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Impact of Secondary Activities and Warning Sounds on Take-over Behavior

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Although levels 3–5 of automated driving systems offer self-driving features, level 3 systems perform dynamic driving tasks (DDTs) under limited conditions. In other words, a human passenger need not drive and monitor surroundings but must be ready to take control of the vehicle as soon as the system issues a take-over request (TOR). However, in this level of automated driving systems or higher levels, drivers can perform a wide range of non-driving related tasks (secondary activities). This study examined the impact of three types of secondary activities, which involved using a smartphone and two types of alert tones, on a driver's take-over behavior.

The first activity was "watching a video," in which a driver watched a television program (six titles recorded, chosen by the study participants) on a smartphone. The second activity was "calculation," in which a driver added two single-digit numbers displayed on a smartphone and entered the last digit of the answer; the third activity was "without any task," where a driver just held a smartphone in one hand and did not perform any action. The frequency of the alerts was 1.6 kHz, and blowing frequencies were set to 2 and 6 Hz. A driving simulator (DS) experiment was conducted with 18 young drivers (21–59 years old) and 19 elderly drivers (64–82 years old). With an automated driving speed set to 80 km/h and the lane defined as the center lane of a three-lane road, each driver performed each secondary activity until the emergence of TOR at a curve section (Road 1) or straight section (Road 2). After the TOR was issued, each driver would keep the smartphone aside and override the automated driving by pressing the pedals or holding the steering wheel. The test results were evaluated based on the drivers' response times determined from videos and driving operations from DS log data.

In this study, one of the participants (a younger driver) did not respond to a 2 Hz alert tone due to the driver's involvement in watching a video on the smartphone. Some of the drivers also exhibited delays in response to TORs. Figure 1 shows the response times to the alerts of the younger drivers to TORs while performing each secondary activity. The response times increased when the drivers were more engaged in secondary activities, especially while watching videos. The number of time delays caused by secondary activities was similar in each movement with no particular difference between the road shapes. The authors believe that the activity of watching video is immersive and affects a driver's hearing sense, making it more difficult to notice an alert. On the contrary, the calculation task required the driver's concentration and alertness and was classified as "not wanting to continue after a TOR" according to the questionnaires asked after the experiment. These characteristics enabled the drivers to take over the driving operations smoothly with greater concentration. Figure 2 shows the movement of participants' vehicles in 10 s from the time of take-overs at Road 1. The horizontal axis represents the ratio of the "lateral (left/right) direction" to the "longitudinal (road) direction" for the distance traveled. The bars are shorter for 6 Hz alerts, which indicate the drivers were able to precisely trace the driving lane. Participants classified the 6 Hz alerts to be "more nervous" compared to 2 Hz alerts by the semantic differential method. Higher frequencies attracted the drivers' attention at take-overs and resulted in more stable driving behavior.

The secondary activities had negative effects on the driver's response time to a TOR. Some characteristics such as "immersion" and "sound effect" may have interfered with the driver's perception. In contrast, the driver's steering operation became smoother by the activity corresponding to "maintaining alertness" and "easy to suspend". Blowing frequencies of the alert also affected the driver's attention; 6 Hz was more suitable for a TOR than 2 Hz. In the future, it is necessary to consider the types of activities and alerts that are acceptable and the types that should be prohibited.

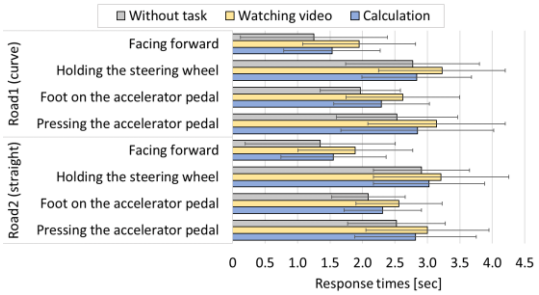

Fig.1 Response times (Younger drivers)

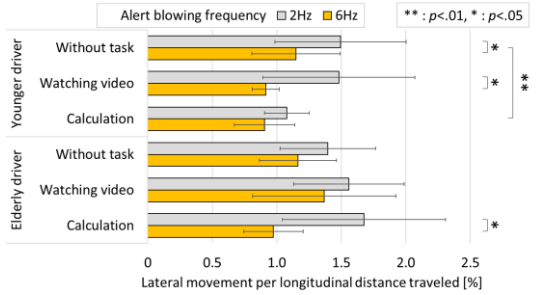

Fig.2 Lateral movement per longitudinal distance traveled (Road 1)