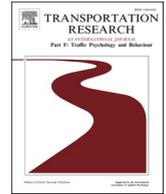




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Effect of multimodal takeover request issued through A-pillar LED light, earcon, speech message, and haptic seat in conditionally automated driving

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ABSTRACT

The driver of a conditionally automated vehicle equivalent to level 3 of the SAE is obligated to accept a takeover request (TOR) issued by the vehicle. Considerable research has been conducted on the TOR, especially in terms of the effectiveness of multimodal methods. Therefore, in this study, the effectiveness of various multimodalities was compared and analyzed. Thirty-six volunteers were recruited to compare the effects of the multimodalities, and vehicle and physiological data were obtained using a driving simulator. Eight combinations of TOR warnings, including those implemented through LED lights on the A-pillar, earcon, speech message, or vibrations in the back support and seat pan, were analyzed to clarify the corresponding effects. When the LED lights were implemented on the A-pillar, the driver reaction was faster ($p = 0.022$) and steering deviation was larger ($p = 0.024$) than those in the case in which no LED lights were implemented. The speech message resulted in a larger steering deviation than that in the case of the earcon ($p = 0.044$). When vibrations were provided through the haptic seat, the reaction time ($p < 0.001$) was faster, and the steering deviation ($p = 0.001$) was larger in the presence of vibrations in the haptic seat than no vibration. An interaction effect was noted between the visual and auditory modalities; notably, the earcon resulted in a small steering deviation and skin conductance response amplitude (SCR amplitude) when implemented with LED lights on the A-pillar, whereas the speech message led to a small steering deviation and SCR amplitude without the LED lights. In the design of a multimodal warning to be used to issue a TOR, the effects of each individual modality and corresponding interaction effects must be considered. These effects must be evaluated through application to various takeover situations.

1. Introduction

In conditionally automated vehicles classified as Level 3 autonomous cars according to the SAE J3016 standard, the automated driving mode may be deactivated by the driver or vehicle (SAE J3016, 2018). In vehicles with this level of automation, drivers are not obligated to keep their eyes on the road. However, if the vehicle requests the driver to take over control, through a takeover request (TOR), the driver should implement the dynamic driving task fallback. Therefore, in Level 3 vehicles, interactions between the driver and vehicle are crucial to ensure road safety. Consequently, original equipment manufacturers and academic societies are conducting

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