RESEARCH ON ATTENTION KEEPING TECHNOLOGY TO REDUCE CARELESS DRIVING ACCIDENTS

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ABSTRACT

We explore how a driver's attention changes when exposed to auditory and haptic stimuli. In many cases, accidents caused by internal factors, typified by drowsy driving and careless driving, result in serious accidents Therefore, it is important to keep the driver from losing attention. Thus far, manufacturers have built systems to promote arousal by engaging visual and auditory alarms when the driver loses attention. However, in such cases the driver has already lost attention when the alarm is engaged. Depending on driving circumstances, it is impossible to immediately stop the vehicle or take a break, and in some cases the driver has no choice but to continue driving despite their decreased level of attention. This paper focuses on auditory and vibratory stimuli as realistic methods of stimulus that can actually be supplied to the driver by products, and establishes stimulus methods with indications of a relationship to autonomic nerve activity. The paper also evaluates the effectiveness of these methods in preventing loss of attention, by supplying the established stimulus under conditions in which drivers have begun to lose attention in the past. The stimulus methods are as follows. (1) Music: Comparatively high-tempo music at around 100–130 beats per minute (bpm). (2) Music with amplified bass: The same music described in (1), but with its bass range amplified. (3) Music with vibration: Music with superimposed vibrations in sync with the bpm of the music described in (1), from a sound source in the seatback peaking at 60 Hz. Test subjects were put into a driving simulator that employed these stimuli and asked to follow the vehicle in front of them for 30 minutes. Each of the 11 test subjects repeated four trials, including trials with no stimuli. Several indicators were collected during these trials. For driving behavior, the indicator was Time-to-Collision (TTC), for subjective sleepiness it was time-dependent change in the Karolinska Sleepiness Scale (KSS), and for a parasympathetic indicator it was Standard Deviation of NN intervals (SDNN), which is the standard deviation of the R-R Interval. The eight test subjects for which data was properly collected tended to exhibit higher minimum TTC during the trails with stimulus than those without. This increased greatly ($p < 0.01$) when bass amplification and superimposed vibrations were used. It was found that subjective sleepiness, which was the time for which test subjects were aware of being sleepy, decreased by 58% with the music stimulus (1), 86% with the music with amplified bass stimulus (2), and 77% for the music with vibration stimulus (3), compared to with no stimulus. Moreover, the SDNN trend revealed parasympathetic acceleration when there was no stimulus, but this was suppressed for both (1) music only and (3) music with vibration. For (2) music with amplified bass in particular, it remained in the same state from the beginning of the test.

Applying the knowledge above to inhibit loss of concentration before it occurs can be expected to help reduce traffic accidents associated with internal factors such as drowsy driving and careless driving.

INTRODUCTION

Honda aims to achieve zero fatalities in traffic accidents involving Honda motorcycles and four-wheeled vehicles by 2050. In Japan, internal factors typified by drowsy driving and careless driving account for 26.2% of the human factors in traffic fatalities (505 incidents) [1]. In the United States, it is estimated that drowsy driving leads to 90,000 collisions, 50,000 traffic accidents resulting in injury, and 800 fatalities per year [2]. In this way, drowsy driving and careless driving often lead to serious accidents. That is why it is important to help prevent the loss of driver attention brought about by drowsy driving and careless driving. Attention detection systems that detect loss of attention, through wandering of the driver’s vehicle and drive duration, are already in practical use. These systems output visual and auditory alerts when a loss of attention is detected. Also, in recent years, cars have started coming to market with functions that assess sleepiness based on facial features obtained from onboard driver monitoring cameras. When the system determines that the driver is sleepy, these functions trigger visual and auditory alarms. All detection/alarm systems are installed with the goal of encouraging the driver to take a break. But in the interest of acceptability, most of them do not activate an alarm until the driver’s level of sleepiness has reached a certain point. However, in such cases the driver has already lost attention when the alarm is engaged. Depending on driving conditions, it is not possible to immediately stop the vehicle or take a break, and in some cases the driver has no choice but to continue driving despite their decreased level of attention. In addition, it is challenging to wake a driver from a state of deep sleepiness of which they themselves are aware [3]. While an alarm stimulus may temporarily restore arousal, as the stimulus is intended to encourage the driver to take a break, it cannot be expected to be continually effective. Because of this, it is hoped that a method for continuously maintaining concentration and inhibiting sleepiness will be found.

It is known that the parasympathetic nerves of the autonomic nervous system are accelerated when people have lost attention during drowsy and careless driving. While it is challenging to control the autonomic nervous system through the force of one's own will, it is known to change in response to various external stimuli. Therefore, it stands to reason that there needs to be a stimulus that can inhibit the acceleration of the parasympathetic nerves in order to maintain concentration while continuing to drive. One example of a phenomenon in which a person's state can change in response to an external stimulus is that known as entrainment. Entrainment describes the phenomenon in which two different rhythms that are close to each other naturally synchronize. It is said that a similar thing happens in humans [4]. There are many events in daily life in which a person's state is changed or guided by entrainment. For example, it has been reported that entrainment, such as humming along when listening to music, becoming one with the music at a live concert and getting excited, or listening to sounds that are a different tempo from one's own heart rate, all influence the autonomic nervous system [5][6]. Entrainment of the autonomic nervous system often focuses on the tempo of music, and it has been reported that the tempo of a song itself can influence how the subjective groove of the music is felt, and influence the autonomic nervous system [7][8]. Also, when attention is given to what qualities of music make it easy to synchronize with, it turns out that such music has many low sounds such as drums [9]. It has been reported that emphasizing beat influences the autonomic nervous system and the desire to move one's body [10][11]. As can be seen, there are numerous examples of studies that examine musical tempo and beat as individual elements, but there are few looking into their combined effects. In addition, while there have been reports on the effects of sound and music stimuli on driving behavior, few studies have mentioned their relationship to subjective sleepiness and autonomic nerve activity.

As such, this study focused on loss of attention due to sleepiness, which is considered to be the most influential factor in loss of attention while driving. Using music focused on entrainment, it evaluated the effect of external stimuli on driving behavior, subjective sleepiness, and autonomic nerve activity, with the goal of developing a human–machine interface (HMI) that can inhibit loss of attention due to sleepiness. In considering stimuli, the study sought to use the vehicle's onboard audio as a stimulus to induce entrainment and intervene in a natural, unobjectionable way. Also, as vibrations have been added to some vehicle seats in recent years, the effect of superimposing vibrations on the music using sound from the seatback was also examined. In the experiment, test subjects were placed in a driving simulator (DS) and told to follow the car ahead of them. This monotonous driving situation can easily induce loss of attention. To help test subjects maintain attention, the music and music with superimposed vibrations mentioned earlier were supplied as stimuli, and the effectiveness of these stimuli in inhibiting the loss of attention was evaluated.

This experiment has been reviewed by the Bioethics Committee meetings for Honda's R&D activities. (Bioethics Committee No. 98HM-056 H)

TESTING METHOD

DS Tasks

In this study, researchers constructed an environment to allow the test subjects to perform the task of following the vehicle ahead of them. The constructed course was a straight road with three lanes, and test subjects were instructed to drive in the middle lane. Figure 1(a) shows the experimental environment and Fig. 1(b) shows an example of what participants saw as they drove during the experiment.

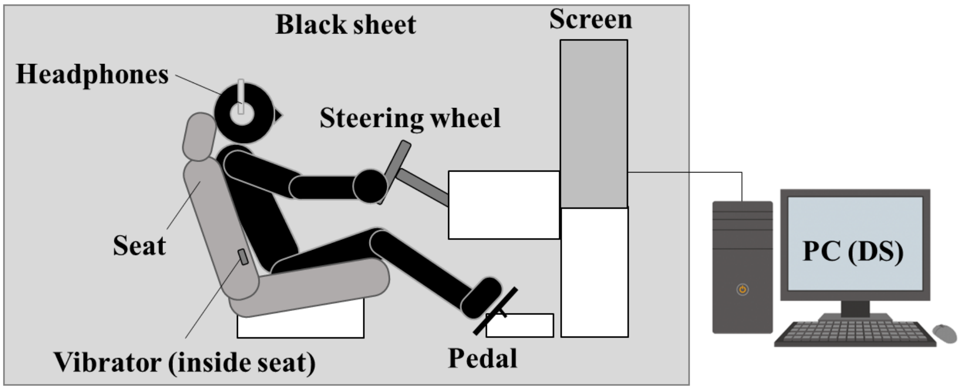

Figure 1(a). Experimental environment

Figure 1(b). Example test run

At the start of the test, the initial vehicle speed was 70 km/h and the initial distance from the vehicle ahead was 30 meters. Test subjects were not told how much distance to leave between their car and the vehicle ahead, and were asked to drive at a distance that they did not feel was dangerous. Test subjects drove for 30 minutes under each condition. Four tests with different conditions were conducted over 4 days, for a total of 120 minutes. To operate their own vehicle, test subjects needed to operate the accelerator and brake to maintain a suitable distance from the car ahead, and steer to maintain a straight line. The car being followed in the simulation was configured to perform two types of random deceleration, as shown in Fig. 2, slowing down to either 50 km/h or 30 km/h. Test subjects were instructed to perform the necessary operations to maintain distance from the car ahead when they noticed it slow down. In order to encourage loss of attention, the car in front was programmed not to decelerate until 15 minutes after the start of the test. Also, to help prevent test subjects from simply reacting to the brake lights of the car ahead, its brake lights were set to stay off. The experiment was also conducted in an environment in which light was blocked by dark curtains to induce sleepiness, as shown in Fig. 1(a).

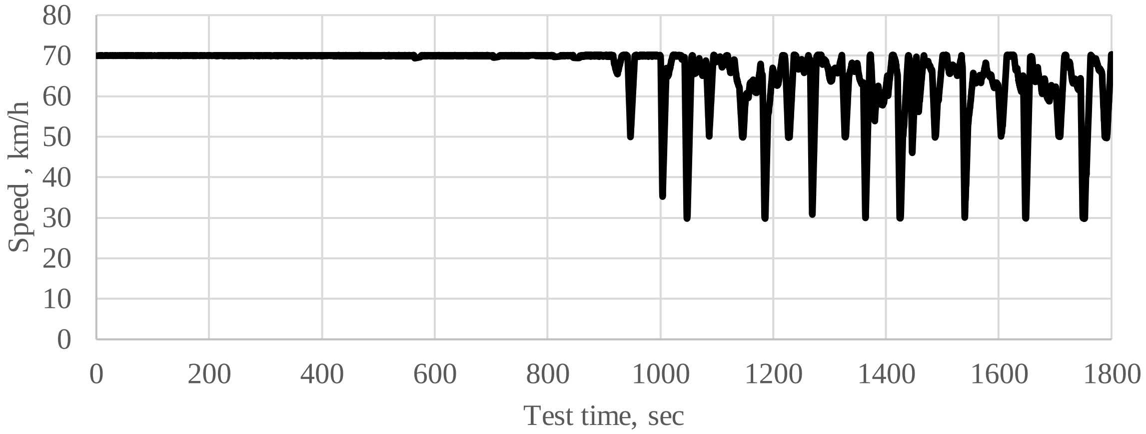

Figure 2. The behavior of the car ahead

Moreover, test subjects wore headphones when performing the driving task, to play back the driving/engine sounds from the simulator, and to present the type of musical stimuli described in the following section.

Stimulation Method

Test subjects performed operations while listening to sounds generated by their own vehicle and the surrounding vehicles that were output from the driving simulator, and music that was output from a PC. Tests were conducted with and without HMI stimuli. Scenario A used no HMI stimulus, and scenario B used HMI stimulus. Before the test, test subjects selected at least five songs that they would like to listen to during the experiment. These were chosen from a set of songs prepared by the experimenters (J-pop and contemporary Western music: 100–130 bpm). The selected music was arranged in a musical playlist set to start playing when the test began, and loop until the test ended. The sound volume during the test was set to a level of 65 dB, and then decreased from that level to a level that the test subject found acceptable. In scenario B1, the selected songs were played without processing as an original sound source. In scenario B2, the selected songs were first processed using the music creation software Cubase to amplify low sounds of 200 Hz or below, and then played back as a sound source. In scenario B3, vibrations corresponding to the bpm of each song were supplied from an vibrations installed in the lumbar section of the seatback (Fig. 1(a)) to correspond with the playback of the original sound source. The oscillator used a Vibro-Transducer VP to convert the electronic signal of the sound into mechanical vibrations, and employed a sound source with a peak of 60 Hz. Furthermore, the music used in scenario B was the same for each test subject.

Table 1 below shows the stimulus levels employed this time.

Table 1. Test stimulus levels

Scenario No.		Test condition (HMI)
A		No music
B	B1	Music(100-130 bpm)
	B2	Music with amplified bass
	B3	Music with vibration

Test Subjects

Eleven healthy adults from whom informed consent had been obtained (six men, five women, average age 37) participated in the experiment. Each held an ordinary motor vehicle license and drove on a daily basis. Physiological indicators could not be properly obtained from some participants, and others were already quite sleepy at the start of the test. In total, accurate data could not be obtained for three people. Therefore, the following data was collected and processed from eight participants.

Measurement Items

Subjective sleepiness index The Karolinska sleepiness scale (KSS) was used as an indicator of subjective sleepiness [12]. As shown in Table 2, the KSS is a questionnaire that test subjects can use to evaluate their own level of sleepiness. The odd numbers in the scale include sensitivity words indicating sleepiness. To allow test subjects to record their own changes in sleepiness during the test in real time, the researchers focused on the expressions used in the odd numbers of the scale. This made the scale easier for test subjects to remember and make judgments about during the driving tests. The evaluation scale for this experiment was defined to consist of levels 1 through 5. Test subjects were instructed to press buttons installed on the steering wheel, which corresponded to the Table 2, according to changes in subjective sleepiness while driving.

Table 2. KSS scale and subjective drowsiness index used in the experiment

KSS scale		**Experiment KSS Scale**	
1	**extremely alert**	**1**	**extremely alert**
2	**very alert**		
3	**alert**	**2**	**alert**
4	**rather alert**		
5	**neither alert nor sleepy**	**3**	**neither alert nor sleepy**
6	**some signs of sleepiness**		
7	**sleepy, but no effort to keep alert**	**4**	**sleepy, but no effort to keep alert**
8	**sleepy, some effort to keep alert**		
9	**fighting sleep**	**5**	**fighting sleep**

Physiological index The R-R interval (RRI) obtainable from electrocardiogram data was acquired as a physiological index for evaluating the effect of external stimuli on the autonomic nervous system. A Silmee wearable heart rate sensor made by TDK was used so as not to interfere with driving. The sampling rate was set to 1 kHz.

Driving behavior index Drivers who possess adequate attention to follow a car traveling ahead of them in the same lane can drive safely by using visual information and other factors to appropriately evaluate the risk of collision with the vehicle ahead. Time-to-Collision (TTC) is calculated as the distance from the driver’s vehicle to the vehicle ahead divided by the relative velocity of the two vehicles. This was used as an indicator of driving behavior to determine whether the driver took action to decelerate in response to deceleration of the vehicle ahead, when attention has or has not been lost. TTC is an indicator that predicts when the driver’s vehicle will collide with the vehicle ahead if the current relative velocity is maintained.

Procedure

Test subjects were asked to avoid excessive work on the day of the experiment, and to refrain from consuming caffeine.

In addition, living organisms have a biological rhythm called the circadian rhythm, and it is thought that sleepiness and physiological index can easily change depending on the time the study is performed. For this reason, the tests were only conducted after lunch during the period from 1 p.m. to 4 p.m., when sleepiness tends to increase. Figure 3 shows the stimulus level course for Test 1.

Trial Run	Rest	Test Run	Questionnaire
～10 min	1 min	30 min	5 min

Figure 3. Test 1 Stimulus Level Course

After the details of the experiment and precautions to be taken were explained to each participant, they were asked to put on a heart rate monitor and get into the driving simulator. Participants practiced driving for a few minutes, rested for 1 minute after practice, then performed the test run. Each test subject performed the experiment under a total of four test stimulus levels. To avoid order effects, the order of test stimulus levels was randomized for each test subject, and they performed one test per day for a total of 4 days.

ANALYSIS METHOD

Minimum TTC

To ascertain the difference in TTC for loss of attention in each test subject at each stimulus level, researchers calculated the minimum TTC value (>0 sec) in each test run for the period from when the preceding vehicle slowed down until the test subject began to decelerate. In comparing the average values of each stimulus level, significance was first confirmed using one-way ANOVA, then Tukey was used for multiple comparison.

Period of Low Attention

It is thought that attention has been lost at Level 4 or higher of the subjective sleepiness index shown in Table 2 when a person is aware of their own sleepiness. Therefore, the cumulative time driving during the experiment at KSS Level 4 or higher was documented for each stimulus level. In comparing the average values of each stimulus level, significance was first confirmed using one-way ANOVA, then Tukey was used for multiple comparison.

Average Rate of Change of Standard Deviation of NN intervals

Sleepiness extrapolated from heart rate information is based on findings related to presumed autonomic nerve activity based on electrocardiogram frequency analysis. However, when a person is fighting sleepiness in order to perform a task, such as in this report, a conflict arises between the body's desire to sleep and the arousal effort required to stay awake and drive. The level of arousal rises and falls when arousal effort is applied, effecting each physiological index. This is said to complicate the change in level of arousal, making it challenging to estimate sleepiness [13]. The Standard Deviation of NN intervals (SDNN), which is the standard deviation of the RRI and the analytical index in the time domain, was thus used to lessen the influence of arousal effort. This value tends to fall during arousal and rise during sleepiness. The average SDNN was compared at 120-second intervals (240 sec, 360 sec, ...), using the average SDNN level 120 seconds directly after the test as a base.

EXPERIMENTAL RESULTS

The change in TTC and SDNN accompanying sleepiness was confirmed. Figure 4a shows the change in TTC and sleepiness for one test subject under Stimulus Level A. The horizontal axis shows time passed and the vertical axis shows the TTC and KSS level at that time. The KSS level rose in the latter half of the test, and the TTC more frequently dropped greatly when the car in front began slowing down. Figure 4b shows the relationship to physiological index at that time. The horizontal axis shows time elapsed, and the vertical axis shows the change in average SDNN at 120-second intervals during the test run with the SDNN at 120 seconds after the start of the test set as 100%. The rate of change was observed to increase from the start of the test run as sleepiness rose, and reached 118% by the end of the test.

Figure 5a shows the change in TTC and sleepiness for the same test subject under Stimulus Level B2. There was little change in TTC despite the elapsed time, and KSS remained at KSS Level 1 for the majority of the experiment. In addition, there was little rise in the rate of change in SDNN shown in Figure 5b as the test progressed, and the value at the end of the test was 81%, which was even lower than at the start of the test.

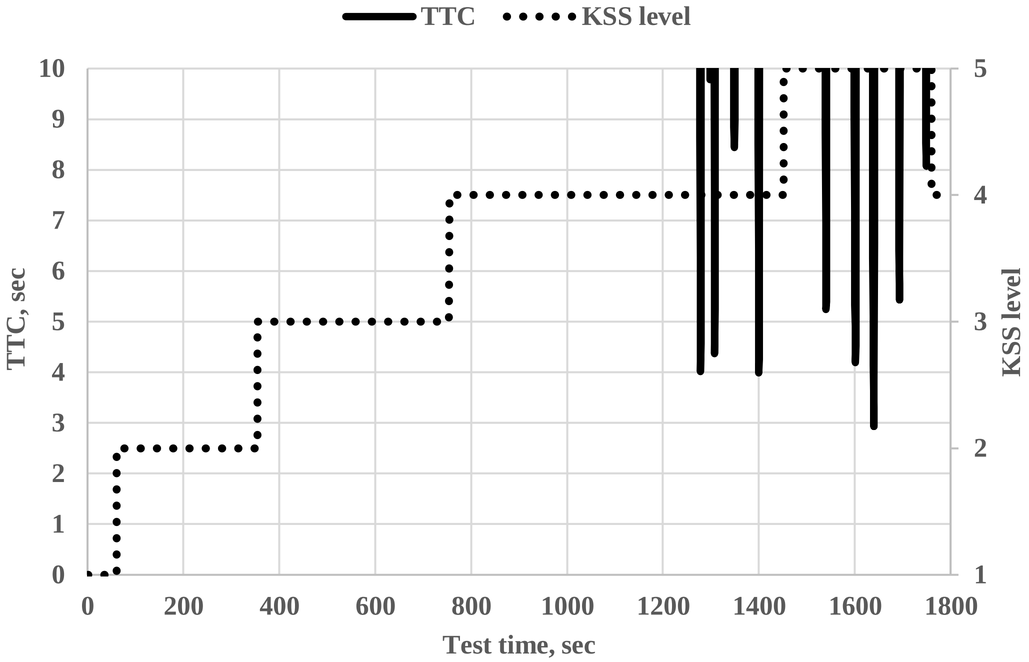

Figure 4a. Change in TTC and sleepiness (Stimulus Level A)

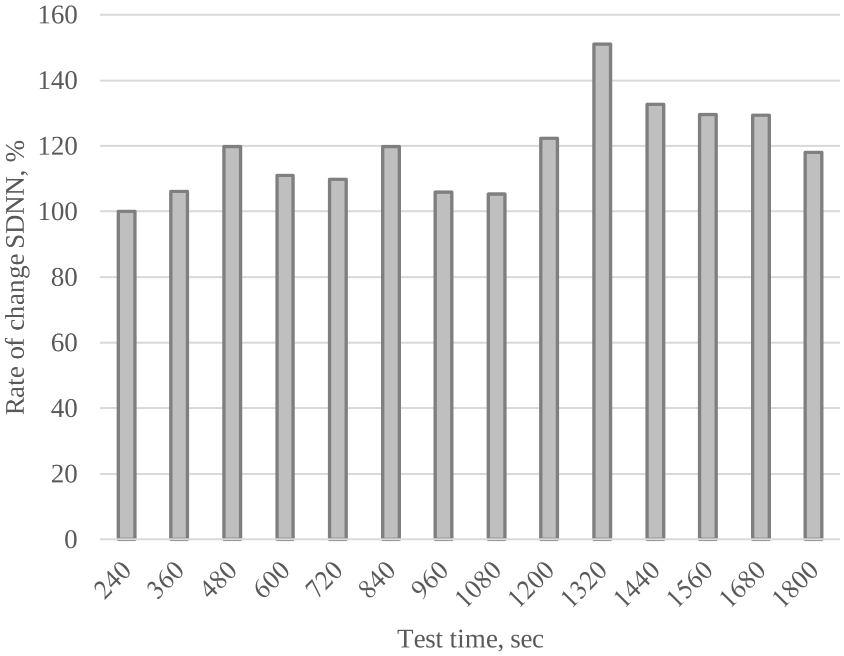

Figure 4b. Average rate of change of SDNN (Stimulus Level A)

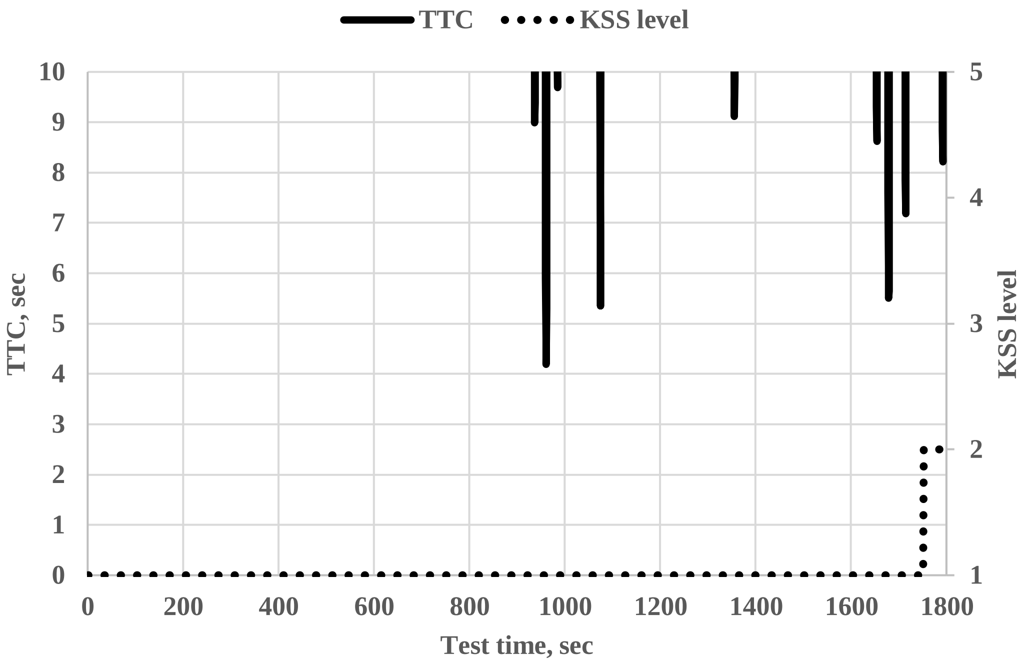

Figure 5a. Change in TTC and sleepiness (Stimulus Level B2)

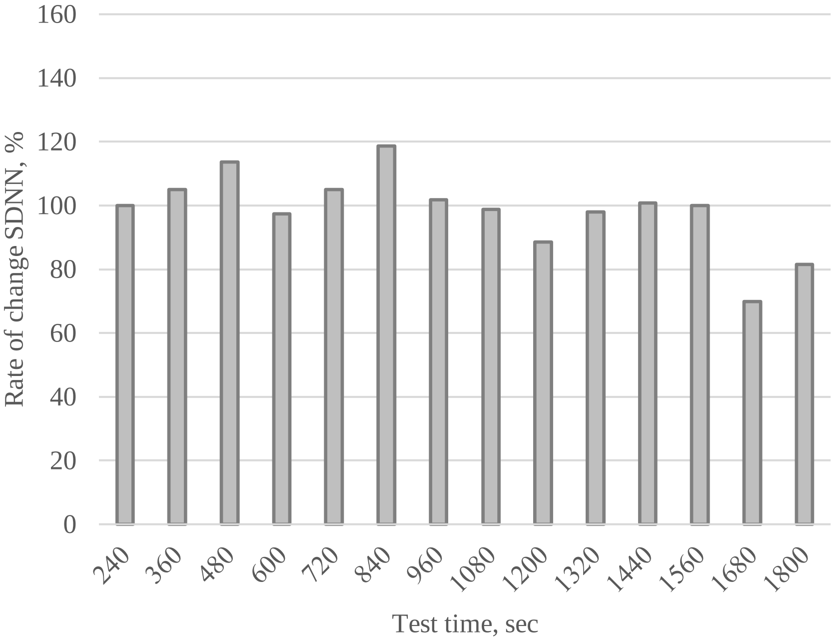

Figure 5b. Average rate of change of SDNN (Stimulus Level B2)

The influence of each stimulus condition on driving behavior was confirmed. Figure 6 shows the distribution of minimum TTC for each of the eight test subjects over all test intervals at each level. The forward collision warning (FCW) operation standard shown in the Forward collision warning system confirmation test [14] stipulates a TTC of >2.4 sec. In contrast to the TTC of <2.4 sec expected with FCW operating, around half of the test subjects drove with a TTC of 2.4 sec or less under Stimulus Level A. Under B1, one of the test subjects drove with a TTC of 2.4 sec or less. It was found that under stimulus levels B2 and B3, all of the test subjects drove with a TTC of 2.4 sec or more. When one-way ANOVA was performed with the experimental conditions as factors, the main effect between experimental conditions was found to be ANOVA F (3,32) = 8.20, p <(0.01). When Tukey multiple comparison was performed, stimulus levels B2 and B3 were found to be greatly higher than Stimulus Level A, at a level of 1%.

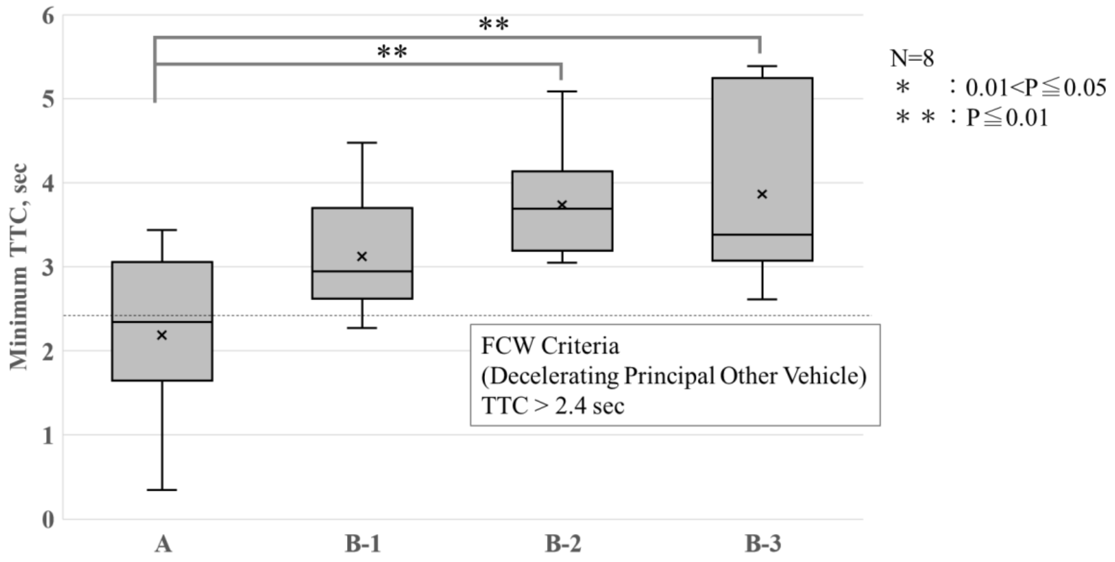

Figure 6. Minimum TTC at each stimulus level

The influence of each stimulus condition on sleepiness was confirmed. Figure 7 shows the total time at KSS Level 4 or higher for each stimulus level. While participants were subjectively aware of their own sleepiness for approximately 1,000 seconds under Stimulus Level A, it was found that applying a stimulus reduced the time that participants were aware of being sleepy by 58% for Stimulus Level B1, 86% for B2, and 77% for B3. When one-way ANOVA was performed with the experimental conditions as factors, the main effect between experimental conditions was found to be ANOVA F (3,32) = 9.65, p <(0.01). When Tukey multiple comparison was performed, Stimulus Level B1 was found to be greatly higher than Stimulus Level A at a level of 5%, while levels B2 and B3 were found to be greatly higher at a level of 1%.

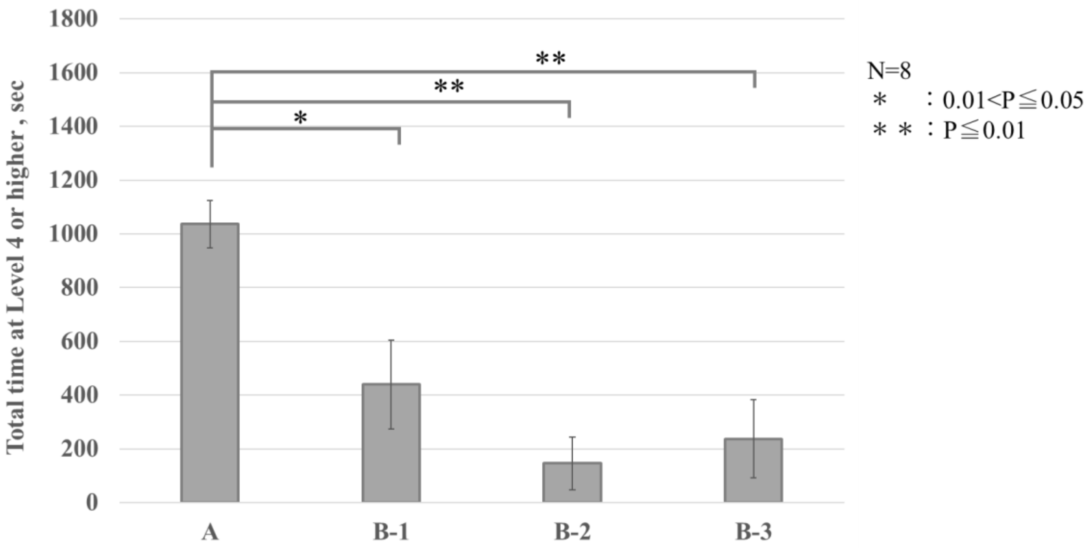

Figure 7. Time aware of sleepiness (KSS ≥4) at each stimulus level

The influence of each stimulus condition on the autonomic nervous system was confirmed. Figure 8a shows the average rate of change in SDNN from Stimulus Level A to Stimulus Level B1, and Fig. 8b shows the comparison of change in KSS. For A, the KSS level was found to increase in the latter half of the test, and the rate of change in SDNN also tended to increase. For B1 as well, a similar trend was observed in the latter half of the test, but both KSS level and the rate of change in SDNN tended to be lower than those of A. For B2, shown in Fig. 9a, it was found that the increase in KSS level was suppressed even during the latter half of the test. Also, the rate of change in SDNN shown in Fig. 9b remained almost unchanged from the start. For B3, shown in Fig. 10a, it was observed that the rise in KSS level was suppressed just as for B2, but the rate of change in SDNN rose in the middle of the test (960 to 1,440 sec), as shown in Fig. 10b.

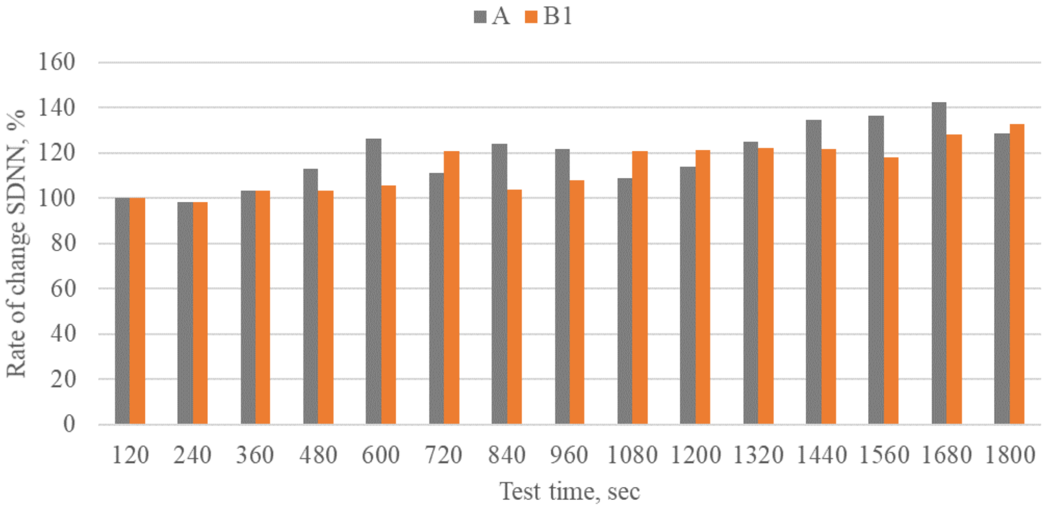

Figure 8a. Comparison of rates of change in SDNN (A vs. B1)

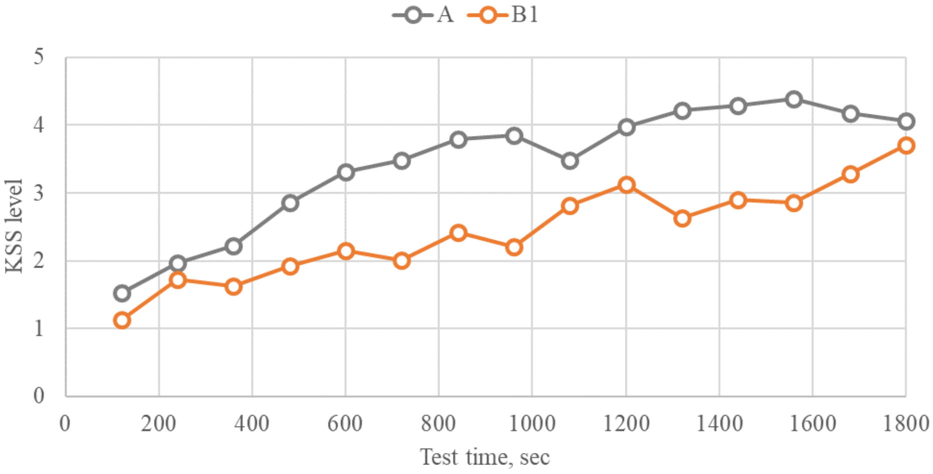

Figure 8b. Comparison of change in average KSS level at 120-sec intervals (A vs. B1)

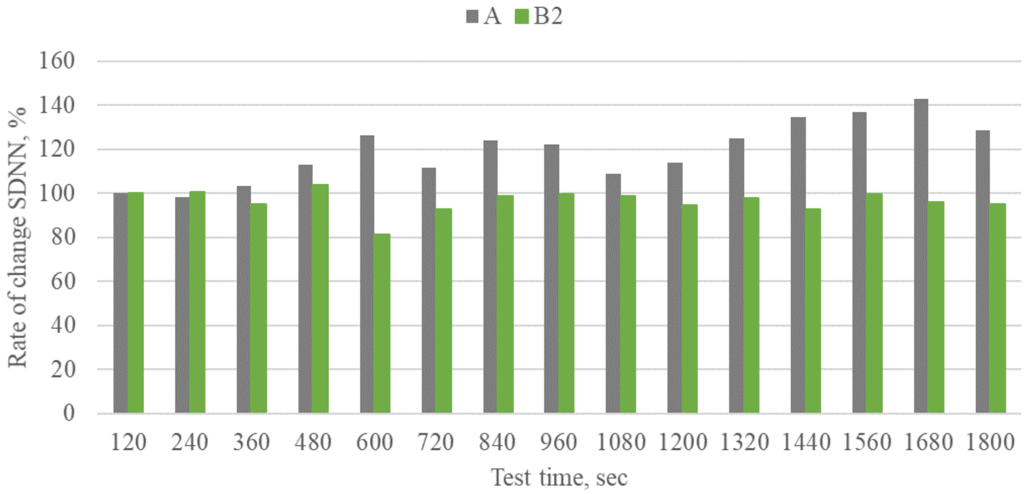

Figure 9a. Comparison of rate of change in SDNN (A vs. B2)

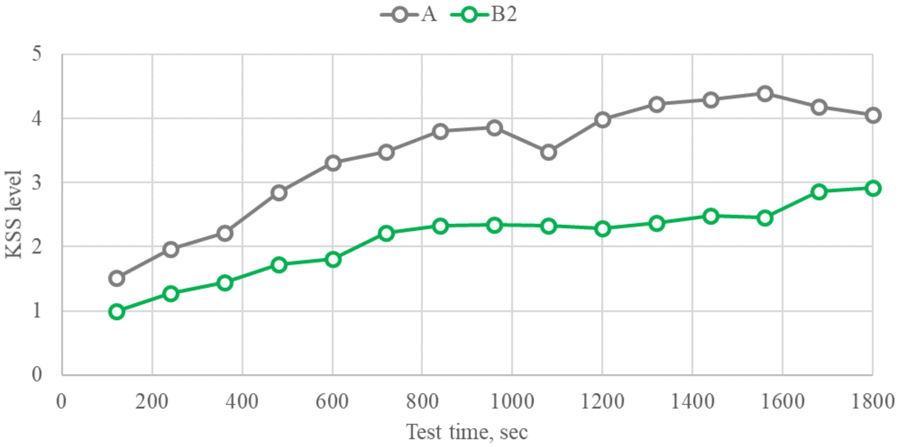

Figure 9b. Comparison of change in average KSS level at 120-sec intervals (A vs. B2)

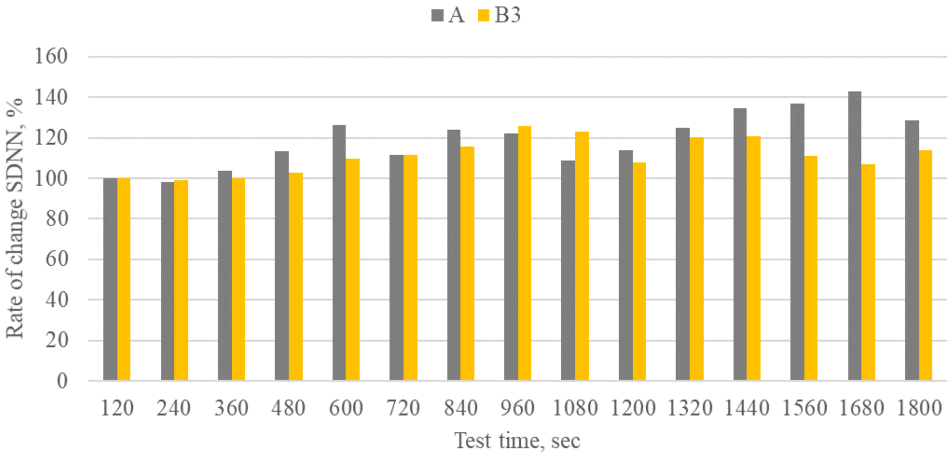

Figure 10a. Comparison of rate of change in SDNN (A vs. B3)

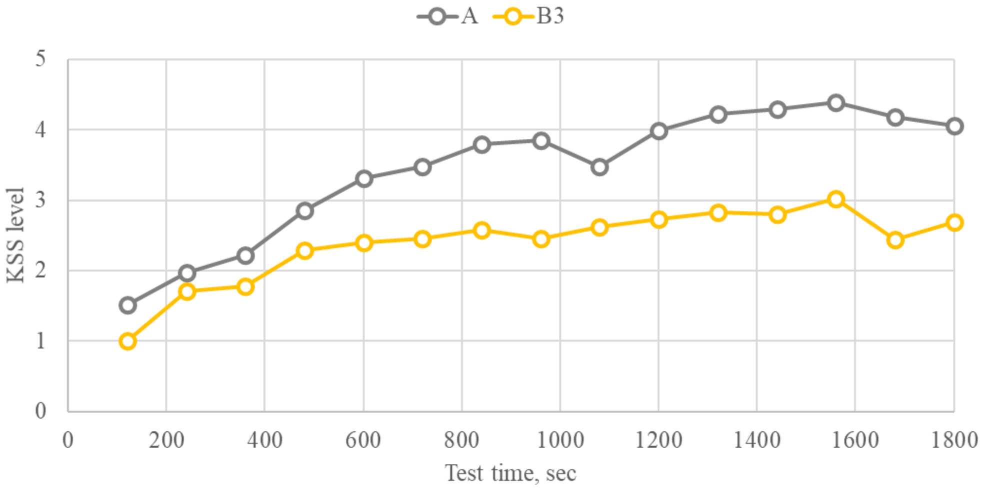

Figure 10b. Comparison of change in average KSS level at 120-sec intervals (A vs. B3)

DISCUSSION

Figure 8a indicates that the increase in the rate of change in SDNN was suppressed for B1 from 480 to 960 sec and 1440 to 1680 sec, respectively, and that can be assumed to be linked to the suppression of rise in sleepiness for B1 shown in Fig. 8b. This suggests that the minimum TTC for A shown in Fig. 6 is trending to the safe side due to the effect of the musical stimulus on the autonomic nervous system. From these results, it can be assumed that the tempo of the music presented in Stimulus Level B1 was somewhat effective in inhibiting loss of attention due to entrainment. In comparing the stimulus methods in scenario B, the average KSS level in B2 and B3, as shown in Figs. 9b and 10b, remained low compared to B1 staying at Level 3 or below. In addition, it was found that the length of time for which test subjects were aware of being sleepy also decreased compared to B1, as shown in Fig. 7. As the KSS level remained low, there was no radical drop in minimum TTC as seen in B1, and it can be assumed that B2 and B3 tended to the safe side. The stimuli in B2 and B3, which this study investigated, focused on enhancing bass and beat stimuli to affect the autonomic nervous system [10] and stimulate the sensorimotor cortex [11]. In particular, the rate of change in SDNN for B2 remained almost unchanged until the end of the test, as shown in Fig. 9a. This suggests that by considering an amplified bass stimulus as well as a musical tempo, researchers were able to inhibit acceleration of the parasympathetic nerves through the recognized effect on the autonomic nervous system, and maintain the state of attention participants had at the start of the test. On the other hand, no clear decreasing trend in the rate of change in SDNN was observed for B3 when compared to B1. One possible reason for this may be differences in how the stimulus was felt by each subject. Concerning the stimulus in B2, some test subjects did not feel any difference compared to the original sound source. As there were no negative comments in particular, it can be assumed that the intensity of the stimulus did not go beyond what was acceptable. However, after the Stimulus Level B3 test, some participants commented that while they clearly felt the vibration of the seatback when the stimulus began, they stopped noticing it after a while. It is thought that this is due to the haptic characteristic of humans known as acclimatization, in which sensitivity to stimuli decreases with time. This could be why the effectiveness of the stimulus decreased. In addition, some participants commented that the stimulus was annoying, and this may have impaired the stability of the physiological index. These differences in the acceptability of the stimulus may have played a part in the failure to inhibit acceleration of the parasympathetic nerves to as great an extent as in B2. For future stimuli, in order to keep the stimulus subliminal, its strengths and weaknesses should be considered. Also, setting personalized stimuli that do not annoy the driver can be expected to stabilize their physiological index and effectively increase acceptability.

CONCLUSION

This study sought to inhibit the loss of attention brought about by careless driving. To this end, the researchers obtained indicators consisting of TTC for driving behavior, SDNN as a physiological index, and KSS for subjective sleepiness, and evaluated the change in each indicator brought about by each stimulus method. It was found that three stimulus conditions were able to move driving behavior toward the safe side: simple musical presentation, music with amplified bass, and music with superimposed vibration. In particular, music with amplified bass was found to suppress the acceleration of the parasympathetic nerves from the standpoint of the physiological index. Also, it is thought that it may be possible to maintain attention using this stimulus. On the other hand, while it is possible to maintain attention by superimposing vibrations, it was not acceptable to some test subjects. It is possible that further improvement can be achieved by personalizing the intensity of the stimulus. In addition, it is thought that signs of sleepiness that will trigger the stimulus can be obtained by using a driver monitor camera or wearable device. The above results demonstrate the feasibility of a system that inhibits loss of attention due to careless driving through natural intervention using music.

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