Understanding Motion Comfort in Automated Driving: Bridging Vehicle Dynamics, Driving Style, and Human-Machine Interaction

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Abstract

Passenger comfort is emerging as a key challenge for the successful deployment and public acceptance of highly automated vehicles. Existing research has examined individual comfort determinants, including vehicle dynamics, driving style, trust, perceived safety, and human-machine interaction (HMI), although these factors have been largely investigated in isolation. Consequently, a comprehensive understanding of how they jointly influence passenger comfort remains limited. This workshop aims to bring together researchers and practitioners from the AutomotiveUI community to develop a holistic perspective on comfort in automated driving. Through interactive brainstorming, small-group discussions, and collaborative framework building, participants will identify key comfort determinants, explore the relationships between vehicle behavior, user characteristics, contextual factors, and HMI designs, and discuss methodological challenges in measuring and improving passenger comfort. The workshop will culminate in a community-driven research agenda and an initial conceptual framework to guide future interdisciplinary research on adaptive, human-centered automated mobility systems.

CCS Concepts

• **Human-centered computing** → **HCI design and evaluation methods**;

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Keywords

Motion Comfort, Integrated Framework, Automated Driving, Automotive User Interfaces, HMI

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1 Problem Statement

Highly and fully automated vehicles (SAE L4-5, [36]) are expected to deliver substantial societal benefits, including improved road safety, increased mobility, enhanced traffic efficiency, and reduced environmental impact. As control shifts from the human driver to the automated system, however, the role of vehicle occupants changes fundamentally from active drivers to passive passengers. While considerable progress has been made in developing the technical capabilities required for automated driving (including remote operation), less attention has been paid to the human-centered factors that influence the passenger comfort/experience.

A critical challenge for the successful deployment and public acceptance of automated vehicles (AVs) is ensuring passenger comfort. However, comfort while being driven by AVs is a highly complex concept, affected by environmental, physical, and psychological factors [7, 29]. According to Peng et al. [29], comfort in AVs is divided into two layers: the physical (driving dynamics which lead to vehicle kinematics and proxemics [11, 44], human body kinematics [24, 25] and motion sickness [10]) and the psychological layer (privacy, trust [12, 23], perceived safety [15], naturalness [30], engagement in NDRTs [21] and situation awareness), both of which can affect each other. These are also affected by environmental and traffic influences, interior design [5, 7], infrastructure, route geometry [1], road roughness, weather, and other road users.

Although previous research has identified the different factors (e.g., trust, reliance, acceptance, and perceived safety) as important determinants of user comfort, there remains no comprehensive understanding of how these factors interact and contribute to physical and psychological comfort in AVs. Furthermore, this becomes even more challenging with all the envisaged designs of AVs (i.e., the handing over of vehicle control, seating backwards [37], engaging in non-driving related tasks (NDRTs) [21], or even working in automated vehicles [13], not having a clear view of the road ahead by displays or structures [43] or immersing in Mixed-Reality environments) has proven to provoke the incidence of physical and psychological discomfort to the occupants [10, 38].

2 Related Work

Research on comfort in AVs has primarily focused on the individual determinants rather than a holistic understanding.

Vehicle dynamics solutions have proven effective in enhancing physical comfort [44], but the literature still underscores the importance of personalized solution to effectively enhance overall comfort in AVs. On contrary with significant emphasis of literature on mitigating motion sickness [6, 18, 31, 39] from the perspective of physical comfort, [25] highlighted another aspect: the whole-body vibration and human body motion while being driven. At the same time, vehicle dynamics driven solutions also neglect the integration of metrics depicting psychological discomfort in the control modules of AVs. Studies consistently show that smooth vehicle control characterized by low acceleration, deceleration, and jerk values contributes positively to perceived comfort [2, 3, 8]. Furthermore, users generally prefer conservative and predictable automated driving behavior with larger safety margins, although preferences may vary across individuals and contexts [42, 45]. At the same time, smooth vehicle control might lead to reduced velocity and eventually to increased travel time, provoking emotional disruption. Factors such as weather, traffic density, and surrounding road users have been shown to influence comfort perceptions and driving style preferences [20, 41].

Beyond vehicle behavior, psychological factors such as trust, acceptance, enjoyment, and familiarity with the automated driving style have been identified as important contributors to the user experience [14, 22]. However, research has been explored in different testing environments (i.e., on-road, test-tracks and driving simulators), raising questions about their absolute validity and internal validity [16, 17, 26]. Xuan et al. [33] showed significant correlation between various factors affecting user experience (trust, pleasure, satisfaction, usefulness, workload, fatigue and perceived safety) with motion sickness. Several studies have investigated also human-machine interfaces (HMIs) to support transitions between manual and automated driving [4, 32, 35] or as a method to provide predictive anticipatory cues to enhance physical comfort [9, 19, 34]. Others have investigated how restrictions and vehicle behavior can enhance the enjoyment of a ride (e.g., [40]).

Research gap: Little research has so far explored how such systems can be designed to influence, personalize, or improve passenger psychological comfort or how these are related. Consequently, a comprehensive understanding of psychological comfort in automated vehicles and the role of adaptive interaction concepts for enhancing comfort remains limited.

This workshop builds on and extends the AutomotiveUI 2025 workshop on measuring passenger comfort and perceived safety [28], which brought together >40 researchers and practitioners, to examine good practices, challenges, and opportunities in measurement methodology, including subjective, objective/physiological, and AI-based approaches. Although that workshop established a valuable shared methodological landscape, the resulting discussions highlighted the need for a broader, integrative perspective connecting measurement practices to the underlying determinants of comfort itself [27]. The present workshop addresses this gap by shifting the focus from measurement methodology to the substantive comfort determinants, namely vehicle dynamics, driving style, and in-vehicle HMI, and how they jointly shape the passenger experience.

3 Workshop Aim, Sessions, Schedule

Motivated by the lack of a comprehensive framework for passenger comfort in highly AVs , this workshop brings together researchers and practitioners from the AutomotiveUI community to develop a holistic perspective on comfort in automated driving. Previous work has examined individual factors in isolation, while these dimensions require a holistic approach. The workshop therefore aims to identify key comfort determinants, explore their interdependencies, and develop a shared research agenda and conceptual model for passenger comfort in automated vehicles.

3.1 Session 1: Setting the stage

After a short **round of introductions**, the workshop will begin with an **interactive brainstorming session**. Participants are first asked to individually reflect on the central question: "What makes passengers feel comfortable in an (L4–L5) automated vehicle?" Each participant silently writes down factors, examples, concerns, and research questions related to comfort. These ideas are then shared and collaboratively **clustered into higher-level themes**. Through facilitated discussion, the emerging clusters are organized into overarching categories, which are expected to include 1. vehicle dynamics, 2. driving style, and 3. in-vehicle HMI (but may also reveal additional dimensions such as trust, personalization, situational context, user characteristics, or environmental factors).

3.2 Session 2: Digging deeper

Building on the 3+ clusters identified, participants divide into **parallel working groups** (or a World Café format) organized around the core dimensions that emerged from the literature (and/or the braingstorming): 1. Vehicle dynamics, 2. (automated) driving style, 3. in-vehicle HMI, etc. Each group is tasked with identifying the most important variables, design parameters, and open research challenges within its respective dimension. For example, the vehicle dynamics group focuses on aspects such as acceleration, braking behavior, jerk, speed adaptation, and motion sickness; the driving style group investigates topics including safety margins, lane-changing behavior, contextual adaptation, and personalized driving preferences; the HMI group explores transparency, explainability, information presentation, trust calibration, and entertainment functions. Each group develops a structured overview of comfort-relevant factors and their assumed influence on the passenger experience.

3.3 Session 3: Linking the dimensions

In the subsequent plenary session, the focus shifts to the interaction between dimensions. All **groups briefly present their findings** and **jointly discuss how they influence each other**. Particular attention is paid to identifying dependencies and trade-offs, and context-specific comfort challenges that are unique to L4–L5 automated vehicles. The goal of this session is to establish connections between isolated research perspectives and to synthesize them into a shared framework for passenger comfort in highly automated vehicles.

3.4 Session 4: Challenges and opportunities

The final part of the workshop is dedicated to the **collaborative discussion of an integrated comfort framework**. **Participants synthesize the identified factors and interactions into a conceptual model** that captures the relationship between the core dimensions with contextual factors and user characteristics. The workshop concludes with an identification of key research gaps, methodological challenges, context-specific comfort issues, and opportunities for future collaboration.

4 Attendance and Advertisements

We propose a half-day workshop, scheduled either in the morning or afternoon. In addition to the workshop organizers, we expect approximately 20–25 participants from the AutomotiveUI community, including PhD students, early-career researchers, senior academics, and industry practitioners with expertise in human factors, HCI, automated driving, AI, and vehicle engineering.

The workshop will be advertised through relevant academic and professional networks, mailing lists, social media channels, the Motion Comfort community on LinkedIn, and a dedicated workshop website. We will further leverage the organizers' extensive connections within the AutomotiveUI and broader HCI communities to attract a diverse and interdisciplinary audience.

5 Expected Outcome

The workshop is expected to generate a shared understanding of passenger comfort in highly automated vehicles by identifying and structuring the key factors that influence the user experience. By integrating previously separate perspectives, such as vehicle dynamics, automated driving style, HMI, trust, motion sickness, and NDRTs, participants will develop an initial understanding of the interaction between relevant core dimensions, such as vehicle dynamics, driving style, and in-vehicle HMIs, that eventually shall lead to a shared framework for L4—L5 passenger comfort. The framework should comprise a taxonomy of influencing factors, prioritized research questions, methodological recommendations, and concrete directions for follow-up AutomotiveUI research and collaborations.

6 Co-Organizers

Andreas Riener is a Professor for Human-Machine Interaction and VR at Technische Hochschule Ingolstadt with co-affiliation at the CARISSMA Institute of Automated Driving. His research interests include HF/ergonomics, adaptive UIs, driver state assessment, and trust/acceptance/ethics in mobility applications. Andreas is on the SC of ACM AutomotiveUI, chair of the German ACM SIGCHI chapter, and SC chair of Mensch und Computer (the German CHI) conference.

Paolo Pretto is a Principal Researcher in Human Factors and Human-Technology Interaction at Virtual Vehicle Research in Graz, Austria. He holds a binational PhD in Neural and Behavioral Sciences (University of Tübingen, Germany) and Perception and Psychophysics (University of Padua, Italy). His work focuses on human perception and behavior in driving and complex technological environments.

Jaka Sodnik is a Professor of Electrical Engineering at the University of Ljubljana. His research focuses on human factors and human-machine interaction in vehicles, with an emphasis on passenger comfort and public acceptance in automated and autonomous vehicles. He is also cofounder of SimFit2Drive, a Slovenian company specializing in cutting-edge solutions for assessing functional and cognitive skills essential for safe driving.

Kristina Stojmenova Pečečnik is a Research Associate at the University of Ljubljana. Her field of research is in-vehicle human-computer interaction. She is mainly focusing on assessment of driver behavior and driver's cognitive load modeling, with the use of biometric and driving performance data.

Georgios Papaioannou is an Assistant Professor at TU Delft, Netherlands. He received the Ph.D. degree from the National Technical University of Athens (NTUA), Greece, in 2019, which received an award regarding its innovation and impact. He conducted post-doctoral research at KTH Royal Institute of Technology in Sweden and Cranfield University in U.K. His current research interests include human factors, automated vehicles, motion comfort, human body modeling, remote driving, immersive reality, motion planning, optimization and control.

Pavlo Bazilinskyy is an Assistant Professor at TU Eindhoven focusing on AI-driven interaction between automated vehicles and other road users. He finished his PhD at TU Delft in auditory feedback for automated driving as a Marie Curie Fellow, where he also worked as a postdoc.

Alexander Meschtscherjakov is a professor for Human-Computer Interaction at University of Salzburg. He researches ambient automotive interfaces, driver-passenger collaboration, driver de-skilling, motion sickness, eHMI, and conversational agents in automated driving. Alexander has organized several workshops at AutoUI and CHI.

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