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Effective Haptic Seat Warning Based on Human Vibration Sensitivity

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I. Introduction

Advancements in autonomous driving technology suggest that situations may arise during driving where a transition from autonomous to manual control is required. In such instances, it is imperative that the driver becomes fully alert. Accordingly, we have focused on vibrotactile stimulation, which has the unique ability to deliver information exclusively to the driver, thus enabling driver assistance without imposing psychological or physical burdens on passengers.

Hirao et al. investigated the vibration sensitivity of the back and buttock to efficiently convey vibratory cues.[1] In the present study, based on this sensitivity distribution, we evaluated the arousal effect provided by seat vibrations.

II. Definition of Vibration Parameters

The parameters that constitute the vibration are defined as shown in Fig. 1. The parameters are: the "single stimulus duration", which represents the duration of one on phase; the "interval," which indicates the duration of one off phase; the "number of cycles," denoting the number of on-off repetitions; the "total duration" of the vibration stimulus; the "amplitude," which is the acceleration on the seat surface; and the "frequency." The waveform of the stimulus is a sine wave.

For the analysis, the duty ratio-which represents the proportion of the total time occupied by the stimulation period-is used. The duty ratio is expressed by Equation 1.

$$duty\ ratio = \frac{Single\ Stimulus\ Duration \times Number\ of\ Cycles}{Total\ Duration} \tag{1}$$

III. Vibration Parameter Determination Experiment

A preliminary experiment was conducted to determine the vibration pattern.

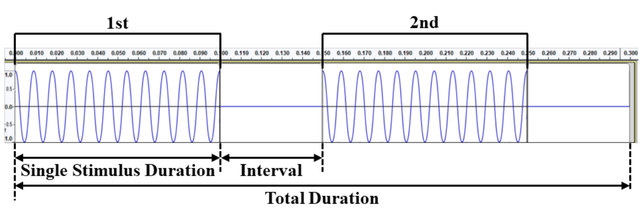

Figure 1. Vibration Paramet

A. Experimental Methods

12 subjects were seated on a vibration presentation seat equipped with built-in vibro-transducers (Acouve Lab. Vp.210). The vibration parameters were standardized at a frequency of 96.5 Hz and an amplitude of 5×10^{-3} m/s², while the remaining parameters were set using various numerical combinations. The stimulation site was the upper part of the back of the pelvis.

B. Experimental Results

When examining the relationship between the duty ratio and the detectability of vibration using vibratory stimuli with parameter settings that varied only in interval length, a peak in vibration detectability was observed. Vibrations were considered most noticeable when the duty ratio was between 0.6 and 0.75 (Fig. 2).

IV. Effect Verification Experiment

Based on the results of the preliminary experiments, the vibration parameters were determined, and an effective verification experiment was conducted. In this experiment, the back vibration sensitivity from previous studies and the effect of the duty ratio on reaction time observed in the preliminary experiments were examined.

A. Experimental Environment and Apparatus

The subjects consisted of 12 individuals in their twenties (9 males and 3 females). A vibration presentation seat equipped with built-in vibrators was used in the driver's seat, while a monitor displayed driving scenes generated by the driving simulator (Forum8 UC-win/Road Ver.17.1.0). A lead vehicle traveling at 100 km/h was positioned, and subjects were required to follow it while maintaining a constant distance. The experimental environment simulated nighttime conditions and was conducted in a dark setting.

B. Experimental Procedure

1) The subject drove a static driving simulator for a certain period.

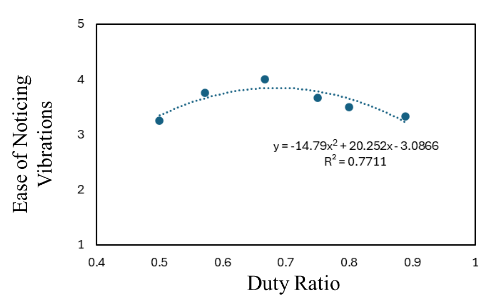

Figure 2. Noticing Peak (2.4(s) single stimulation duration)

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2) The vibrator was activated when the sleepiness expression score [2] reached 3.

3) Upon noticing the vibration, the subject pressed the button on the steering wheel.

4) The reaction time was measured as the duration from the onset of the vibration until the button was pressed.

The subjects' facial expressions were observed via video by the experimenter. The evaluation of drowsiness levels adopted the sleepiness expression score [2]. In this system, there are five levels ranging from 1 (alert state) to 5 (extremely drowsy state). An index of 3 corresponds approximately to a moderately drowsy state.

C. Vibration Stimulus Conditions

Based on Hirao et al. and referencing Fig. 3, which displays the sensitivity thresholds, vibratory stimuli were presented to two regions. With three types applied to each: the upper waist (sensitive) and the back of pelvis (less-sensitive) shown in Fig. 4. The vibration duration was uniformly set to 2.55 seconds, and the frequency was set to 110 Hz based on Fig. 5 that shows the frequency at which sensitivity increases. The duty ratio was set at 0.59 (from the vibration parameter determination experiment), 0.27, and 1.00 (continuous vibration).

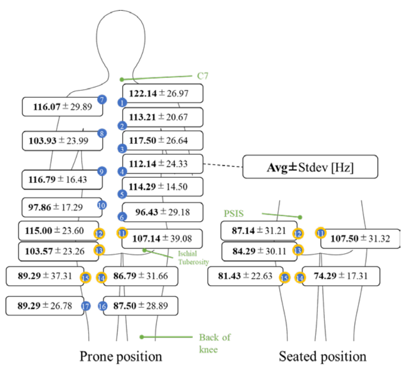

Figure 3. Acceleration Map [1]

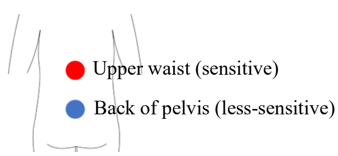

Figure 4. Stimulation Site

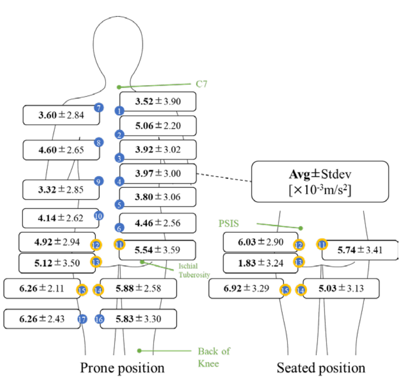

Figure 5. Frequency Map [1]

D. Results and Discussion

Regarding the effect of back vibration sensitivity on reaction times, the reaction times at two stimulation sites were compared for each combination of subject and vibration sample. Among the 36 combinations, 69.4% showed that the reaction time at the upper waist was shorter than that at the back of pelvis, which corresponds with the expected characteristics of back-body sensory sensitivity. Therefore, although no statistically significant difference was observed, it can be said that higher vibration sensitivity tends to be associated with faster reaction times.

Regarding the effect of duty ratio on reaction times, 3 subjects who did not detect vibratory stimuli were excluded from the analysis. As can be seen from the graph in Fig. 6, in the highly sensitive waist region, the results were consistent with those of the vibration parameter determination experiment. In contrast, for the less sensitive back of pelvis, vibrations with a duty ratio of 1.00 resulted in shorter reaction times. In other words, although statistical significance was not observed, when the magnitude of the vibratory stimuli applied to the back exceeds a certain level, a duty ratio of around 0.6 appears to represent the peak of detectability.

V. Conclusion and Future Perspectives

To derive stimulus that efficiently awaken drivers in a state of reduced alertness, the following trends were observed:

- Reaction times to vibrations were shorter in areas with lower sensitivity thresholds.

- When the magnitude (amplitude) of vibratory stimulation applied to the back exceeded a certain level, a peak in detectability was observed around a duty ratio of 0.6.

Future issues as follows. First, since some subjects did not respond to the vibratory stimulation on the back of pelvis, it is necessary to check the driver's posture and the contact state with the seat. Second, quantifying the arousal effect of vibratory stimulation is needed. Third, because the experiments were conducted under static conditions, they should be performed under dynamic driving vibrations.

References

[1] A. Hirao, A. Yosida,“Vibration sensitivity measurement of back and buttocks for effective seat vibration warning”, Advances in Human Factors of Transportation, vol. 148, 2024, pp.642–652

[2] H. Kitazima, N. Numata, K. Yamamoto, Y. Goi, “Prediction of Automobile Driver Sleepiness : 1st Report, Rating of Sleepiness Based on Facial Expression and Examination of Effective Predictor Indexes of Sleepiness”, Transactions of the Japan Society of Mechanical Engineers Series C, vol. 63, issue 613, 1997, pp.3059-3066 (In Japanese)

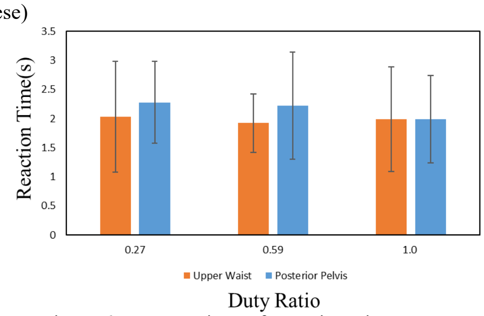

Figure 6. Comparison of Reaction Times