

Optimization of Multisensory Stimulation Based on Physiological Indicators

- Investigation of Stimulus Combinations Contributing to Arousal Enhancement -

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Recent vehicle cabin systems integrate music, airflow, and fragrance stimuli to improve occupant comfort and user experience. These systems are also expected to contribute to maintaining driver alertness. However, multisensory stimuli are known to interact with each other, and an optimal setting for an individual stimulus may not provide the same effect when combined with other stimuli. To better understand these combined effects, this study investigated the main and interaction effects of music, airflow, and fragrance stimuli on arousal using both subjective and physiological evaluations.

To investigate the effects of multisensory stimulation on arousal, experiments were conducted in a parked vehicle using combinations of music, airflow, and fragrance stimuli. Three participants performed a monotonous viewing task designed to reduce arousal. Each stimulus factor consisted of two levels: low-pass and full-band music (HF- and HF+), footwell and facial airflow (Foot and Face), and light and strong fragrance intensity (Light and Strong). An L8 orthogonal array was employed to systematically quantify the main effects of individual stimuli and the interaction effects among music, airflow, and fragrance stimuli. Subjective ratings, electroencephalography (EEG), and electrocardiography (ECG) were used to evaluate arousal responses. EEG Fast- α power and the ECG index SD2/SD1, which showed high correlations with subjective arousal, were selected as representative physiological indicators.

The results of the subjective evaluations, EEG, and ECG measurements indicated that all music, airflow, and fragrance stimuli contributed to enhanced arousal, as shown in Fig. 1. In particular, the Level 2 conditions of music (HF+) and airflow (Face), together with the Level 1 fragrance condition (Light), tended to produce greater arousal effects. However, individual differences were observed in responses to stimulus intensity.

Differences in the contribution of interaction effects were also observed among participants. Participant A showed large interaction contributions across all stimulus combinations, as shown in Fig. 2. The arousal-enhancing effect of high-frequency music (HF+) was reduced when combined with airflow directed toward the face (Face) or a light fragrance (Light). In addition, the relaxing effect of a light fragrance (Light) was altered when combined with airflow directed toward the feet (Foot), as shown in Fig. 3.

These interaction effects may be attributed not only to multisensory integration but also to interference among stimuli. Airflow may interfere with music perception and fragrance delivery, thereby affecting the effectiveness of the stimuli. The results suggest that, for multisensory arousal-support systems, integrated control that considers interactions among stimuli, interference effects, and individual differences is more effective than optimizing each stimulus independently. These findings are being utilized in practical design studies, such as intermittent airflow control for sustained arousal effects and customizable fragrance settings that account for differences in user preferences and sensitivities.

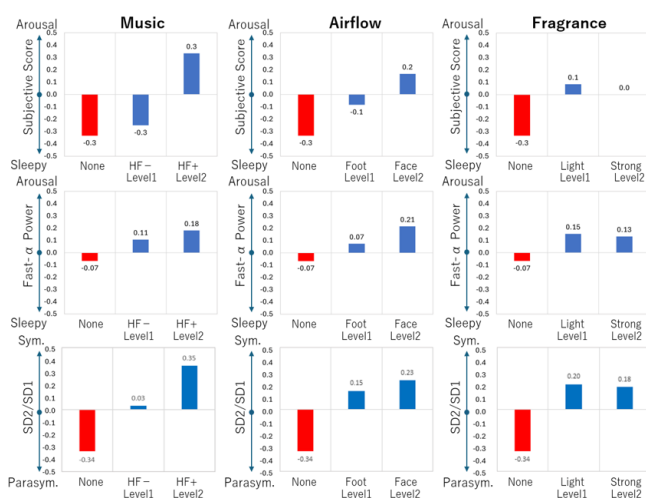


Fig.1 Main effects of music, airflow, and fragrance stimuli on subjective and physiological indices (Mean Value, N=3)

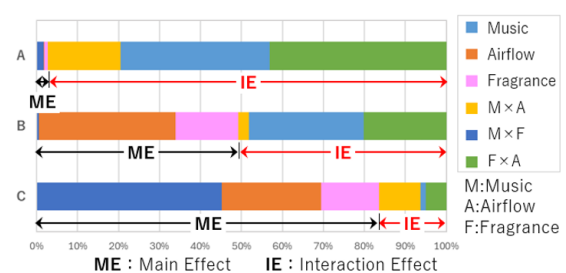


Fig.2 Percentage Contribution of Main Effects and Interaction Effects to EEG Response (Subject A,B,C)

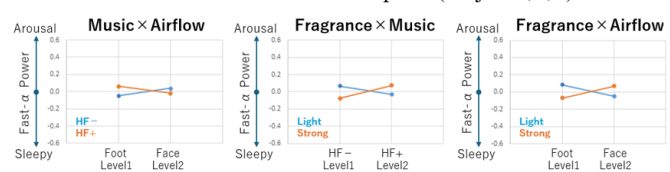


Fig.3 Two-Factor Interaction Effects on EEG Response (Subject A)