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Maintaining driver alertness and suppressing the decline in thermal comfort through thermal stimulation inside the vehicle

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In Level 2 autonomous driving, which has become increasingly widespread in recent years, drivers are still required to continuously monitor the surrounding environment to ensure safe operation. Previous studies using a driving simulators (DS) have reported that alertness may decline during prolonged periods of autonomous driving, highlighting the need for effective countermeasures. Heating, ventilation, and air-conditioning (HVAC) has been proposed as a promising method for maintaining alertness without compromising comfort. Laboratory studies have shown that temporarily lowering the ambient temperature and subsequently returning it to baseline can help sustain an alertness-maintaining effect while preserving thermal comfort. Building on these findings, this study aimed to examine whether a comparable effect could be reproduced in an actual vehicle cabin using the HVAC system under realistic driving conditions.

In the control condition (Condition A), the cabin temperature was maintained at a constant 26°C, which is generally considered comfortable. In the experimental condition (Condition B), the temperature was temporarily lowered to 23°C, a level known to enhance alertness. To reproduce Condition B inside the cabin, the vent orientation, HVAC temperature settings, and airflow were systematically adjusted, and two small fans were placed in the front passenger footwell to promote uniform air circulation. Under both conditions, participants performed a 50-min car-following task in a highway scenario with no obstacles and minimal scenery variation, using a fixed real vehicle whose steering and pedal inputs were mapped in real time to the driving simulator. Thermal comfort was rated every 2 min 3s using a four-point scale. Alertness was assessed by calculating the PERCLOS from facial images. Based on previous studies, we defined an eye-closure rate above 0.075 as indicating moderate sleepiness. Ten healthy adults participated (6 males, 4 females; mean age = 27.3 years). After changing into designated light clothing, they rested for 20 min in the room where the temperature was maintained at constant 26°C , practiced the DS task for 2.5 min to familiarize themselves with the task, and then performed the 50-min driving task.

Thermal comfort showed a slight shift toward discomfort in Condition A and a more pronounced shift in Condition B. However, ratings consistently remained between −1 (slightly uncomfortable) and 0 (comfortable), suggesting that major reductions in thermal comfort were successfully avoided despite the temperature manipulation(Fig.2). PERCLOS gradually increased in Condition A, exceeding the 0.075 threshold approximately 20 min after task onset. In contrast, PERCLOS in Condition B remained below 0.075 for the entire 50-min task duration, suppressing the increase observed in Condition A(Fig.3). Furthermore, when examining the change relative to the 20-min time point, the increase in PERCLOS was smaller in Condition B, indicating that temporarily lowering the temperature effectively mitigated the decline in alertness over time.

These results indicate that the alertness-maintaining effect previously demonstrated in laboratory environments can also be reproduced in a vehicle cabin using the HVAC system, even when slight differences exist between the cabin and laboratory thermal environment. This suggests that, even when some variability exists in the cabin thermal environment, alertness can be maintained as long as drivers perceive the temporary temperature decrease, while reductions in thermal comfort are kept minimal. In contrast to earlier laboratory studies, the positional relationship between the driver and the foot vents in the cabin may have influenced thermal comfort ratings in both conditions. Therefore, future work should investigate HVAC control strategies that lower cabin temperature more uniformly while avoiding direct cold airflow to the feet, as well as determine how long a single thermal stimulus can sustain alertness under real-world driving conditions.

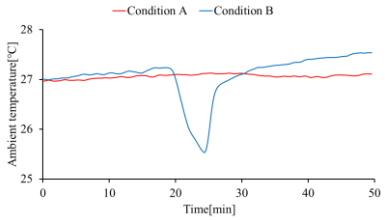

Fig.1 Ambient temperature

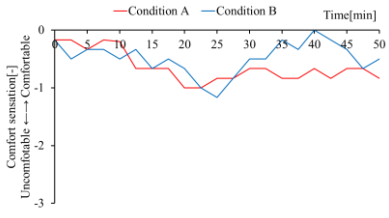

Fig.2 Comfort sensation vote

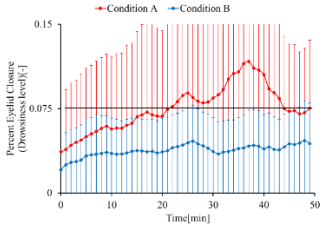

Fig3 Percent Eyelid Closure