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ANALYSIS OF DRIVER'S EEG GIVEN TAKE-OVER ALARM IN SAE LEVEL 3 AUTOMATED DRIVING IN A SIMULATED ENVIRONMENT

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ABSTRACT−As partially automated driving vehicles are set to be mass produced, there is an increased necessity to research situations where such partially automated vehicles become unable to drive. Automated vehicles at SAE Level 3 cannot avoid a take-over between the human driver and vehicle system. Therefore, how the system alerts a human driver is essential in situations where the vehicle autonomous driving system is taken over. The present study delivered a take-over transition alert to human drivers using diverse combinations of visual, auditory, and haptic modalities and analyzed the drivers' brainwave data. To investigate the differences in indexes according to the take-over transition alert type, the independent variable of this study, the nonparametric test of Kruskal–Wallis was performed along with Mann–Whitney as a follow-up test. Moreover, the pre/post-warning difference in each index was investigated, and the results were reflected in ranking effective warning combinations and their resulting scores. The visual-auditory-haptic warning scored the highest in terms of various EEG indexes, to be the most effective type of take-over transition alert. Unlike most preceding studies analyzing post-take-over-alert human drivers' response times or vehicle behavior, this study investigates drivers' brainwave after the take-over warning.

KEY WORDS : Autonomous vehicle, Take over warning, Multi-modal warning, Single modality warning, EEG (Electroencephalogram), Power spectrum analysis

1. INTRODUCTION

Of late, automated driving system technology has developed considerably, and autonomous vehicles at the SAE (Society of Automotive Engineers) Level 3 are expected to be mass produced within the next 5 ~ 10 years. However, since autonomous vehicles at Level 3 are not completely autonomous, human drivers always have to be ready to resume manual driving (Cho and Moon, 2014). Autonomous vehicles at Level 3 transfer driving control from the system to a human driver in the event of an emergency. In this case, if a human driver fails to recognize a take-over warning or is flustered by an unexpected take-over warning, an accident could occur. Therefore, the HMI (Human Machine Interaction) at the point of take-over transition from vehicle to driver is essential. In relation to this, unlike previous studies on HMI of conventional non-autonomous vehicles, a study on a new HMI technique is required, for safe take-over in autonomous vehicles (Yun and Yang, 2019).

Gold *et al*. (2013) implemented visual-auditory modal combination warnings in a TOR (Take-Over Request) scenario. Based on 62 participants' reaction time data, post-TOR travel trajectories, glances on the areas of interest while changing, and maximum acceleration, they showed that presenting a take-over alert 7 seconds in advance led to faster user reaction than 5 seconds earlier. Borojeni *et al*. (2016) compared alarm methods using an LED (Lighting Emitting Diode) on the steering wheel in a TOR scenario. Based on 21 participants' reaction time data and time of the collision with an obstacle, they found that the user reaction was more prompt when the LED was lit dynamically, flashing toward the direction of take-over transition cause rather than being lit statically. Hester *et al*. (2017) compared no alert, sound alert, and task-irrelevant voice alert in a TOR scenario. From 24 participants' data on reaction time, and the time to look away from the driving task, they concluded that the task-irrelevant voice alert helped more subjects avoid a collision. Louw and Merat (2017) observed user behavior and gaze pattern before and after manual driving resumption under TOR depending upon the degree of fog. Under a heavy fog condition, the subjects gazed between the road and dashboard, but under a light fog condition, they tended to look at the middle of the road. These results indicated that although the users' gaze was dispersed while doing a secondary task, a visual alert was still necessary for TOR events. The previous study found that when an auditory display was added to a visual display, driver reaction time was shortened and driving performance was improved. Naujoks *et al*. (2014) investigated the effect of visual and visual+auditory TOR on drivers' reaction time and driving performance. Drivers showed shorter reaction times under

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