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Drowsiness Prevention System in Automatic Driving – Effects of Light Position on Comfortable and Unconscious Wakefulness During Driving

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ABSTRACT

With today's automated driving assistance, drivers must always remain awake and aware of road conditions. In an emergency or when having difficulty operating the automated driving system, the driver must immediately assume vehicle control. In particular, autonomous driving is currently used mainly on highways, where drivers are prone to drowsiness due to the monotonous driving environment. Faced with this problem, many researchers and companies have developed drowsiness-prevention driving systems to prevent drivers from falling asleep. However, most conventional methods force people to wake up to unpleasant loud sounds, neglecting the driver's sense of driving experience. This study aims to identify the effects of light position on comfortable and unconscious wakefulness during driving. Specifically, we investigated 20 participants' concentration, reaction time and stimulation experience evaluated by brainwave apparatus, the Mackworth Clock Vigilance Test (MCVT), Karolinska Sleepiness Scale (KSS) and the Subjective Evaluation Survey when three stimuli were used: voice only, voice and handle lighting, voice and ambient lighting. The results showed no significant differences between the three stimulation modalities in KSS ($p = .082$) and MCVT ($p = .547$). Conversely, the evaluation of audio-visual experience was significantly impacted by the position of lighting by Bonferroni pairwise comparisons: when the handwheel light was displayed, participants felt more surprised than with the other two stimuli ($p = .03$). The findings of this study compare the effects of different light positions on the audio-visual experience and provide reference suggestions for the visual placement of drowsiness prevention systems.

Keywords: Automatic driving, Audio-visuals experience, Drowsiness prevention

INTRODUCTION

Due to the rapid technological progress of automated driving, advanced driver assistance systems (ADAS) can support drivers to perform driving tasks more safely. However, one of the most pressing research questions in highly automated driving (HAD) is how to aid the driver in making safe transitions between manual and automated control (Bazilinskyy et al., 2018). The driver of automatic cars may occasionally need to switch from their secondary task to the driving task when an urgent situation happens (Janssen et al., 2019). During this switch, the driver must always remain awake and aware of road conditions to ensure they can take over the system in time. Unfortunately, when drivers no longer effectively control their vehicles, they are easily distracted and drowsy (Zhou et al., 2020). In particular, autonomous driving is currently used primarily on highway road conditions, where the driver is easily to drowsiness due to the monotonous driving environment. Drowsy driving is the culprit in 20% – 30% of fatal traffic accidents (Murata, 2016) and is one of the major causes of rear-end collisions (Guo et al., 2021).

To increase traffic safety and reduce the number of accidents due to drowsy driving, numerous universities, research centers, and automotive companies (such as Toyota, Benz and Audi) are contributing to developing a drowsiness prevention system (DPS) in automatic driving. Most researchers have focused on developing the technical aspects of DPS (Dinges et al., 2005), including sensors for measuring physiological (Sahayadhas et al., 2012) (Richman and Moorman, 2000), behavioral changes (Slater, 2008) (Mardi et al., 2011) (Balandong et al., 2018) and algorithms to quantify and predict (McDonald et al., 2018) these changes. For instance, Anthony et al. designed and evaluated a contextual and temporal algorithm for detecting drowsiness-related lanes (McDonald et al., 2018). The algorithm reduces the false positive rates in highway and rural environments, which are typically problematic for vehicle-based detection algorithms. It may be combined with visual-auditory methods to improve driving safety.

Meanwhile, for the warning design of the drowsiness prevention system, the main way of expression is to design an alarm sound (ZHANG, 2020) and a warning light (Schwarz et al., 2019) on the dashboard. Ann used the Korean traditional instrument gong sound, kkwaenggwari sound, cymbals sound, tofu bell sound and shaman bell sound in the drowsiness prevention system (Ann, 2018). All five proposed sounds were proved by frequency analysis, EEG analysis and MOS test survey that awakening is sufficient. However, most conventional methods force people to wake up unpleasantly, neglecting the driver's sense of driving experience.

Compared to previous research, this study tended to investigate how to keep the driver awake in a relaxed and unconscious state during autonomous driving. Additionally, the purpose of this study was to use a combination of different in-vehicle light positions and voice reminders to compare the differences in drivers' concentration, sleepiness, and audition subjective assessments during driving.

MATERIALS AND METHODS

Participants

A total of twenty participants (MAge = 33.7 ± 7.6 years old) took part in the experiment. The sample consisted of $n = 11$ females and $n = 9$ males. On average, participants had owned their driving license for 8.2 years (SD = 4.31). The sample quoted their driving experience as "very experienced"

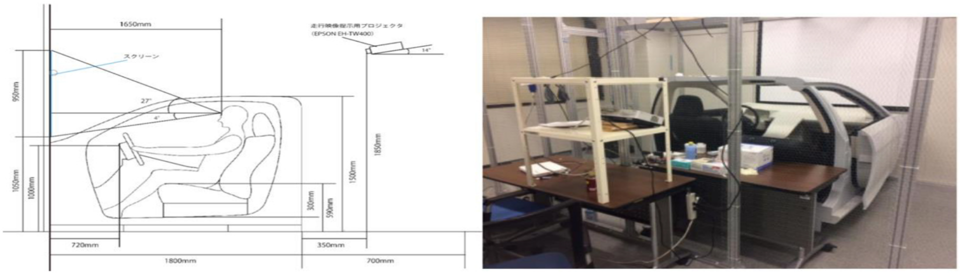

Figure 1: Domestic sedan-type vehicle.

Figure 2: Handle Lighting (left) and Ambient Lighting (right).

(20%) or “experienced” (75%). Only 1 participant was “inexperienced” (5%) with driving. Regarding how to avoid drowsiness while driving, 60% of the participants chose to listen to music and 30% indicated that they chewed gum to stay awake.

Apparatus

The study was conducted in a full-scale model of a domestic sedan-type vehicle in a silent room. The dimensions of the car model and participants’ seating position are shown in Figure 1. The screen was placed on the curtains in front of the mock-up to show the driving environment. As the angle at which the participants looked at the screen during the experiment varied with their height, it was calculated assuming a height of 170cm. Provided the participants with 1920 × 1200 video quality and a horizontal field of view of 180 ° × 31°.

In the experiment, we set up three kinds of stimulus materials to keep the driver awake, (1) voice reminder, (2) steering wheel light with voice reminder, and (3) ambient light with voice reminder. As shown in Figure 2, The visual stimulus is a basic LED white light, and the brightness is adjusted according to the automotive ambient light regulation. When the participant misses or delays the response to the red dot jump time in MCVT, he/she will be judged as having drowsiness and the stimulus will be displayed.

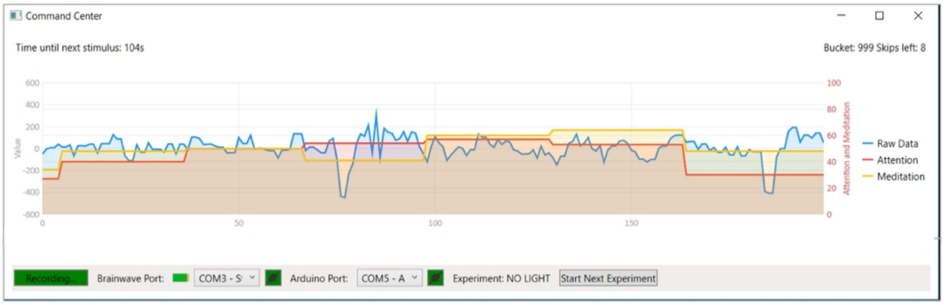

Figure 3: EEG measurement interface.

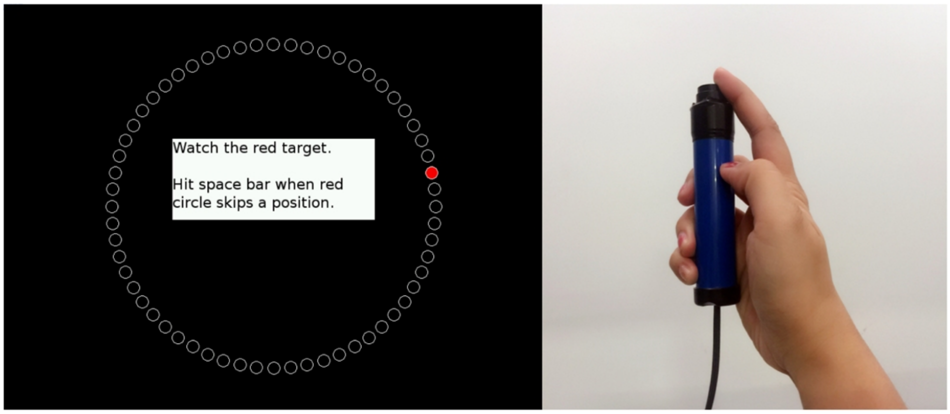

Figure 4: Mackworth Clock vigilance Test (left) and Reaction time of pressing the button (right).

Assessment and Measurements

Drowsiness can be assessed by using either subjective or objective data. The experiment used method to assess subjective fatigue is the Karolinska Sleep Scale (KSS) (Jarosch et al., 2019). Participants state their subjective drowsiness on a 9-point Likert scale: extremely alert (1), alert (3), neither alert nor sleepy (5), sleepy – no difficulty remaining awake (7) and extremely sleepy – fighting sleep (9). For objectively assessing drowsiness, the experiments were conducted using Mind Wave Mobile, which is a brainwave headset equipped with Think Gear Asics, for collecting drowsiness data. This product can output data converted to digital signals after noise elimination from the acquired EEG signals, data analysed by the algorithm, and electromyogram data of blink (see Figure 3).

To measure the participants' attention during driving, the experimental procedure used the Mackworth Clock Vigilance Test (MCVT) to collect reaction times. MCVT mentions that vigilance work, monitoring, requires the best physiological and mental state to react (Lichstein et al., 2000). It is characterized by lengthy uninterrupted periods by the participant, attention to find small stimuli and react to their cause (Veksler and Gunzelmann, 2018). As shown in Figure 4 on the left picture, the red dot is turned in sequential order

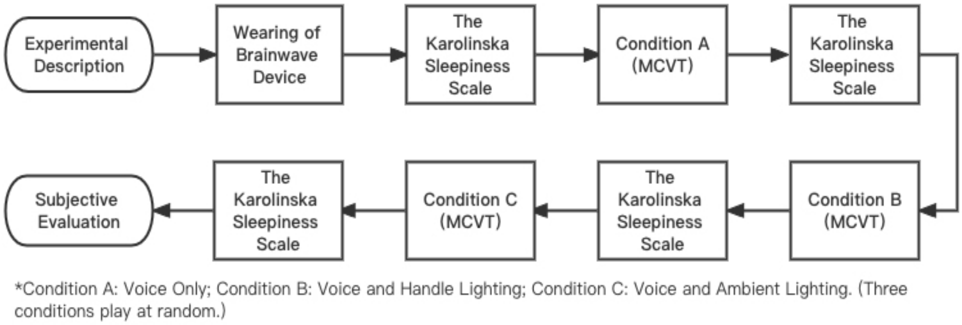

Figure 5: Experimental procedure.

like a clock, occasionally skipping. Suppose the participant notices when the red dot skips and immediately presses the button. The reaction time of pressing the button is recorded. Data for Miss, False, and detected were extracted from the MCVT and analyzed using the following formula (1). If a red dot in sequential progress skips, it is judged "detected" when clicked within 3 seconds; if not clicked within 3 seconds, it is identified as "missed"; Furthermore, if the red dot does not skip but is clicked, it is recognized as "false start".

$$\text{Score} = \frac{n_{\text{detected}}}{n_{\text{false start}} + n_{\text{missed}} + n_{\text{detected}}} * 100\% \tag{1}$$

Three scale values (no, yes, neither) were given for the following six items in the subjective evaluation of lighting stimulations. The questions were positive "excited" and "awakened" and negative "surprised," "anxious," "angry," and "uncomfortable" to evaluate the participants' subjective feeling state during driving.

Procedure

The study lasted a maximum of 2 hours per participant and was conducted from 9 am to 11 am or 2 pm to 4 pm. In an invitation letter, participants were asked to avoid drinking caffeinated beverages 7 hours before participating in the experiment and ensure they do not get hungry during the experiment. Furthermore, the experimental purpose and the principles of the takeover system in autonomous driving are also described.

On the experiment day, participants were asked to complete a brief questionnaire concerning their sleep and drug-taking behaviour since the previous day and fill out basic information, including age, gender, driving experiences, and driving drowsiness countermeasures. Once the participants completed the questionnaire, the experiment started according to the process shown in Figure 5. Firstly, the participants explained the experimental procedure and how to use MCVT, then they were fitted with brainwave devices and filled out the KSS as a baseline for drowsiness. After the preparation was completed, we informed the participants that the experiment would begin with one hand on the steering wheel and one hand holding the MCVT button (see the

Table 1. Results from repeated measures ANOVA of MCVT score.

Mackworth Score				
	No Light	Handwheel	Ambient	*p*-Value
Total	0.60	0.54	0.57	0.547
By Gender	0.53	0.42	0.51	0.535
(F)	0.64	0.62	0.59	
By Driving Freq.	0.62	0.55	0.55	0.575
(< once a month)	0.58	0.57	0.59	

right picture in Figure 4). Each driving condition was 20 minutes in duration, and stimulus conditions were presented when MCVT was determined to be incorrect or missed. The stimulus conditions were presented in random order across the three driving conditions to eliminate bias. After each driving condition, the participant was asked to redo the KSS test to compare the subjective data on sleepiness. The subjective evaluation questionnaire for the three stimuli was completed after the three driving conditions.

RESULTS

The Effect of Light Position on Attentional Focus

According to the results from the independent sample t-test as shown in Table 1, there is no significant difference between each stimulus in the MCVT score ($p = .547 > .05$). Also, we indicated there was no significant difference between MCVT score by gender ($p = .535 > .05$) and driving frequency ($p = .575 > .05$).

Comparatively, we hypothesized that each individual is different and that the ambient light affected participants differently. We separated the subjects into three groups according to the awake score of KSS (yes, neither, no) during the ambient light stimulus. We tested whether there were significant effects on Mackworth's score after experiencing ambient light. As a result, each participant had no significant difference ($p = .206 > .05$).

The Impact of Light Position on Drowsiness

As shown in Figure 6, the results of the KSS showed that drowsiness was slightly more potent after each condition compared to before the experiment score in the questionnaire. Meanwhile, drowsiness after prolonged driving was more pronounced for participants when only voice stimulation was available. Comparatively, the handle light condition resulted in lower levels of drowsiness. In addition, we analyzed whether the KSS score differed after experiencing each stimulus. We found that the effect was identical for all three stimuli ($p = .082 > .05$). Also, according to the results from the independent sample t-test, there is no significant difference between the three stimuli evaluation scale by gender ($p = .0821 > .05$) and driving frequency ($p = .0621 > .05$).

Assuming that each person is different and the ambient light affected participants differently, we separated the subjects into three groups according

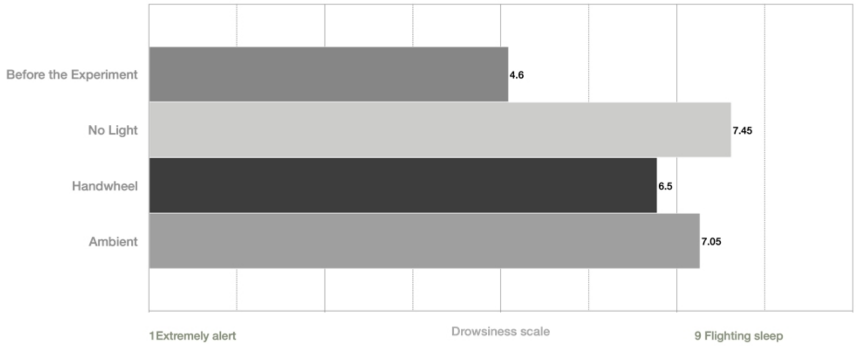

Figure 6: Results of the Karolinska Sleepiness Scale.

Table 2. Results from repeated measures ANOVA of subjective evaluation test.

Adjusted with Greenhouse-Geisser				
	No Light	Handwheel	Ambient	*p*-Value
Excited	0.30	0.55	0.30	0.327
Awake	0.40	0.95	0.85	**0.029***
Supervised	0.10	0.85	0.30	**0.003****
Anxious	0.45	0.35	0.10	0.254
Angry	0.35	0.50	0.30	0.538
Strange	0.55	0.75	0.40	0.325

$^{*}p < .05$ $^{**}p < .005$.

to the awake score of KSS (yes, neither, no) during the ambient light stimulus. We tested if there was a difference in KSS score after experiencing ambient light. As a result, each participant had no significant difference ($p = .613 > .05$).

However, there was a significant effect between the before experiment's KSS score and ambient score ($p = .013 < .05$) and handwheel score ($p = .003 < .005$). This means using ambient and handwheel lights would significantly reduce driver drowsiness in automatic driving.

Subjective Evaluation of Lighting Position

We conducted a repeated-measures ANOVA for each emotional item to determine whether there were distinct effects (see Table 2). Excited, Anxious, Angry, and Strange responded similarly to each stimulus. The total rating indicated that the participants did not experience these emotions. However, the *p*-Value for Awake ($p = .029 < .05$) and Surprised ($p = .003 < .05$) was less than 0.05, so we performed a post hoc test to determine if there was a significant difference.

Consequently, we used Bonferroni to adjust the Pairwise Comparison for multiple comparisons (see Table 3). Regarding Awake, we could not identify a recognizable significance ($p > .05$). All three stimuli had the same effect on the Awake sensation. For Surprise, we found a significant difference between

Table 3. Results from Bonferroni pairwise comparisons of awake and surprised.

Bonferroni Pairwise Comparisons					
Awake		*p*-Value	**Surprised**		*p*-Value
No Light	Handwheel	0.071	No Light	Handwheel	0.012
	Ambient	0.139		Ambient	0.890
Handwheel	No Light	0.071	Handwheel	No Light	**0.012***
	Ambient	1		Ambient	**0.036***
Ambient	No Light	0.139	Ambient	No Light	0.890
	Handwheel	1		Handwheel	0.036

*$p < .05$.

the Handwheel and No Light ($p = .012 < .05$) and between the Handwheel and Ambient ($p = .036 < .05$). The effect of the Handwheel in the feeling of Surprise was different from the effect of No Light and Ambient.

CONCLUSION

As the results showed, different combinations of light position and voice had no effect on driver concentration ($p = .547 > .05$). Meanwhile, neither novice nor experienced drivers had any change in driving concentration due to the lights ($p = .575 > .05$). However, the use of ambient lights ($p = .013 < .05$) and handwheel lights ($p = .003 < .05$) would significantly reduce driver drowsiness in autonomous driving. The drowsiness prevention stimulus with only voice reminders is far less effective than the audible combination with the light stimulus.

Furthermore, we identified the same effect of the three stimulus combinations on the perception of "wakefulness". Regarding "surprise", the evaluation of the audiovisual experience was significantly influenced by the position of the light: participants felt more surprised when the handwheel light was displayed than with the other two stimuli (no light, $p = .012$; ambient, $p = .036$).

The findings of this study compare the effects of different light positions on the audiovisual experience and provide reference suggestions for the visual placement of drowsiness prevention systems.

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REFERENCES

Ann, I.-S., 2018. A study on warning sound for drowsiness driving prevention system. J. Acoust. Soc. Am. 143, 1961–1961. https://doi.org/10.1121/1.5036446

Balandong, R.P., Ahmad, R.F., Mohamad Saad, M.N., Malik, A.S., 2018. A Review on EEG-Based Automatic Sleepiness Detection Systems for Driver. IEEE Access 6, 22908–22919. https://doi.org/10.1109/ACCESS.2018.2811723

Bazilinskyy, P., Petermeijer, S.M., Petrovych, V., Dodou, D., de Winter, J.C.F., 2018. Take-over requests in highly automated driving: A crowdsourcing survey on auditory, vibrotactile, and visual displays. Transp. Res. Part F Traffic Psychol. Behav. 56, 82–98. https://doi.org/10.1016/j.trf.2018.04.001

Dinges, D.F., Maislin, G., Brewster, R.M., Krueger, G.P., Carroll, R.J., 2005. Pilot Test of Fatigue Management Technologies. Transp. Res. Rec. J. Transp. Res. Board 1922, 175–182. https://doi.org/10.1177/0361198105192200122

Janssen, C.P., Iqbal, S.T., Kun, A.L., Donker, S.F., 2019. Interrupted by my car? Implications of interruption and interleaving research for automated vehicles. Int. J. Hum.-Comput. Stud. 130, 221–233. https://doi.org/10.1016/j.ijhcs.2019.07.004

Jarosch, O., Bellem, H., Bengler, K., 2019. Effects of Task-Induced Fatigue in Prolonged Conditional Automated Driving. Hum. Factors J. Hum. Factors Ergon. Soc. 61, 1186–1199. https://doi.org/10.1177/0018720818816226

Lichstein, K.L., Riedel, B.W., Richman, S.L., 2000. The Mackworth Clock Test: A Computerized Version. J. Psychol. 134, 153–161. https://doi.org/10.1080/00223980009600858

Mardi, Z., Ashtiani, S.N., Mikaili, M., 2011. EEG-based drowsiness detection for safe driving using chaotic features and statistical tests. J. Med. Signals Sens. 1, 130. https://doi.org/10.4103/2228-7477.95297

McDonald, A.D., Lee, J.D., Schwarz, C., Brown, T.L., 2018. A contextual and temporal algorithm for driver drowsiness detection. Accid. Anal. Prev. 113, 25–37. https://doi.org/10.1016/j.aap.2018.01.005

Murata, A., 2016. Proposal of a Method to Predict Subjective Rating on Drowsiness Using Physiological and Behavioral Measures. IIE Trans. Occup. Ergon. Hum. Factors 4, 128–140. https://doi.org/10.1080/21577323.2016.1164765

Richman, J.S., Moorman, J.R., 2000. Physiological time-series analysis using approximate entropy and sample entropy. Am. J. Physiol.-Heart Circ. Physiol. 278, H2039–H2049. https://doi.org/10.1152/ajpheart.2000.278.6.H2039

Sahayadhas, A., Sundaraj, K., Murugappan, M., 2012. Detecting Driver Drowsiness Based on Sensors: A Review. Sensors 12, 16937–16953. https://doi.org/10.3390/s121216937

Schwarz, C., Gaspar, J., Miller, T., Yousefian, R., 2019. The detection of drowsiness using a driver monitoring system. Traffic Inj. Prev. 20, S157–S161. https://doi.org/10.1080/15389588.2019.1622005

Slater, J.D., 2008. A definition of drowsiness: One purpose for sleep? Med. Hypotheses 71, 641–644. https://doi.org/10.1016/j.mehy.2008.05.035

Veksler, B.Z., Gunzelmann, G., 2018. Functional Equivalence of Sleep Loss and Time on Task Effects in Sustained Attention. Cogn. Sci. 42, 600–632. https://doi.org/10.1111/cogs.12489

Zhang, H., 2020. A User-centered Auditory Design in Interaction Between Electric Vehicle and Pedestrian. Int. J. Affect. Eng. 19, 217–226. https://doi.org/doi:10.5057/ijae.TJSKE-D-19-00037

Zhou, F., Alsaid, A., Blommer, M., Curry, R., Swaminathan, R., Kochhar, D., Talamonti, W., Tijerina, L., Lei, B., 2020. Driver fatigue transition prediction in highly automated driving using physiological features. Expert Syst. Appl. 147, 113204. https://doi.org/10.1016/j.eswa.2020.113204