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Evaluating Mixed Reality Training for Calibrating Operators' Mental Models of Advanced Driver Assistance Systems

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1. Narrative

1.1. Introduction

Advanced Driver Assistance Systems (ADAS) offer safety benefits by handling active driving tasks. However, due to limited operational design domain, these systems may require driver intervention, making drivers' mental models about system limitations and capabilities an important factor when operating them. Literature suggests most drivers are uninformed or unaware of their systems (McDonald et al, 2018), lacking complete or accurate mental models. Mental models (MM) are described as reflections of operators' knowledge of system's purpose and various functioning states (Seppelt & Victor, 2020). Incomplete MM of systems' limitations may also adversely affect drivers' hazard avoidance behavior.

Hazard avoidance (HA) is a blanket term for a collective, continuous set of behaviors related to awareness, perception, and response, that drivers need to exhibit to safely drive on the roadway (Pradhan & Crundall, 2017). When driving manually, HA is related to environmental awareness (Horswill & McKenna, 2004). However, with ADAS handling driving tasks, drivers' mental workload may be reduced (De Winter et al., 2014) making more mental resources available for non-driving tasks (Naujoks et al., 2016), resulting in them being 'out-of-the-loop' (Merat et al., 2019) and unable to attend to threats (Louw & Merat, 2017). This emphasizes the importance of understanding the relationships between MM and HA in the context of ADAS.

MM is influenced by knowledge, experience, and training. Research shows that training improves MM about vehicle automation (Forster et al, 2019; Pradhan et al, 2022), but there is sparse evidence associating improved MM about ADAS through training to improved HA. Hence, it is essential to establish these relationships through empirical research.

1.2. Results

The first research phase involved an extensive literature review and brainstorming sessions. This yielded a conceptual framework (Figure 1), which mapped relationships between training, MM, and HA, and introduced behaviors for HA in the ADAS context. While traditional HA is related to environmental awareness (Pradhan & Crundall, 2017), for ADAS, system awareness also plays a role. System awareness may be influenced by drivers' MM about system states and functions. For perception, drivers need to collect and interpret system-related information from in-vehicle displays, and also their surroundings. Responses can involve vehicle control or system control (change ADAS parameters) or both. Another literature review was conducted to identify and shortlist outcome measures for HA behaviors. The framework also generated the following hypotheses which would be tested in the third phase,

- H1. Training improves drivers' MM about ADAS.
- H2. Quality of drivers' MM affects System Awareness.
- H3. Quality of drivers' MM affects Lookout behaviors.
- H4. Quality of drivers' MM affects System Control.
- H5. Training platform impacts drivers' MM.

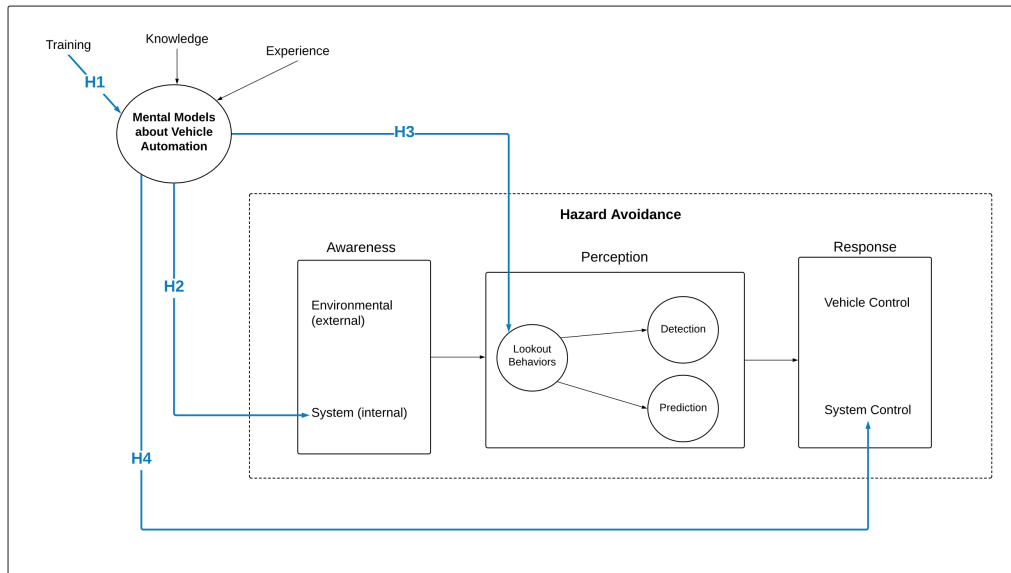


Figure 1.

The second phase involved conceptualizing and designing training content to improve drivers' MM about ADAS. The Virtual Reality platform was chosen since literature recommends it as effective for delivering training and improving user knowledge and behavior (Madigan & Romano, 2020). The VR training program was developed using the Unity game engine and was designed to be delivered through the HTC Vive ProEye (Figure 2). The ADAS feature chosen for the training was Adaptive Cruise Control (ACC), which controls vehicle speed and gap distance from lead vehicle and was chosen since literature shows that drivers are unaware or misinformed about ACC features (McDonald et al, 2018; Jenness et al, 2008). This phase is currently ongoing and almost finished.



Figure 2.

The training program has five modules along with quizzes and follows an error-based training approach (Ivancic & Hesketh, 2000). Participants will go through the training module and then answer the quiz. If answered incorrectly, the instructor will present the module again, and the quiz will be answered once again to correct errors. The program features an immersive VR environment where participants are seated in an ACC-equipped vehicle with a clear view of the

steering wheel, IP, and road to their front. User interface (UI) elements will change based on user input, and text-based information is overlaid on-screen and is aided by voice-over narrations. In-vehicle and environmental elements are highlighted. The first module provides an overview of ADAS and ACC. The second module provides information about ACC states, controls, and IP display icons. In the third module, participants will experience a scripted instance of ACC functioning in real-time showcasing different ACC functions and states. The fourth module presents information about ACC limitations. The final module presents an edge-case event (where ACC malfunctions) and relevant areas to be visually scanned and response actions to be performed to avoid oncoming hazards are explained.

In the third phase, an experimental driving simulator study will be conducted to test our hypotheses. The VR platform would be evaluated and compared to two other training platforms - visualization training method (Pradhan et al, 2022) and owner's manual. Independent variables will be quality of drivers' MM and training platform. Dependent variables will measure drivers' system awareness through task-based probes; lookout behaviors through eye movements; and system control abilities through vehicle measures.

This study has received institutional review board approval and will be recruiting 36 licensed participants who are naïve to ADAS, aged between 18 and 65 years. Their MM about ADAS will be measured using an MM survey and their hands, feet, eye movements, and verbal responses will be recorded. Participants will be randomly assigned to one of three training groups. Participants will first go through their assigned training material and then drive through the simulator drive. The project is currently in progress and is scheduled to be completed by December 2022 with the remaining tasks being data collection and analyses.

1.3. Significance and impact

This research will provide empirical evidence regarding HA in the ADAS context and how it differs from traditional driving. The research could then be expanded to explore HA for higher levels of vehicle automation. The work will also bridge gaps about relationships between MM and HA in the ADAS context, and their overall improvement through training. The VR-based training will add to existing works about the benefits and advantages of VR usage for training and education.

1.4. Where might this lead?

The work conducted for this Fellowship could have major implications regarding training for vehicle automation usage as these systems become increasingly prevalent in vehicles. This could consequently impact policies regarding licensure, infrastructure, and vehicle design. The work could help VR-based applications gain a foothold in the training and educational field and make learning an immersive and engaging experience.

List of Journal Papers, Scholarly Reports, and Presentations

Research from the first phase was presented at the Doctoral Colloquium at the 13th International ACM SIGCHI Conference on Automotive User Interfaces and Interactive Vehicular Applications in Fall 2021 (citation is provided below).

Pai, G. (2021). Drivers' Hazard Avoidance During Vehicle Automation: Impact of Mental Models and Implications for Training. 13th International ACM SIGCHI Conference on Automotive User Interfaces and Interactive Vehicular Applications.

The work done in the first phase will be submitted as a journal article and the manuscript is in the early stages of preparation. Upon completion of the study, the work and results from both second and third phases will be submitted as a journal article. The expected citations are listed below.

1. Pai, G. & Pradhan A. K. (under preparation). A Conceptual Framework for Drivers' Hazard Avoidance in the context of Vehicle Automation. Human Factors.
2. Pai, G. & Pradhan A. K. (to be submitted). Does Training for Mental Models Improve Drivers' Hazard Avoidance when Driving with Adaptive Cruise Control?. Applied Ergonomics.

How did the Fellowship make a difference?

The fellowship helped in finding the right direction for my dissertation research and utilizing state-of-the-art technology to carry out the goals and objectives of the research. Our research group has conducted studies on the effect of training on drivers' mental models about ADAS, and the obvious next direction was to understand if improved mental models through training have any impact or improvement in driver behaviors. We believe that the Link Foundation fellowship is a highly prestigious accolade for doctorate students in the field of simulation and training research. Therefore, it was important for us to use this opportunity to answer important research questions regarding training, mental models, and associated impact on hazard avoidance for ADAS driving, since ADAS and vehicle automation features are becoming ever so prevalent in modern vehicles. Moreover, there is scant research on these topics at the moment, creating an urgent need to fill in the gaps. Having Prof. Pradhan as my dissertation chair and faculty advisor was valuable here since he has in the past conducted research on improving hazard perception and anticipation behaviors for traditional manual driving. It was in our discussions that we decided how the use of virtual or mixed reality platforms, which has gained the spotlight in the training and educational fields, was most suited for a complex training regime that was required to improve drivers' mental models and in turn, their hazard avoidance for ADAS driving. The Fellowship helped to reinforce this confidence in our belief in VR technologies for training purposes. The Fellowship is also a monumental accolade and a tremendous honor, one which will no doubt help me in my professional career after graduation.

Required Information

Name: Ganesh Pai Mangalore

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