Exploring the Effects of Multimodal User Interfaces in Autonomous Vehicles

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Abstract

This short paper presents a study design created to explore how multimodal user interfaces (UIs) influence comfort, user experience, and overall well-being in fully autonomous vehicles. The study uses a motion-based driving simulator equipped with real vehicle components to provide realistic driving conditions. Participants are asked to complete two trials: a baseline trial and one with either a simple or extended multimodal UI combining auditory, tactile, and speech-based feedback. Driving scenarios include lane changes, emergency braking, V2X and V2V communication, and road surface variations. Data collection integrates physiological measures (EGG, EDA, PPG), self-assessment questionnaires on motion sickness (MSAQ) and user experience (UEQ), and performance on a reading comprehension task simulating non-driving activities. The paper provides some initial data about the participants' demographics and their user experience with the UI, and gives an insight into the planned nest steps in terms of analysis and results application. The findings from this study will provide an insight into the potential of multimodal HMI design to enhance safety, comfort, and user acceptance in autonomous vehicles.

Keywords

User interface, autonomous vehicle, multimodal interaction, non-driving related task

1. Introduction

This short paper presents a user study design focusing on investigating how the integration of a multimodal user interface (UI) in a fully automated vehicle (i. e. autonomous vehicle (AV)) affects the AV user's comfort, user experience and overall well-being when using these technologies. By focusing on human-vehicle interaction, the study explores the role of and potential of human-machine interaction (HMI) in enhancing user satisfaction and mitigation of potential discomfort and motion sickness. Additionally, it examines how drivers engage in non-driving related tasks when using autonomous vehicles and how these activities influence their overall well-being and interaction with the vehicle.
This study is conducted as part of Ljubljana Pilot, one of four Pilots in the HorizonEurope project Federated cyber-physical infrastructure for operational design domain continuity (FRODDO) [1].

2. Methodology

The study is conducted in a motion-based driving simulator, with the visuals presented on a triple 49-inch screen configuration. Although an AV is used for the study, the simulator is equipped with real car parts including a steering wheel, pedals, gear box and a dashboard, to increase the immersiveness and realistic representation of a driving environment.

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2.1. Driving scenarios

Two versions of one driving scenario (please see **Figure 1**) were developed for the study, differing in the starting and ending points, and consequently route used by the AV during the trial. This enables very similar driving conditions that allow for comparison of results, while making them different enough to avoid anticipation effects with subsequent trials for the same user. The scenario included driving on a highway, city, and rural roads and lasted for about 13 minutes.

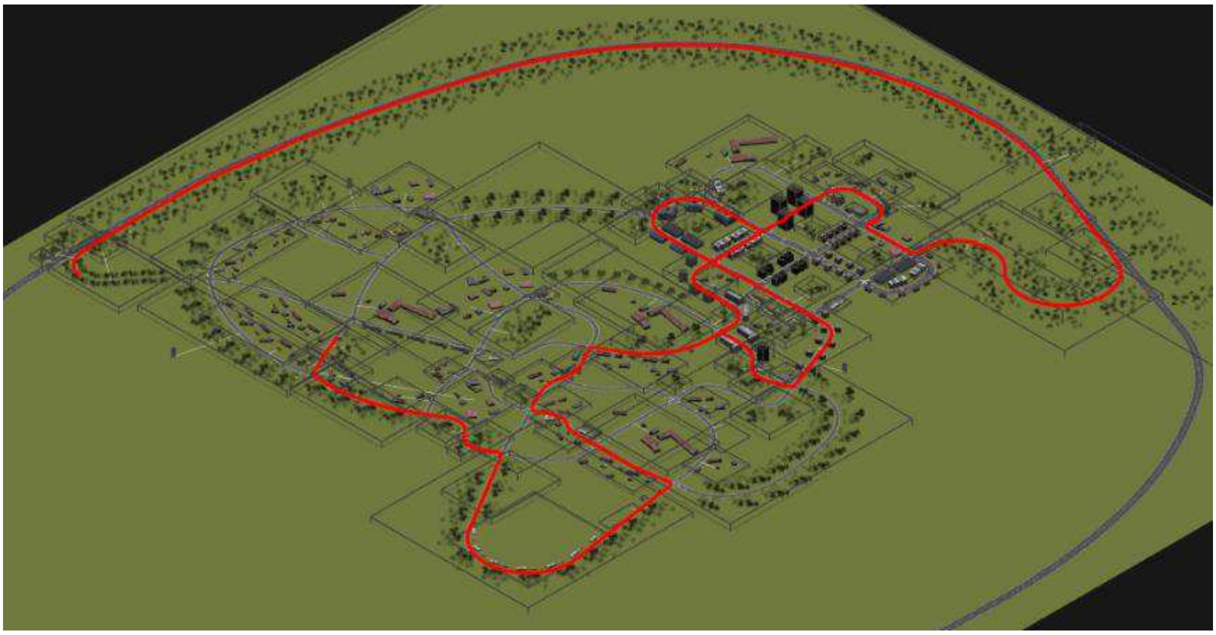

Figure 1: Driving scenario map used in the study.

The driving scenarios were developed in SCANeR Studio [2]. To explore the effects of the UI on the AV user's comfort, five different types of driving situations were developed:

1) **Lateral movement** (e.g., lane change, turning at intersection),
2) **Longitudinal movement** (e.g., emergency braking, front vehicle stop, see **Figure 2**),
1) **Preventive aggressive maneuvering of the vehicle to prevent an accident caused by other traffic participants** (e.g., street cams detecting dangerous situation),
2) **Unexpected acceleration and avoiding the obstacle** (e.g., next vehicle will move out of the way, so we can speed up), and
3) **Road deformation** (e.g., street bumper, don't spill your coffee).

Each trial featured 12 driving situations.

2.2. User interface

To communicate the vehicle's actions in each of the five groups of driving situations, a multimodal user interface was developed, which featured:

- simple auditory sounds (beeps, chimes, and turning signal sounds),
- synthesized speech (description of the vehicle's action and/or the event in the environment that provoked the vehicle's action), and
- tactile information (in the form of vibrations, placed in the driving seat).

Different combinations of modalities were then used for different driving situations, based on the nature of the event and its potential impact on the driver's safety. To further access the effect of abstract from representational messages, two versions of the multimodal interface were explored:

- Simple UI: featuring only simple auditory sounds, and for critical events also tactile information
- Extended UI: all of the elements of the simple UI with the addition of synthesized speech.

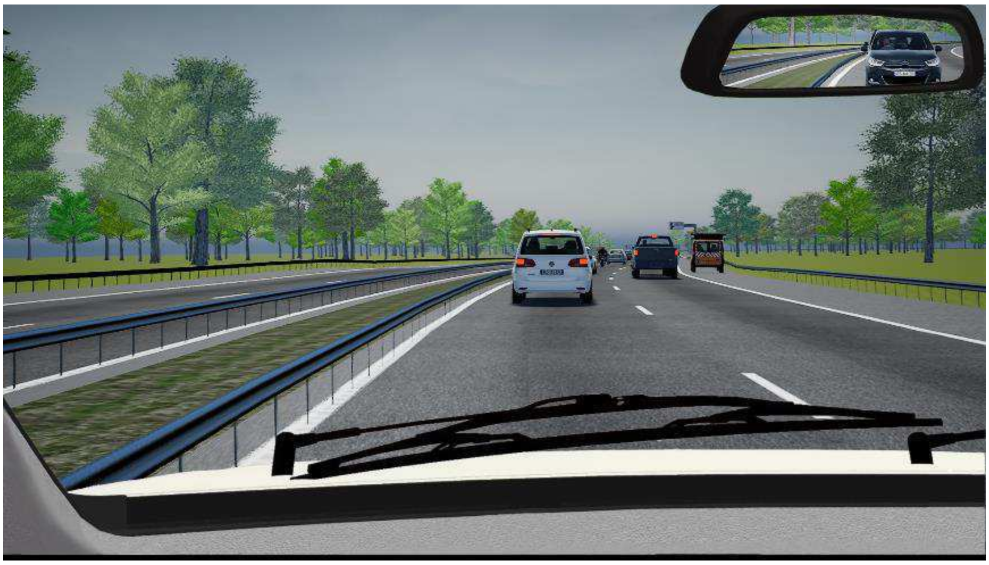

Figure 2: An example of a situation where drivers could benefit from appropriate UI design: Emergency braking due to congestion on a highway road.

2.3. Study design

The study design was approved by the University of Ljubljana's Ethical Committee, no. 049-2025. It was developed following guidelines as seen in Research Methods in Human-Computer Interaction [3].

This study has a mixed design. The effects of using an UI in AVs are observed within-subject. For this, each participant completes two trials: a baseline trial without any UI, and one trial with one of the UIs. The effects of the format of the messages (abstract beeps vs. representational speech) are observed between-subjects, comparing only the results from trials each participant performs with one of the UIs. The trial order and version of driving scenario used was randomized to avoid confound effects (such as increased comfort due to increased familiarity with the equipment in the second trial), that would emerge if the same order was used. This was made possible by using 2 versions of the driving scenario and three versions of the UI assistance (baseline or no UI, simple UI and extended UI). Table X presents the possible 8 combinations designed following the rules of a Latin square. This was then repeated until the predefined number of participants was reached.

Table 1
Trial order randomization using Latin square design.

Trial order combination	Driving scenario – version 1	Driving scenario - version 2
1	1B	2S
2	1B	2E
3	2S	1B
4	2E	1B
5	2B	1S
6	2B	1E
7	1S	2B
8	1E	2B

*B = Baseline trial; S = Trial with Simple UI; E = Trial with Extended UI.

Prior to the start of the study, each participant is provided with a written study description, explaining the goals of the study and tasks of the participant. This is followed by an informed consent, where the participants are further informed about the potential risks and benefits of participation in the study. The informed consent was prepared based on the Informed template for conducting studies with human participants at University of Ljubljana. Each participant is provided with a 10€ gift card, as a compensation for their time and effort for participating in the study.

The effects are observed through three groups of dependent variables: physiological data, self-assessment data and performance data of a non-driving related task the participants are asked to complete during each trial.

Physiological data is collected with Bitalino [4] with 100 Hz sampling frequency, using an electrogastrogram [EGG] sensor, an electrodermal activity [EDA] sensor, and a photoplethysmogram [PPG] sensor as shown in **Figure 3**. In addition, gaze and other pupilometry variables are collected with Tobii Pro Glasses 3 wearable eye tracker with 100 Hz sampling frequency [5].

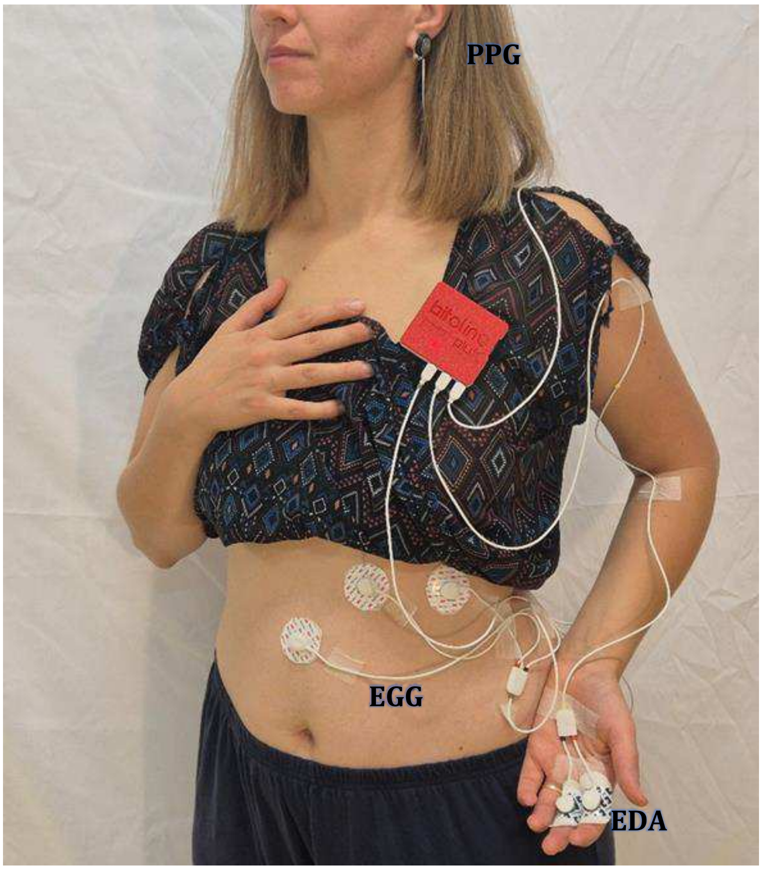

Figure 3: Sensors used for collections of physiological data.

The self-assessment data focuses on gathering information about motion sickness and user experience with the UIs. Motion sickness is observed using the Motion Sickness Questionnaire (MSQ) [6]. With this questionnaire, the participant is asked to rate their current physical status prior the start of the study, and after each trial. The results are then compared to explore any effects of the UI on motion sickness. The user experience is collected with the User Experience Questionnaire [7]. Each participant completes the UEQ immediately after completing the trial with the UI. The questionnaire consists of 26 questions, which can be answered using a 7-point Liker scale (1 – Completely agree, 7 – Completely disagree). The answers are used to provide scores on six aspects of user experience – Attractiveness, Perspicuity, Efficiency, Dependability, Stimulation and Novelty.

Lastly, participants are asked to complete a non-driving task (NDRT) during each trial. The introduction of a NDRT is simulation of how AV users are expected to spend their time when using an AV, i.e. engage in tasks such as reading, writing or interacting with electronic devices. In this study, a reading comprehension task is introduced, which requires the participant to read a text and then complete a short quiz asking them about information from the text. The reading comprehension task is an adaptation from an exam aimed at 8th grade pupils in Slovenia. The reasoning behind using this task is two-fold: a) it is engaging and cognitively demanding enough to require the participants to focus on the task and not on driving, and b) it is relatively simple enough for all participants to complete it, so that it does not discourage or evoke any unnecessary performance pressure. Two versions were used, to provide different texts in each of the trials. Lastly, the study collected information about the participant's demographics, such as age, gender, driving and simulation technology experience.

3. Participants demographics and experience

24 participants (10 male and 14 female) aged between 21 and 64 (M = 40.21, SD = 13. 71) took part in the study until September 30th. All of the participants had a valid driving license (M = 20.79, SD = 13.45), with 66.67% of them reporting to drive daily, 20.83% few times a week, 8.33% few times a month, and 4,17% only few times a year.

Participants were further asked about their past experiences with driving simulation, playing mobile and video games, and use of advanced driving assistive systems (ADAS), to better understand their levels of familiarity with the topic and lab environment used for conducting the study. The results are presented in **Table 2**.

Table 2
Participant's experience with driving simulation, video and mobile games and use of ADAS.

Criteria	**Never**	**Once**	**Few times**	**Multiple times**
Used a driving simulator	29.17 %	25 %	33.33%	12.5 %
	Never	**Once a week or less**	**Few times a week**	**Every day**
Plays games	54.16 %	29.17 %	12.5%	4.17 %
	Never	**Once**	**Few times**	**Multiple times**
Uses ADAS	37.5 %	8. 33 %	12.5 %	41.67 %

4. Next steps

The intermediate next step is completing the data collection. A total of 30 participants is foreseen to take part in this study. This will be followed by data analysis of all three groups of dependent variables.

The physiological EGG, EDA and PPG signals will be used to assess the effect of the UI on the participants' comfort, stress, arousal and overall wellbeing, by comparing the results from the baseline trial with the trials with the UI. A mixed model will be applied, to further explore whether the information modality and message format (abstract vs. representational) has any effect on these physiological states. The gaze and pupilometry data will be used to explore the effects of the UI on trust, with the gaze data considered as a direct indicator of trust. The results from the NDRT performance will be used as an indirect indicator about the participant's trust in the AV and the impact of the UI on it, with positive correlation indicating the participants trust and vice versa, negative correlations low trust and urge for monitoring the driving rather than focusing on the NDRT.

The self-reported motion sickness will be also used to assess the effects of the absence/presence of an UI – and the version of it - on the participant's motion sickness. The self-reported user experience will be used to obtain an understanding of the impact of the UI on the participants' experience, and by using the benchmark values featured in the UEQ Data Analysis

Tool (UEQ, Germany), obtain an insight on how the evaluated UI compares to other products (business software, web pages, web shops, social networks) featured in the benchmark.

Lastly, the demographic data will be used to investigate if there are any age, gender or experience correlations with the user experience, comfort and trust when using an AV and any potential impacts the presence/absence of an UI has on them.

After completing the analysis, we hope the findings from this study will provide an insight into the potential of multimodal HMI design to enhance safety, comfort, and user acceptance in autonomous vehicles.

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