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Development of Wakefulness-Maintenance Support Technology Using Stochastic Resonance

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This study investigates a wakefulness-maintenance support technology that employs functional stochastic resonance (SR) to extend wakefulness during monotonous driving without causing discomfort. Conventional Driver-Monitoring-System (DMS) provide drowsiness alerts, but their effect fades within minutes and strong stimuli may annoy drivers.

SR is a phenomenon in nonlinear systems in which adding an optimal level of noise enhances the detectability or processing of weak signals. Human physiological systems, including the baroreflex and sensory pathways, have been shown to exhibit SR effects. In the context of driving, appropriately tuned micro noise may stabilize information transmission between the thalamus and the cortex, thereby improving wakefulness-maintenance.

To evaluate this hypothesis, a controlled driving simulator study was conducted with 22 participants. A driving simulator provided a monotonous driving environment designed to promote drowsiness, while facial-expression-based drowsiness levels were measured every 30 seconds. When a participant reached a specified threshold of drowsiness, a conventional alert was displayed; in the SR condition (in the condition with noise), it was followed by the presentation of subtle auditory micro noise, whose intensity shifted among five predefined levels. Wakefulness-maintenance duration was defined as the time from the alert until the participant again reached a drowsiness level indicating significant impairment. Physiological responses were assessed using Root Mean Square of Successive Differences (RMSSD) as an autonomic index, and C2 metrics derived from EEG signals to estimate cortico-thalamic loop strength, a marker known to decrease during sleep onset.

The simulator results demonstrated that wakefulness-maintenance duration increased by approximately 1.5x in the condition with noise compared with the condition without noise, showing a statistically significant improvement (Fig.1). Importantly, post experiment interviews confirmed that no participants consciously perceived the micro noise, and none reported annoyance. RMSSD plotted against noise intensity produced a bell-shaped curve consistent with SR theory, with peak responsiveness at intermediate noise levels (Fig.2). EEG analyses indicated reduced variability in C2 metrics during the post alert interval when micro noise was presented, suggesting stabilization of neural information transmission, which aligns with proposed SR related mechanisms.

A subsequent real vehicle study involving 12 participants further evaluated the practical feasibility of SR based wakefulness-maintenance support. Although statistical significance was not reached—likely due to environmental noise and small sample size—the results exhibited the same directional tendencies as the simulator experiment. Effect sizes between intermediate noise levels were of medium magnitude, supporting the presence of SR related physiological modulation under real world driving conditions. As in the simulator experiment, none of the drivers reported awareness of the micro noise stimulus.

Overall, the study demonstrates that inaudible micro noise can enhance driver wakefulness while avoiding the drawbacks of stronger traditional alerts. By leveraging SR, this approach provides a promising foundation for next-generation DMS technologies capable of delivering effective, non-intrusive alertness support. Future work includes optimizing noise intensity personalization and conducting larger scale evaluations to further validate the technology.

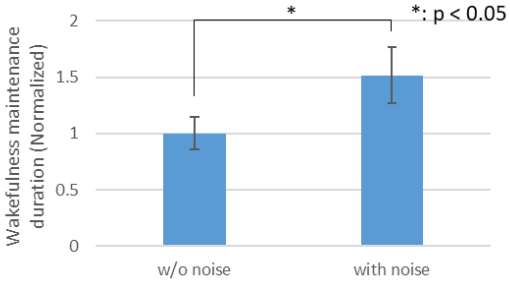

Fig.1 Comparison of wakefulness maintenance duration (error bars represent SEM)

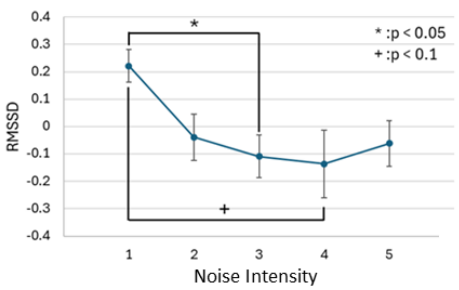

Fig.2 Signal-to-Noise Ratio curve confirmation results in the condition with noise (error bars represent SEM)