’m about to yield”. “Yielding”, “Taking right” and “I’m resting”, for the symbol interaction mode we will omit the No Biking sign, the Biking Sign, the Smiley and the Look And Cycle sign, and for the road projection interaction mode we will omit the Bike image road projection. Further research is necessary to validate the results and develop a vehicle-to-bicyclist-communication-feedback-module.

VI. Limitations and Future Work

The questionnaire has several limitations, since there are too many aspects to consider for a feedback module to ask about each aspect in a questionnaire due to complexity and time constraints. However, this questionnaire was developed as a first study to reduce the amount of extensive options that could potentially be used as a feedback module. In this study, we asked about general concepts and therefore omitted, e.g., current law requirements, location, color or size of a possible vehicle-to-bicyclist-communication-feedback-module. Another limitation is that, although we tried to avoid bias as much as possible by introducing randomization and using a well selected set of possible options, bias in this questionnaire can not completely be considered excluded.

This study also shows that it is necessary to follow-up on the questionnaire results with a more immersive study, such as in Virtual Reality to include several factors such as speed, balancing on a bicycle and perceived safety.

The results of this questionnaire are the basis for further research regarding a vehicle-to-bicyclist-communication-feedback-module and is planned to be used to develop a communication capability between an autonomous vehicle and a bicyclist. In further studies, we plan to use the results of this questionnaire in a Virtual Reality (VR) user study to create and simulate the selected interaction modes in more detail and in different environments. As a subsequent step we will use the results of the questionnaire and the VR user study to verify in the real-word on a vehicle.

VII. Conclusion

We presented a study that investigated numerous feedback module options focused on bicyclists to identify a feedback module for communicating between a bicyclist and an autonomous vehicle. We examine which mode increases most legibility, public acceptance and trust in the autonomous vehicle's decision. This study is focused on bicyclists, who move at a higher speed than other vulnerable road users such as pedestrians, and the location of the bicyclist can be anywhere around the autonomous vehicle. We did not observe differences between interface types, in contrast to our previous vehicle-to-pedestrian communication feedback module study. It is plausible to use the same interaction modes as for the vehicle-to-pedestrian communication feedback module due to economic reasons. In that study, the symbol-based interaction mode was selected as the interaction mode, that most increases legibility, public acceptance, and trust in the autonomous vehicle, if one interaction mode is used and a combination of text-based and symbol-based interaction modes if several interaction modes are used, see [6]. Since the results between interface types are not significant we plan on validating the results in future studies.

Acknowledgments

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