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Multimodal warning design for take-over request in conditionally automated driving

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Abstract

Purpose: Humans are required to respond to a vehicle's request to take-over anytime even when they are not responsible for monitoring driving environments in automated driving, e.g., a SAE level-3 vehicle. Thus, a safe and effective delivery of a take-over request from an automated vehicle to a human is critical for the successful commercialization of automated vehicles.

Methods: In the current study, a set of human-in-the-loop experiments was conducted to compare diverse warning combinations by applying visual, auditory, and haptic modalities under systematically classified take-over request scenarios in conditionally automated driving. Forty-one volunteers consisting of 16 females and 25 males participated in the study. Vehicle and human data on response to take-over request were collected in two take-over scenarios, i.e., a disabled vehicle on the road ahead and a highway exit.

Results: Visual-auditory-haptic modal combination showed the best performance in both human behavioral and physiological data and visual-auditory warning in vehicle data. Visual-auditory-haptic warning combination showed the best performance when considering all performance indices. Meanwhile, visual-only warning, which is considered as a basic modality in manual driving, performed the worst in the conditionally automated driving situation.

Conclusions: These findings imply that the warning design in automated vehicles must be clearly differentiated from that of conventional manual driving vehicles. Future work shall include a follow-up experiment to verify the study results and compare more diverse multimodal combinations.

Keywords: Visual modality, Auditory modality, Haptic modality, Human factors, Autonomous vehicle

1 Introduction

Automated driving can reduce traffic accidents caused by human errors, thereby resulting in environmental improvement through reduced traffic jam and offer freedom to users in non-driving activities when automated systems are active [9]. Therefore, automated driving systems have become participants of development and testing for many car manufacturers and federal research institutes. General consensus shows that highly automated cars will be prevalent on public roads by 2030 [16, 23].

Many automotive companies and engineers worldwide are now focused on developing sensor systems for automated vehicles. It is important to develop high-performance sensors for automated vehicle; however, to satisfy both technological and commercial aspects, human–machine interaction (HMI) must be considered [13].

Automation levels of automated vehicles are defined based on diverse criteria; in particular, HMI depends on each automated level. For example, at the lowest level of automation, i.e., no automation or level 0 in [27], the human driver is in full control of the car. In full automation, i.e., level 5 in [27], the human driver is not involved in any driving task at all. According to Society of Automotive Engineers (SAE) automation level 3, that is,

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