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Don’t Worry, I'm in Control! Is Users’ Trust in Automated Driving Different When Using a Continuous Ambient Light HMI Compared to an Auditory HMI?

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Ambient LED displays have been used to provide peripheral light-based cues to drivers about a vehicle's current state, along with providing requests for a driver’s attention or action. However, few studies have investigated the use of an ambient LED display to improve drivers' trust, perceived safety, and reactions during L3 automated driving. Due to the ambient nature of an LED lightband display, it could be anticipated that it would provide reassurance of the automation status while automation is on, along with providing a gentle cue for non-urgent transitions of control. This video submission presents a methodological overview of a driving simulator study designed to evaluate the effectiveness of an ambient peripheral light display (Lightband HMI) in terms of its potential to improve drivers' trust in L3 automation, along with a comparison of a Lightband and Auditory HMI in terms of their effectiveness in facilitating transitions of control.

CCS CONCEPTS • **Human-centered computing→Interaction design→Empirical studies in interaction design • Human-centered computing→Human computer interaction (HCI)→HCI design and evaluation methods→Laboratory experiments**

Additional Keywords and Phrases: human-machine interface; autonomous vehicles; ambient displays; trust; human factors; transfer of control

1 INTRODUCTION

Ambient LED displays provide peripheral light-based cues to drivers about a vehicle's current state, along with requests for a driver’s attention or action. They have been investigated as potential collision warning tools [3], lane change decision aids [6], a means to help modulate drivers’ speed [9, 15], and to guide drivers’ attention to identify targets (road users/obstacles), and indicate vehicle intention [12, 13]. Peripheral ambient light displays have also been used to inform drivers of malfunctioning ADAS [7], and to facilitate collaborative driving tasks between the driver and the co-driver [13].Recently, light displays have been applied in the context of automated driving. For example, Borojeni et al. [2] conveyed contextual information through ambient displays to assist drivers during take-over requests and found that this resulted in shorter reaction times and longer times to collision, without increasing driver workload. More commonly, light displays have been to provide information/warnings to drivers about other road users, or the AVs intentions [4]. The research in both manual and automated driving shows that, in general, ambient lights are rated highly by drivers, and drivers are sensitive to peripheral cues [6]. However, few studies have investigated the use of these displays to improve drivers' perceptions of trust and safety during automated driving, and to facilitate transitions between L3 automated driving and manual driving. Therefore, the current driving simulator study, conducted in the L3Pilot project, co-funded by the European Commission, aimed to evaluate the effectiveness of an ambient peripheral light display (Lightband HMI) in terms of its potential to improve drivers' trust in L3 automation. Trust was measured through a questionnaire, and through level of engagement in a non-driving task during L3 automated driving. In addition, we assessed whether this Lightband HMI could be used to facilitate effective transitions of control between L3 automated driving and manual driving, compared to a more conventional Auditory HMI.

2 METHOD

2.1 Participants

Following approval from the University of Leeds Research Ethics Committee (Reference: LTTRAN-132), we recruited 41 drivers (20 Male average age 44 years), via an online social media platform. Participants received £30 for taking part in the experiment and were free to withdraw at any point.

2.2 Design and Procedure

2.2.1 Equipment

The experiment was conducted in the full motion-based University of Leeds Driving Simulator (UoLDS). When active, the automated driving system (ADS) assumed lateral and longitudinal vehicle control and maintained a maximum velocity of 70 mph. The status of the ADS was indicated through a symbol that was located on the left panel of the vehicle’s dashboard display (Figure 1). The symbols for “Take-over request” and “Engage automation” pulsed at a rate of 2 Hz until the driver resumed control or engaged automation as required. The display of the symbols for “Manual control” and “Automation engaged” remained constant.

2.2.2 Experimental Design

A 2X5 within-participant design was used for this study, with the factors HMI type (Lightband, Auditory) and Take-over number (1-5). HMI type was fully counterbalanced across participants.

HMI type specifies the HMI drivers were presented with during automated driving and the take-over i.e., Lightband or Auditory. The vehicle's dashboard display contained the same symbols for both conditions (Figure 1). In the Lightband condition, an LED-based lightband notification system was displayed in the vehicle cabin during automated driving and take-overs (Figure 1). During manual driving, the lightband was not active. When automation was available to be engaged, the lightband pulsed with a blue light at 2 Hz until the driver turned automation on. During automated driving, the lightband displayed a solid blue light to indicate that the automation was operating normally. During take-over requests, the lightband pulsed with a red light at 2 Hz until the driver resumed manual control. The lightband HMI was not accompanied by any auditory warnings. In the Auditory condition, participants received an auditory alert (880 Hz, repeating every 1 s, alternating on/off 0.5 s) to notify the driver to engage or disengage the automated driving system. However, unlike in the Lightband condition, there was no auditory signal during automation to indicate that the automation was operating normally.

Take-over number specifies the number of times drivers resumed control during the experimental drive, for each HMI condition. There were five takeover requests in each drive.

In both conditions, during automated driving, participants were instructed to engage in a visual non-driving related "Arrows" task [5]. The Arrows task required participants to search for, and touch, the upward-facing Arrow, displayed in a 4x4 grid of Arrows, using a touch screen in the centre console. The screen displayed the current participant's cumulative score and a 'score to beat' to keep them engaged in the task.

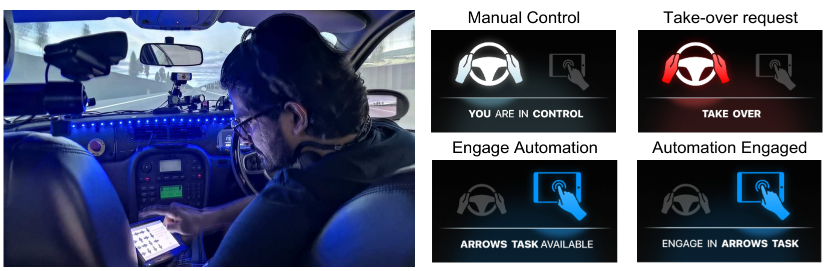

Figure 1: Example of a driver performing the Arrows task during automated driving in the Lightband HMI condition (left), and the HMIs located in the vehicle's dashboard display (right).

2.2.3 Procedure

During recruitment, participants were emailed a screening and demographics questionnaire, which included questions about age, gender, driving experience, and experience with different Advanced Driver Assistance Systems (ADAS). The questionnaire also included the Arnett Inventory of Sensation Seeking [1], traffic locus of control questionnaire [11] and the Van Der Laan system acceptance scale [14]. To be eligible to take part in the experiment, participants had to hold a valid licence to drive a car, have at least one year's experience driving in the UK, and not have participated in a driving simulator study that included interaction with automated vehicles. Prior to arrival, participants were emailed a description of the study, information about COVID-19 procedures during the experiment, and were asked to sign a consent form.

Upon arrival at the simulator, the experimenter asked the participant a series of questions to ensure COVID-19 compliance. They were then taken into the building where the experiment was explained in more detail, and they were given the opportunity to ask questions. Participants were taken into the simulator dome and the experimenter explained all the safety procedures, driving controls of the vehicle, and various dashboard icons, as well as how to do the Arrows task. Participants were asked to drive in the centre of the lane, maintain the 70-mph speed limit, and adhere to the standard rules of the road, ensuring safe operation of the vehicle, throughout the drive. The drives took place on a three-lane motorway with ambient traffic. Before each of the two experimental drives, participants performed a short practice drive. To avoid confusing participants, practice drives only showed the HMI system that they would experience in the subsequent experimental drive.

The experiment began with the participant driving in manual mode, after which they received an instruction from the automated driving system to turn the automation on. Once automation was engaged, participants began performing the arrows task. After 2 minutes, participants received a notification to take over control. To turn automation off, participants had to have both hands on the steering wheel (as judged by the capacitive steering wheel), be looking at the road ahead (as judged by the driver monitoring system) and pull the left indicator stalk towards them. There was no lead vehicle or obstacle during the take-overs. However, during the automated drive, vehicles did move in and out of the lane ahead. Our aim was to implement a non-critical take-over request that did not cause drivers any distress.

Each experimental drive lasted ~17 minutes, with five ~2-minute automation segments, interspersed with ~1-minute manual driving (Figure 2). There were five take-over requests per drive (10 in total). The entire experiment lasted 2 hours. After the practice drive, and after each experimental drive, participants rated their perceptions of trust, safety, and HMI usability, by answering a series of questionnaires on a mobile tablet.

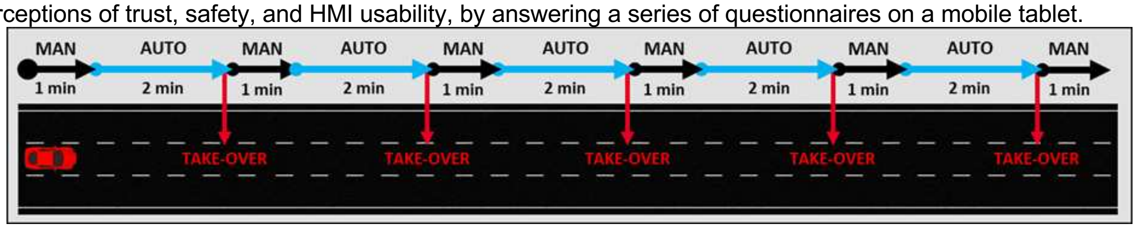

Figure 2: Schematic representation of each experimental drive.

3 CONCLUSIONS

With the increased availability and testing of automated vehicle systems in recent years, the research focus is moving to investigating how to ensure user comfort while automation is engaged. With research showing that drivers would like to engage in non-driving related activities while automation is switched on [10], it is important to ensure that users have sufficient trust in the system to become engaged in these activities. In this work in progress, we aim to evaluate the effectiveness of an ambient peripheral light display (Lightband HMI) in terms of its potential to improve drivers' trust in L3 automation, along with its impact on transitions of control between automated and manual driving. We hypothesised that the Lightband HMI will lead to increased trust in the automated driving system by providing a constant peripheral visual feedback about the system’s status, allowing drivers to move their eyes away from the road without having to constantly check the dashboard to ensure that automation is on. The comparison with a conventional auditory HMI will allow us to evaluate whether a peripheral Lightband can also provide an effective cue to aid with transitions between automation and manual driving in non-critical situations. It is anticipated that the Lightband will provide a gentler cue for non-urgent transitions, which drivers may prefer to an auditory HMI. The results of this study will allow us to develop design recommendations for promoting driver trust and acceptance of automated vehicles.

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