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# EFFECT OF PLEASURABLE MUSICAL CHILLS ON DRIVER'S PHYSIOLOGICAL RESPONSE

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Abstract. *Recently, it has become feasible to enjoy high-quality music by improving the quietude of cars' interiors and the sound quality of audio systems. This can result in the experience of "pleasurable musical chills". These include goosebumps and states of elation or of being moved. However, no studies have been reported on the effect of high-quality sound and musical chills on drivers' comfort and driving performance. We focus on these musical chills by examining drivers' physiological responses and investigating the influence of high-quality audio with various sound presentations. Physiological responses such as brain activity, breathing, and heartbeat were examined to reveal their relationship with musical chills. It can be concluded based on the results that drivers experiencing musical chills through high-quality music could increase their elation and concentration. Thus, experiencing musical chills provides drivers a sense of pleasure and excitement.*
**Keywords:** Musical chills, Hi-Fi audio, Physiological response analysis, Semantic differential method

1. **Introduction.** There have been a lot of studies on the emotional response, autonomic nervous system response, and brain activity induced by music listening [1,2]. The sound of music introduced significant positive correlations between subjectively reported pleasure states and objectively measured increases in autonomic nervous system activity [3]. The emotional power of music can provoke a pleasurable emotional response: pleasurable musical chills [4]. The stimuli that produce this response are specific to music involving high realistic sensations, such as live performance and high-quality audio. It is considered that musical chills, which include goosebumps and states of elation or of being moved, generate positive effects such as pleasure and joy. Studies on musical chills induced by music have shown that it activates the sympathetic nervous system and produces brain activity that reflects the pleasant sensation of receiving a substantial reward [1-3]. In recent years, cars have become increasingly comfortable and attractive to drivers. This has enabled them to experience the pleasure and excitement of driving. The improvement in the quietude of cars' interiors and the sound quality of audio systems has made it feasible to enjoy high-quality music. This can result in drivers experiencing musical chills while driving, and it can be a new value for cars that provides drivers' a sense of pleasure and excitement. No study has investigated the effect of high-quality sound and musical chills

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on drivers' comfort and driving performance. Here, we investigate the influence of high-quality audio with various sound presentations and musical chills on drivers' physiological responses. The objective of this study is to clarify the effect of musical chills on drivers' mental states. Physiological responses such as brain activity, breathing, and heartbeat are examined to understand their relationship with musical chills. Sound quality impressions are evaluated using the semantic differential (SD) method [5]. This would help in the design and sound quality evaluation of cars' audio systems by clarifying the mechanism of emotional variations caused by listening to music.

This paper is organized into five chapters, and the following chapter describes the analytical methods. Chapter 3 describes the experimental method and results of Experiment 1, listening to music in resting state, and Chapter 4 describes Experiment 2, listening to music while driving. Finally, Chapter 5 shows the summary of the results.

2. **Analytical Method.** Physiological responses such as brain activity were measured and examined by electroencephalography (EEG), respiratory rate and heart rate variability (HRV). Sound quality impressions were evaluated using the SD method. Each analysis method is described below.

2.1. **EEG analysis.** The EEG was classified by the frequency band. Table 1 shows the classification table for EEG [6]. These waves were extracted by applying a band-pass filter to EEG. Both proportion and stability of each wave were analyzed.

TABLE 1. Classification of EEG [6]

| Name | Frequency band [Hz] | Condition |
|---|---|---|
| $\theta$ wave | 4-8 | Sleep-introducing |
| $\alpha$ wave | 8-13 | Wakeful, Rest, Closing eyes |
| $\beta$ wave | 13-30 | Tension state, Opening eyes |

First, the proportion of $\alpha$ waves was calculated using Equation (1):

$$\alpha \text{ wave proportion } (\%) = \alpha \text{ wave}/(\alpha \text{ wave} + \beta \text{ wave}) \tag{1}$$

Second, the brain wave's stability was considered for the effective duration. The effective duration ($\tau e$) is defined as the delay time until the amplitude of the normalized autocorrelation function (ACF) is reduced by 10%. Hence, $\tau e$ is high when the brain wave is stable. The delay time was estimated from the straight-line regression calculated using the initial declining portion (0 dB $> 10\log|\phi(\tau)|$ dB $> -5$ dB).

The effective duration was calculated using normalized ACF. It is defined by Equations (2) and (3) [7]:

$$\Phi(\tau) = \frac{1}{2T}\int_0^{2T} p(t)p(t+\tau)dt \tag{2}$$

$$\phi(\tau) = \frac{\Phi(\tau)}{\Phi(0)} \tag{3}$$

In this equation, $2T$ is an integral interval, $\tau$ is the delay time, $p(t)$ is one of the brain waves, $\Phi(\tau)$ is the ACF, and $\phi(\tau)$ is the normalized ACF. The ACF indicates the similarity of the signal itself and its stability.

The previous study reported that the $\alpha$ wave around the occipital region was periodically stable when a participant was experiencing psychological preference and that the $\beta$ wave was unstable when the participant was experiencing elation [7].

2.2. **Respiratory analysis.** Respiratory analysis was conducted by measuring the participant's thoracic variation with reduced strain. In addition, we used a method to identify one breath from the respiratory waveform and calculate the indicators [8]. This method was modified partially, and an analysis program for the experiment was formulated. The respiratory rate was used as a respiratory indicator because the respiratory rate increases when the sympathetic nervous system of the autonomic nervous system is activated.

2.3. **HRV analysis.** The autonomic nervous system controls the heartbeat interval fluctuations. The HRV analysis is used to quantify various strains and impressions [9]. The autonomic nervous system is closely related to the psychological state of the person. It consists of the sympathetic and parasympathetic nervous systems. The sympathetic nervous system is activated by concentration and excited states and the parasympathetic nervous system is activated by a relaxed state. The musical chills were related to the activation of the sympathetic nervous system [2,3,9].

In this study, we used a band-pass filter and wavelets to remove the sound source and motion artifact noise while recording. Furthermore, the smoothed data was calculated from the waveform envelope. The HRV was extracted from these data, and an HRV analysis was conducted. The low-frequency power (LF), high-frequency power (HF), and their ratio (LF/HF) were calculated as evaluation indicators by using frequency analysis. Moreover, pNN20 and Lorenz plots (LP) (an indicator of the parasympathetic nervous system) were calculated from the heartbeat intervals and used as evaluation indicators. pNN20 is the percentage of the difference between successive RR intervals that exceeds 20 ms [10]. LP is a method to evaluate the scatter of a plot where the horizontal and vertical axes are the $N$th and $N+1$th RR intervals, respectively [11].

## 3. Experiment 1: Listening to Music in Resting State.

3.1. **Experimental methods.** In the first experiment, we investigated the physiological responses of the participants while listening to music in the resting state. The experiment was conducted in four different environments: live music, high-quality speaker (DIATONE DS-2000Z), earphones (MTA-HRP01), and iPhone 8. Thereby, the differences in sound qualities could be distinguished clearly. The live music and recording experiments were conducted in the main hall of Hiroshima City University auditorium with a jazz band playing there. Figure 1 shows the environment of the live music experiment. In the other experimental environments, we used sound sources that recorded live music and presented these at the volume that each participant generally prefers while listening to music. The participants' physiological responses were also measured. Table 2 lists the measurement instruments used. Seven participants (males with normal hearing capability) were

FIGURE 1. Live music experiment

Table 2. Measurement instruments used in Experiment 1

| Measuring object | Measuring instruments |
|---|---|
| EEG | "EEG-9100" (Nihon Kohden Corporation) |
| Respiration | "T.K.K.3345" (Takei Scientific Instruments Co., Ltd.) |
| PCG | Stethoscope "Littmann Electronic Stethoscope Model 3200" (3M*TM* Littman*TM*.)<br>Microphone "MI-1531" (ONO SOKKI)<br>Preamplifier "MI-3140" (ONO SOKKI) |

included in the experiment. The local ethics committee approved the experiment, and all the participants provided informed consent. The experiment was conducted with the participants being in a resting state. They were instructed to press a button when they experienced musical chills.

3.2. **Result and discussion.**

3.2.1. *EEG analysis.* The measured EEG was analyzed to evaluate the percentage and stability of each frequency band. During the analysis, we focused on the 6 s after the participant pressed the button. The analysis showed that the percentage of $\beta$ waves increased marginally in both occipital and left parietal regions. The stability analysis results of the $\beta$ wave demonstrated that it was marginally unstable in the left frontal and left parietal regions. These results indicated that the participants felt elated when they experienced musical chills.

3.2.2. *Respiratory analysis.* These results indicated that the respiratory rate of the participants tended to be higher while listening to music than without music, particularly with live music and earphones. It was considered that these results were obtained for the live music because the participants experienced musical chills almost during listening and were tensed. In addition, it was considered that these results were obtained for the earphones because the sound source was a binaural recording. The respiratory rate tended to be higher in the 5 s before and after the button was pressed than for the overall song. This indicated that the sympathetic nervous system was activated when musical chills were experienced.

3.2.3. *HRV analysis.* The results of the HRV analysis indicated no significant differences in the physiological responses of the participants with and without music. In addition, there was no correlation between LF/HF and each of the parasympathetic nervous system indicators. However, the results of the parasympathetic nervous system indicators indicated that this system was inhibited while listening to live music.

From these results, it can be concluded that listening to music influenced elation and that participants were in a tense, excited, or elated state when they experienced musical chills. Moreover, these results and the results of the subjective evaluation indicate that they were in a tense state when they listened to live music.

4. **Experiment 2: Listening to Music While Driving.**

4.1. **Experimental methods.** The second experiment focused on the experience of listening to music while driving. We investigated the physiological responses of drivers when listening to music while operating the driving simulator. Here, the jazz sound source (playback time 8:30) recorded in Experiment 1 was presented as a stimulus sound using three speakers: a high-quality speaker (B&W 706S2), a normal speaker (NUFORCE S-1), and an iPhone 8. The speakers were presented randomly without being revealed to the participants. Figure 2 illustrates the experimental environment, and Table 3 lists the measurement instruments used. Seven participants (males with normal hearing) were

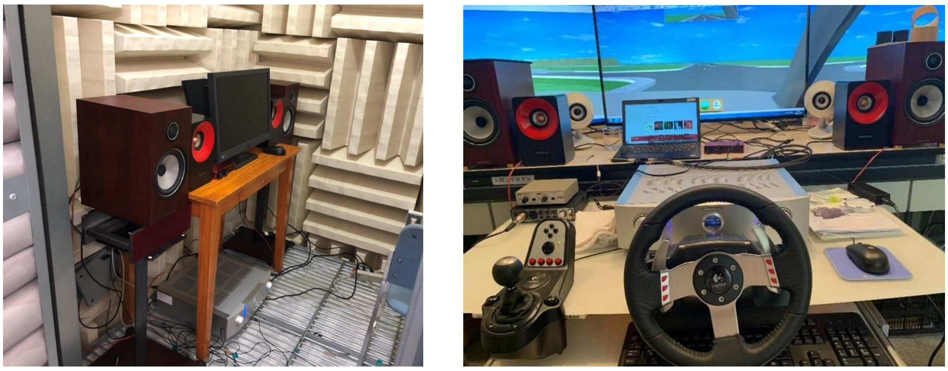


Figure 2. Environment of Experiment 2

Table 3. Measurement instruments used in Experiment 2

| Measuring object | Measuring instruments |
|---|---|
| EEG | "EEG-9100" (Nihon Kohden Corporation) |
| Respiration | Wearable sensor "Hexoskin" (KISSEI COMTEC Co., Ltd.) |
| ECG | Wearable sensor "Hexoskin" (KISSEI COMTEC Co., Ltd.) |

included in the experiment. The local ethics committee approved the experiment, and informed consent was obtained from all the participants. The participants were instructed to drive around an 8-shaped course until the music stopped and to press a button when they experienced musical chills. In addition, the speakers' hearing impressions were evaluated using the SD method. This method has been already used in our previous studies to relate impressions to the physical quantity [12]. In this experiment, 23 adjective pairs were employed, and we evaluated each pair on a 7-point scale. A brief questionnaire was administered before and after the experiment.

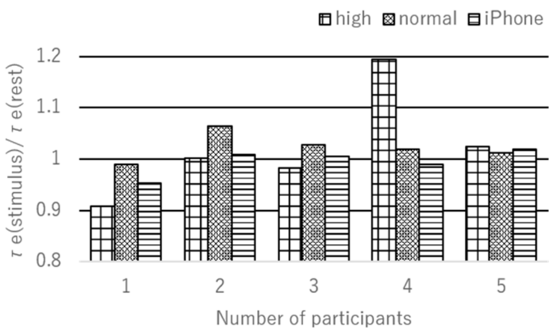
### 4.2. **Result and discussion.**

4.2.1. *Subjective evaluation and SD method.* The questionnaire administered after the experiment and the results of the SD method are as follows.

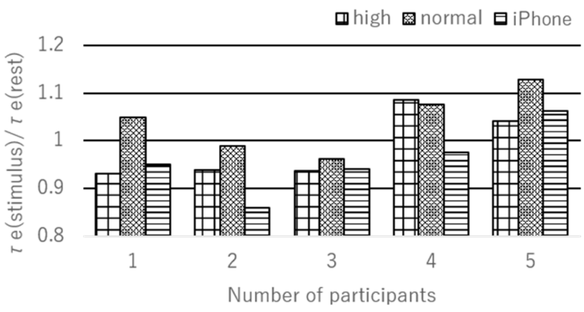
- Four out of seven participants said that the normal speaker had the best sound quality.
- Musical chills were more likely to be experienced when the driving operation matched the climax of a song.
- The "bright", "spacious", and "expansive" factors received positive ratings for the high-quality speaker, whereas the "bright" and "familiar" factors received positive ratings for the normal speaker and iPhone. In addition, most of the factors received positive ratings for the high-quality and normal speakers and negative ratings for the iPhone.
- The high-quality speaker had a clear sound image, depth, and a sense of spaciousness. The normal speaker had a sense of existence that enabled individuals to hear directly from the speaker.

In this experiment, we compared these results with the physiological responses and discussed them.

4.2.2. *EEG analysis.* An analysis of the ratio of $\alpha$ waves and the brain wave's stability showed that the $\beta$ wave tended to stabilize when the participants listened to music with a normal speaker (see Figure 3). These results were consistent with the results of subjective evaluations. This indicated that the $\beta$ wave was stable in the parietal region when the sound quality was perceived as high.



(a) Left parietal region



(b) Right parietal region

FIGURE 3. Results of stability of $\beta$ wave

4.2.3. *Respiratory analysis.* The results of the respiratory analysis indicated that the respiratory rate tended to increase as the sound quality improved. Therefore, the sympathetic nervous system was activated with the increase in the sound quality.

4.2.4. *HRV analysis.* The HRV analysis indicated that the sympathetic nervous system was most activated, and the parasympathetic nervous system was most inhibited when a normal speaker was used (see Figure 4). Moreover, there was a significant negative correlation between LF/HF and each of the three parasympathetic nervous system indicators. There was a positive correlation among all the combinations of the three parasympathetic nervous system indicators.

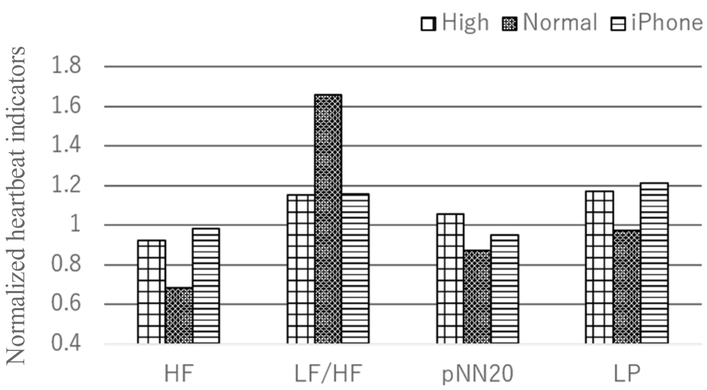


FIGURE 4. Results of HRV analysis

These physiological responses showed no significant difference in the 5 s before and after the button was pressed. One of the reasons for this is that the participants were in a multitasking state, that is, driving, listening to music and pressing the button.

It can be concluded from these results and the speaker's characteristics that the sense of existence of the speaker was associated with the sound quality impression evaluation and experiencing of musical chills.

5. **Conclusions.** This study investigated the effects of listening to music on the psychological state of the drivers. Two experiments were conducted to investigate the influence of sound quality and musical chills on physiological responses. First, the results of the EEG analysis indicated that the participants were in a tense, excited, or elated state when they experienced musical chills in the resting state. In addition, the results showed that the $\beta$ wave was stable when the sound quality was perceived as high while the participants were driving. Second, the results of the respiratory analysis indicated that the sympathetic nervous system was more activated when the participants were listening to music,

particularly with high sound quality. Moreover, the results indicated that the sympathetic nervous system was activated when musical chills were experienced. Third, the results of the HRV analysis indicated that the parasympathetic nervous system was inhibited when the participants were listening to live music (in the resting state), and that the sympathetic nervous system was activated while listening to music with a normal speaker (while driving). This was consistent with the subjective evaluation. Finally, the results of the subjective evaluation indicated that the sense of existence of the speaker activated the sympathetic nervous system and increased the probability of the participants experiencing musical chills.

We conclude that drivers experiencing musical chills by listening to high-quality music could increase their elation and concentration. Thus, it is feasible to regulate a driver's mental state by altering the sound quality to experience musical chills. Experiencing musical chills would be a new additional value for cars that would provide drivers' a sense of pleasure and excitement. In the future, we will investigate effective indicators for estimating musical chills and their relationship with the physiological responses.

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