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Effects of nature sounds on the attention and physiological and psychological relaxation

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ABSTRACT

This study aims to verify the effects of nature sounds on attention, and physiological and psychological relaxation. Twenty-six university students (mean age: 21.5 ± 1.9 years) participated in this study, and the experiment was conducted with one person at a time. A mixed sound of valley water and birds in a forest environment was used as the nature sound, and a road traffic sound was used as the urban sound (control). The participants performed the following steps: (1) closed their eyes and rested for 1 min; (2) opened their eyes and completed attention tasks while hearing nature or urban sounds for 1 min; (3) closed their eyes again and rested while hearing the same sound for 1 min. We used Harris and Harris grid for the attention task. We measured the participants' oxy-hemoglobin concentration, heart rate variability, and heart rate for physiological evaluation, and used semantic differential method, and profile of mood states for psychological evaluation. As a result, ① There was no significant difference in the results of the attention task; however, the scores were slightly higher when hearing nature sound. ② The oxy-hemoglobin concentration and heart rate was lower, and parasympathetic nerve activity was enhanced when hearing nature sound than when hearing urban sound. ③ Once participants heard nature sound, they felt more comfortable, relaxed, and natural, and the negative mood state was lower, while the positive mood state was higher than urban sound. This suggests that hearing nature sounds may be an effective way to relieve stress in everyday life.

1. Introduction

Although more than half of humanity resides in urban environments (Ritchie and Roser, 2018), humans have historically lived in natural environments for long periods (Brunet et al., 2002). Since humans originate from nature, they instinctively want to be connected with nature and feel comfortable in natural environments (Wilson, 1984).

Among the various elements that make up the natural environment, nature sounds, such as the sounds of birds, wind, and water, are resources that can be easily accessed in everyday life. As modern humans increasingly desire to use such nature sounds (YouTube culture & trends, 2022), their importance as a resource for relaxation also increases.

The positive effects of nature sound on human relaxation have been demonstrated in several studies (Aletta et al., 2018; Ratcliffe, 2021). Anderson et al. (1983) investigated the preferences of 20 male and female university students after they heard various sounds, including sounds from urban, rural, and natural environments. Their study showed that nature sounds, such as the sounds of songbirds, crickets, and wind in trees were preferred by the participants. Alvarsson et al. (2010) examined the recovery effects of 40 male and female university students when they heard four sounds, including nature sound (50 dB), high noise (80 dB), low noise (50 dB), and ambient noise (40 dB) after exposure to stress stimulation. The nature sound was evaluated as the most pleasant and familiar sound environment, and they confirmed that the skin conduction level, which increased in the stress state, recovered most quickly when hearing nature sound. Medvedev et al. (2015) investigated the soundscape and skin conductance level of participants when they were exposed to various sounds for four minutes after a two-minute stress-inducing period. The participants rated nature sounds, such as birdsong and ocean, as being especially pleasant, and the skin conductance level was significantly reduced when they were exposed to such sounds. Largo-Wight et al. (2016) divided 40 participants into three groups; one group heard nature sound, another group heard classical music, and the control group was not exposed to sound, and the authors measured the changes before and after 15 min of exposure to sounds. They found that the muscle tension, pulse rate, and self-reported stress were most decreased in the group that heard nature sound. Jo et al. (2019b) involved 29 female university students to

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investigate the differences in physiological and psychological responses when hearing forest sound and city sound. It was found that when hearing forest sound, the brain activity and autonomic nervous system activity of the participants were relaxed, and they felt more comfortable, relaxed, and natural. Moreover, negative mood states were lower and positive mood states were higher than when hearing city sound. Ochiai et al. (2020) involved 22 males with gambling disorders to examine the differences in physiological and psychological response after hearing forest sound and city sound, and they confirmed results similar to those of Jo et al. (2019b). Furthermore, various studies have been conducted to verify the positive effects of nature sounds on the bodies and minds of people (Emfield and Neider, 2014; Hedblom et al., 2017; Luo et al., 2021; Ratcliffe et al., 2013).

It has been shown that people use approximately 1/3 of their day for studying or working (OECD Statistics, 2022). Most people spend considerable time adapting to a rapidly changing society and performing the required tasks, which is a requisite to survive in this competitive society. However, it deepens negative mood states (such as depression and anxiety) and deteriorates sleep quality owing to lack of sleep (Afonso et al., 2017; Ogawa et al., 2018), which eventually results in the outbreak of chronic diseases that many modern people suffer from. In particular, it is associated with the development of cerebrovascular and cardiovascular diseases (Lin et al., 2018). Therefore, the efficiency of attention and subsequent recovery is crucial. Recent research has shown that experiencing nature has positive effects on human attention, concentration, cognitive function, and mental fatigue recovery (Bratman et al., 2012; Abbott et al., 2015; Ohly et al., 2016; Van Hedger et al., 2019). It is thought that nature sounds can also play a positive role in these aspects.

However, research related to this topic remains insufficient. In particular, no studies have examined both the efficiency of attention and subsequent recovery effects of nature sounds. Therefore, the novelty of this work is that it aims to verify the effects of nature sounds on attention, and physiological and psychological relaxation.

Hypothesis I. When hearing nature sounds, attention will be higher than when hearing urban sounds.

Hypothesis II. When hearing nature sounds, people will be more physiologically relaxed than when hearing urban sounds.

Hypothesis III. When hearing nature sounds, people will be more psychologically relaxed than when hearing urban sounds.

2. Methods

2.1. Participants

The participants included male and female university students aged 20 years and higher. Among them, those receiving treatment at hospitals, those with a history of allergic reactions or multiple drug side effects, those with a history of heart diseases, those with hearing problems, students from the department to which the research director belongs, and students taking courses taught by the research director were excluded to ensure the findings are unbiased.

Participants were recruited by posting notices on the campus bulletin board and the online community of university students. Among those who expressed their intention to participate in this study, only those who satisfied the inclusion criteria were included.

In total, 26 healthy male and female university students (mean ± standard deviation, 21.5 ± 1.9 years old) participated in this study. There were 10 male (22.0 ± 1.4 years old) and 16 female (21.2 ± 2.1 years old) students (Table 1).

This study was approved by the Institutional Review Board of Kongju National University (KNU_IRB_2021–34). Sufficient information on the experiment was provided to all participants in a pre-orientation, and KRW 10,000 was paid as a reward at the end of the experiment.

Table 1
Participants information.

	Age	Height (cm)	Weight (kg)	BMI (km/m^2)
Total (n = 26)	21.5 ± 1.9	166.6 ± 7.8	63.3 ± 11.4	22.8 ± 3.4
Male (n = 10)	22.0 ± 1.4	172.9 ± 6.4	70.2 ± 9.8	23.4 ± 2.9
Female (n = 16)	21.2 ± 2.1	162.4 ± 5.6	58.8 ± 10.2	22.3 ± 3.7

(mean ± standard deviation)

2.2. Sound

A mixed sound of valley water and birds in a forest environment was used as the nature sound, and the road traffic sound of the Han-gang Bridge was used as the urban sound (control). The sound pressures of the two original audio sources were analyzed using the Praat sound analysis program (Boersma and Weenink, 2022). The results showed that the average sound pressure of nature sound was 51.1 ± 3.6 dB, while the average sound pressure of urban sound was 73.0 ± 8.1 dB (Fig. 1).

Since the sound pressures of the two sounds were different, we adjusted the sound pressure to the same level by adjusting the volume of the speakers when presenting the sounds to the participants. The sound stimulation was presented using a Bluetooth speaker (SRS-X11, Sony Korea, Korea) positioned 1.3 m behind the seat of the participants (Fig. 2).

We measured the actual sound pressure of the presented sounds at 1-second intervals using a sound level meter (DT-95, CEM instruments, China), and the average sound pressure of the nature sound was 46.8 ± 1.0 dB and the average sound pressure of the urban sound was 46.8 ± 1.4 dB (Fig. 3). There was no significant difference in the sound pressure between the two sounds ($p > 0.05$, independent t-test).

2.3. Experimental design

The experiment was conducted in the laboratory for 15 days, from May 17 to June 1, 2021. The temperature was maintained in the range of 22–26 °C, and the humidity was maintained between 40% and 60%.

Within-subjects design was used; each participant heard both nature and urban sounds. To exclude the effect of order, half of the study participants were first asked to hear the nature sound and the other half to the urban sound.

Fig. 4 illustrates the experimental process. The experiment was

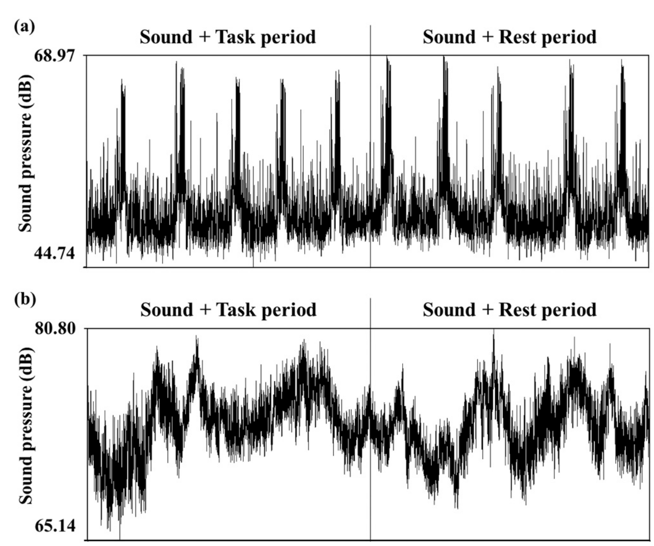

Fig. 1. Changes in the sound pressure of two original audio sources analyzed by Praat. (a) Nature sounds (mixed sound of valley water and birds in a forest environment). (b) Urban sounds (road traffic sound).

Fig. 2. Experimental scene.

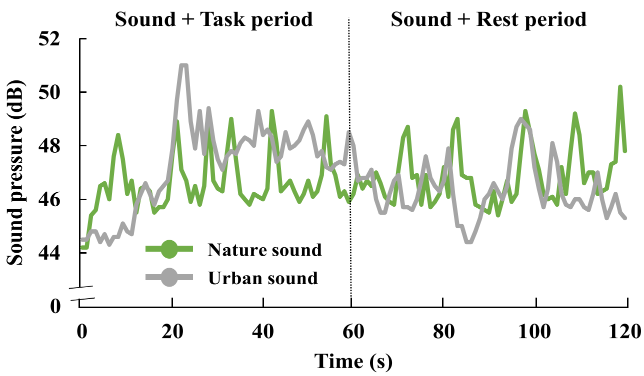

Fig. 3. Changes in the sound pressure of the nature and urban sounds.

conducted with one person at a time. The participants listened to the explanation of the experiment and filled out the consent form before performing the following steps: (1) wore a physiological measurement device; (2) closed their eyes and rested for 1 min (Rest period); (3) opened their eyes and completed attention tasks while hearing the nature or urban sounds for 1 min (Sound + Task period); (4) closed their eyes again and rested while hearing the same sound for 1 min (Sound + Rest period); and (5) completed a subjective evaluation. Following a five-minute break, we repeated the process, with the participants who heard the nature sound now hearing the urban sound and vice versa.

3. Measurements

3.1. Attention task

3.1.1. Harris & Harris grid

The Harris & Harris grid is a grid in which numbers from 0 to 99 are randomly arranged in a 10 × 10 cell drawn on a white square. When the test started, the participant searched for numbers in ascending order from a specific number, and the degree of attention was determined by the numbers found during a given time (Fig. 5). The more numbers you find, the higher the attention span (Harris and Harris, 1984).

In this study, the attention task was conducted for 1 min using a square grid of 800 px by width and length created in hypertext markup language (HTML).

3.2. Physiological indicators

3.2.1. Functional near-infrared spectroscopy (fNIRS)

Functional near-infrared spectroscopy (fNIRS) is a method of measuring the degree of brain activation by identifying changes in cerebral blood flow using near-infrared rays (Hoshi and Tamura, 1993; Villringer et al., 1993). There is an emitter and detector on the attachment surface of the fNIRS measuring device. Once the emitter emits near-infrared rays (wavelength 680–1000 nm) to the prefrontal cortex, the detector absorbs the reflected rays and measures the oxy-hemoglobin (HbO) and deoxy-hemoglobin (HbR) concentrations in the prefrontal cortex (Holtzer et al., 2011; Ferrari and Quaresima, 2012). Because HbO and HbR absorb near-infrared rays of 700–900 nm wavelengths, the change in concentration can be measured by the amounts of reflected rays. When the brain is activated, HbO concentration increases and HbR concentration decreases; when brain activity stabilizes, HbO concentration decreases and HbR concentration increases (Lee et al., 2018; Perrey, 2008).

In this study, NIRSIT LITE for Adults (OBELAB Inc., Korea) was used to measure HbO concentration in the prefrontal cortex. The NIRSIT LITE comprises five emitters and 13 detectors that emit near-infrared rays of 780 and 850 nm, measuring prefrontal cortex activity on a total of 15 channels. Fig. 6 illustrates the location of each channel in the fNIRS.

3.2.2. Heart rate variability (HRV) and heart rate (HR)

Heart rate variability (HRV) is a method of measuring autonomic nervous system responses using the change in the interval between R and R waves in the heartbeat (R-R interval; RRI) (Kobayashi et al., 1999). Frequency analysis was performed following RRI measurement, and the frequency in the range of 0.04–0.15 Hz is regarded as low frequency (LF) and the frequency in the range of 0.15–0.4 Hz is regarded as high frequency (HF) (Kim et al., 2005). HF is used as an indicator of parasympathetic nerve activity, which increases with physiological

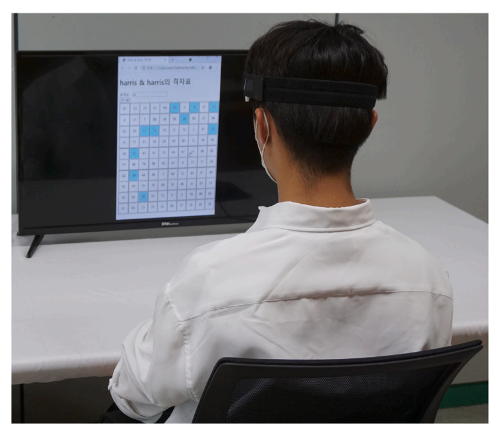

Fig. 5. Attention task using Harris & Harris grid.

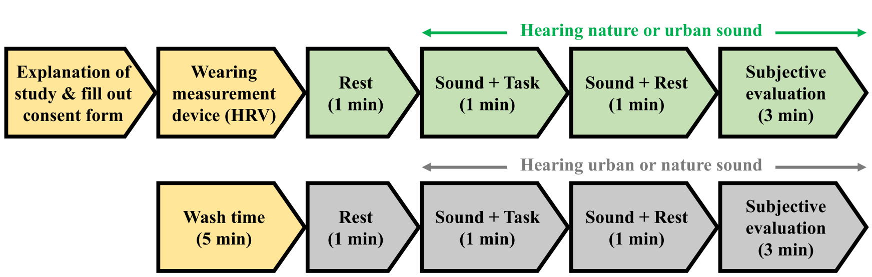

Fig. 4. Experimental process.

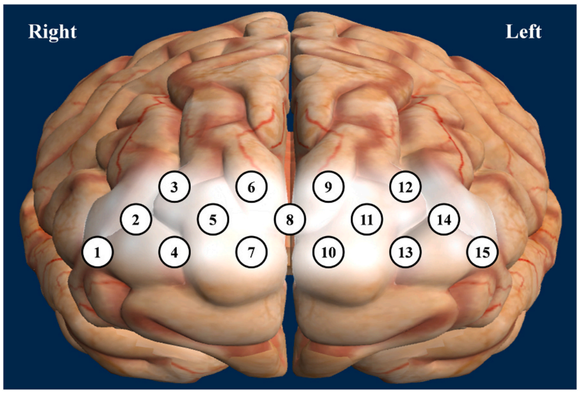

Fig. 6. Location of each channel in the fNIRS.

relaxation (Cacioppo et al., 1994). LF/HF ratio is used as an indicator of sympathetic nerve activity, which increases with physiological awakening (Terathongkum and Pickler, 2004).

Heart rate (HR) indicates the number of heartbeats per unit time.

In this study, RRI and HR data were measured using myBeat WHS-1 (Union Tool Co., Japan) and frequency analysis was conducted using MemCalc/win (GMS, Japan). Because HRV values have a large deviation for each individual, the HF and LF/HF values were transformed into natural logarithm (ln) values to normalize the participants' HRV values. (Kobayashi et al., 2012).

3.3. Psychological indicators

3.3.1. Semantic differential (SD) method

The semantic differential (SD) method is a method of subjectively evaluating an individual's feelings toward a specific object using bipolar adjectives (Osgood, 1952).

In this study, three adjective pairs were used: 'very comfortable ↔ very uncomfortable', 'very relaxed ↔ very arousal', and 'very natural ↔ very artificial', and comfortable, relaxed, and natural feelings were evaluated on a 13-point scale.

3.3.2. Profile of mood states (POMS)

The profile of mood states (POMS) is a method of measuring a person's mood state, and has been commonly used in research to measure changes in the mood state of study participants since its development in 1964 (McNair and Lorr, 1964). It involved a questionnaire that consisted of 30 questions representing mood states on a 5-point Likert scale. Each question represents one of six mood states: tension-anxiety (T–A), depression (D), anger-hostility (A-H), fatigue (F), confusion (C), and vigor (V). Total mood disturbance (TMD) can be calculated using 'T-A' + 'D' + 'A-H' + 'F' + 'C' - 'V'.

The Korean Version of Profile of Mood State-Brief (K-POMS-B) revised by Yeun and Shin-Park (2006) was used to evaluate mood states.

4. Statistical analysis

Among the 26 participants, the data of five for the attention task, seven for fNIRS, and seven for HRV and HR were excluded because of external factors, such as noise and bad weather (heavy rain), and errors in the data measurement and analysis process.

The statistical package for social sciences (SPSS) (version 27.0) was used for statistical analysis, and the significance level was set to $p < 0.05$. The Wilcoxon signed-rank test was employed to analyze the results of the attention task and the psychological indicators. The following two methods were used to analyze the physiological indicators. (1) To verify the changes relative to nature and urban sounds, a comparison of changes according to period within the same sound was performed, and a paired t-test (one-sided) with Holm correction was used. (2) To clarify the recovery effects of nature sounds, a comparison of the differences between the nature and urban sounds in the Sound + Rest period was carried out, and the paired t-test (one-sided) was used.

5. Results

5.1. Attention task

For the attention task, the score was 9.43 ± 0.96 (mean ± standard error) when hearing the nature sound and 8.76 ± 0.76 when hearing the urban sound. The score was slightly higher when hearing the nature sound; however, there was no significant difference between the two sounds.

5.2. Physiological indicators

5.2.1. Functional near-infrared spectroscopy (fNIRS)

Fig. 7 presents the HbO concentration of fNIRS (channel 14) when hearing the nature and urban sounds, and Fig. 8 illustrates the results of channel 15. Channels 14 and 15 are located on the left side of the prefrontal cortex. In both figures, the graph on the **left side** represents the changes in the overall mean HbO concentration during each period. When hearing the nature sound, the HbO concentration was significantly decreased in the Sound + Rest period (channel 14: −0.00098 ± 0.00025 μM; channel 15: −0.00223 ± 0.00061 μM) than in the Rest period (channel 14: 0.00069 ± 0.00038 μM, $t = 3.69$; channel 15: 0.00050 ± 0.00060 μM, $t = 3.20$; $p < 0.05$, Figs. 7, 8 **left side**). There was no significant difference in the urban sound. The graphs on the **right side** compare the overall mean HbO concentration in the Sound + Rest period. When hearing the nature sound (channel 14: −0.00098 ± 0.00025 μM; channel 15: −0.00223 ± 0.00061 μM), the HbO concentration was significantly lower than that of the urban sound (channel 14: −0.00016 ± 0.00037 μM, $t = 1.84$; channel 15: −0.00059 ± 0.00064 μM, $t = 1.86$; $p < 0.05$, Figs. 7, 8 **right side**).

5.3. Heart rate variability (HRV) and heart rate (HR)

Fig. 9 shows the ln(HF) values of HRV when hearing the nature and urban sounds. The graph on the **left side** illustrates the changes in the overall mean ln(HF) values during each period. When hearing the nature sound, ln(HF) values were significantly increased in the Sound + Rest period (5.77 ± 0.20 $lnms^2$) than in the Rest period (5.38 ± 0.24 $lnms^2$, $t = 0.90$, $p < 0.05$, Fig. 9 **left side**). There was no significant difference in the urban sound. The graph on the **right side** compares the overall mean ln(HF) values in the Sound + Rest period. When hearing the nature sound (5.77 ± 0.20 $lnms^2$), ln(HF) values were significantly higher than those of the urban sound (5.49 ± 0.24 $lnms^2$, $t = 0.89$, $p < 0.05$, Fig. 9 **right side**).

Fig. 10 shows the heart rate when hearing the nature and urban sounds. The graph on the **left side** represents the changes in the overall mean heart rate during each period. When hearing the nature sound, heart rate was significantly decreased in the Sound + Rest period (75.21 ± 2.02 beats/min) than in the Rest period (77.61 ± 2.34 beats/min, $t = 0.78$, $p < 0.05$, Fig. 10 **left side**). There was no significant difference in the urban sound. The graph on the **right side** compares the overall mean heart rate in the Sound + Rest period. When hearing the nature sound (75.21 ± 2.02 beats/min), heart rate was significantly lower than that of the urban sound (77.18 ± 2.44 beats/min, $t = -0.62$, $p < 0.05$, Fig. 10 **right side**).

6. Psychological indicators

6.1. Semantic differential (SD) method

Fig. 11 presents the participants' feelings using the SD method after

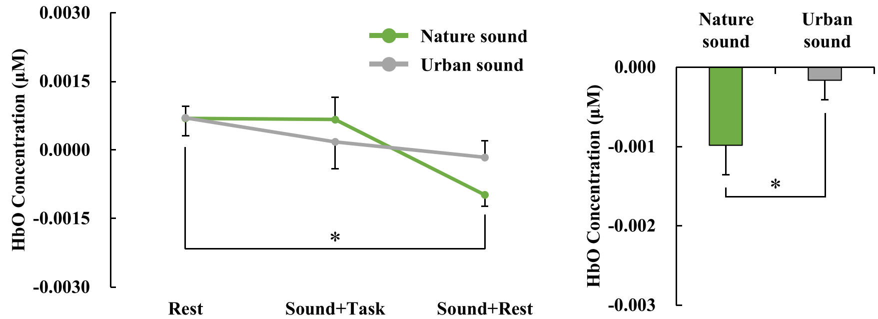

Fig. 7. HbO concentration of fNIRS (channel 14) when hearing the nature and urban sounds. **(Left)** Changes in the overall mean HbO concentration during each period. N = 19, mean ± standard error, * $p < 0.05$, using a paired t-test (one-sided) with Holm correction. **(Right)** Comparison of the overall mean HbO concentration in the Sound + Rest period. N = 19, mean ± standard error, * $p < 0.05$, using a paired t-test (one-sided).

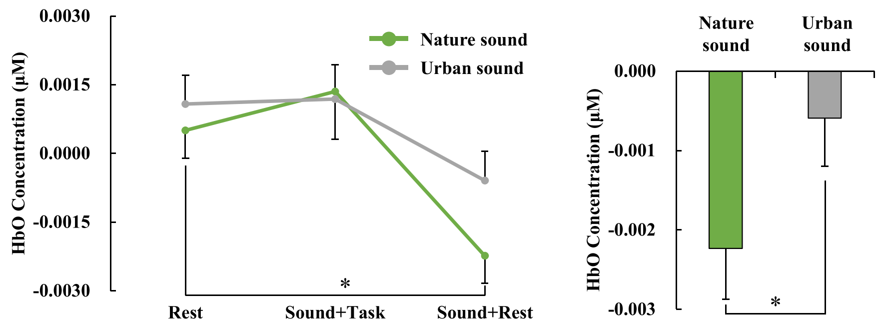

Fig. 8. HbO concentration of fNIRS (channel 15) when hearing the nature and urban sounds. **(Left)** Changes in the overall mean HbO concentration during each period. N = 19, mean ± standard error, * $p < 0.05$, using a paired t-test (one-sided) with Holm correction. **(Right)** Comparison of the overall mean HbO concentration in the Sound + Rest period. N = 19, mean ± standard error, * $p < 0.05$, using a paired t-test (one-sided).

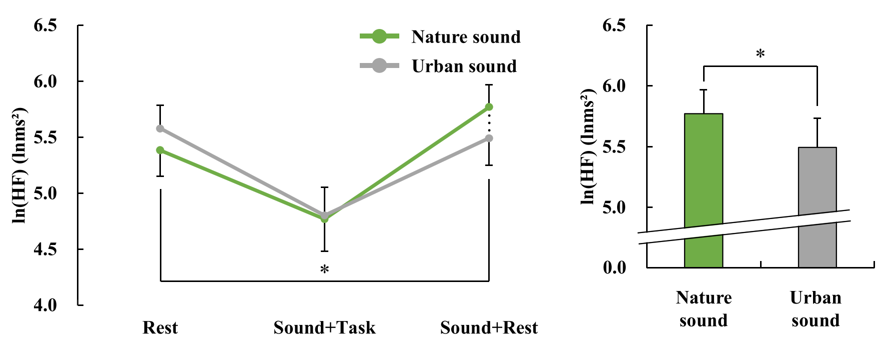

Fig. 9. ln(HF) values of HRV when hearing the nature and urban sounds. **(Left)** Changes in the overall mean ln(HF) values during each period. N = 19, mean ± standard error, * $p < 0.05$, using a paired t-test (one-sided) with Holm correction. **(Right)** Comparison of the overall mean ln(HF) values in the Sound + Rest period. N = 19, mean ± standard error, * $p < 0.05$, using a paired t-test (one-sided).

hearing the nature and urban sounds. The scores after hearing nature sound and urban sound were as follows: comfortable feelings: 2.88 ± 0.32 vs. − 0.31 ± 0.41; relaxed feelings: 3.15 ± 0.42 vs. − 2.31 ± 0.58; natural feelings: 2.96 ± 0.41 vs. − 1.46 ± 0.42. It is evident that the scores of comfortable, relaxed, and natural feelings were significantly higher after hearing the nature sound than those of the urban sound ($p < 0.05$, Fig. 11).

6.2. Profile of mood states

Fig. 12 presents the participants' mood states using the POMS after hearing the nature and urban sounds. The subscales scores after hearing nature sound and urban sound were as follows: tension-anxiety (T-A): 1.38 ± 0.31 vs. 5.50 ± 0.82; depression (D): 0.27 ± 0.13 vs. 1.46 ± 0.41; anger-hostility (A-H): 0.23 ± 0.13 vs. 2.31 ± 0.46; fatigue (F): 1.62 ± 0.35 vs. 3.38 ± 0.51; confusion (C): 3.42 ± 0.38 vs. 3.88 ± 0.52; vigor (V): 8.04 ± 0.68 vs. 3.35 ± 0.60. For the nature sound, the scores of the negative subscales (T-A, D, A-H, F, and C) were significantly lower, and the scores of the positive subscale (V) were significantly higher than those of the urban sound ($p < 0.05$, Fig. 12 **left side**). The TMD score was − 1.12 ± 1.03 (nature sound) and 13.19 ± 2.20 (urban sound), and it was significantly lower after hearing the nature sound than that of the urban sound ($p < 0.05$, Fig. 12 **right side**).

7. Discussion

This study aimed to verify the efficiency of attention when hearing nature sounds and changes in the recovery effect of nature sounds after a task requiring attention. Accordingly, we investigated differences in attention, changes in prefrontal cortex and autonomic nervous system activity, and differences in participants' feelings and mood states based on hearing nature and urban sounds.

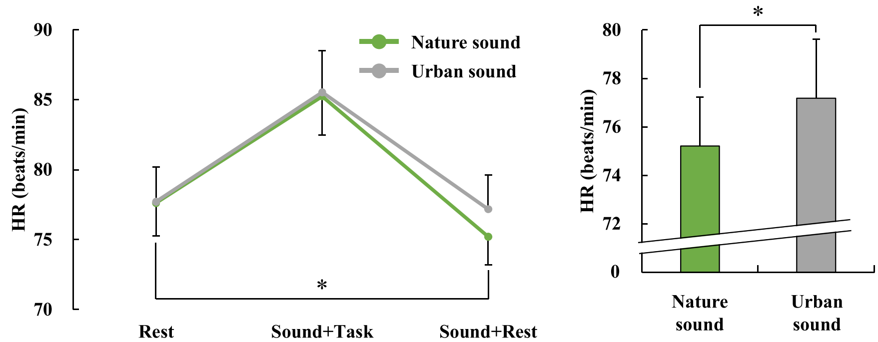

Fig. 10. Heart rate when hearing the nature and urban sounds. **(Left)** Changes in the overall mean heart rate during each period. N = 19, mean ± standard error, * $p < 0.05$, using a paired t-test (one-sided) with Holm correction. **(Right)** Comparison of the overall mean heart rate in the Sound + Rest period. N = 19, mean ± standard error, * $p < 0.05$, using a paired t-test (one-sided).

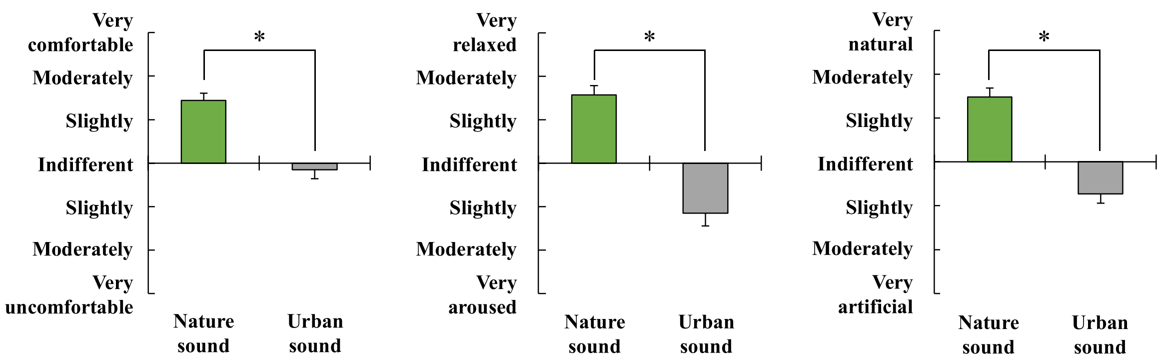

Fig. 11. Participants' feelings using the SD method after hearing the nature and urban sounds. The results of **(Left)** comfortable feeling; **(Middle)** relaxed feeling; **(Right)** natural feeling. N = 26, mean ± standard error, * $p < 0.05$ using Wilcoxon signed-rank test (one-sided).

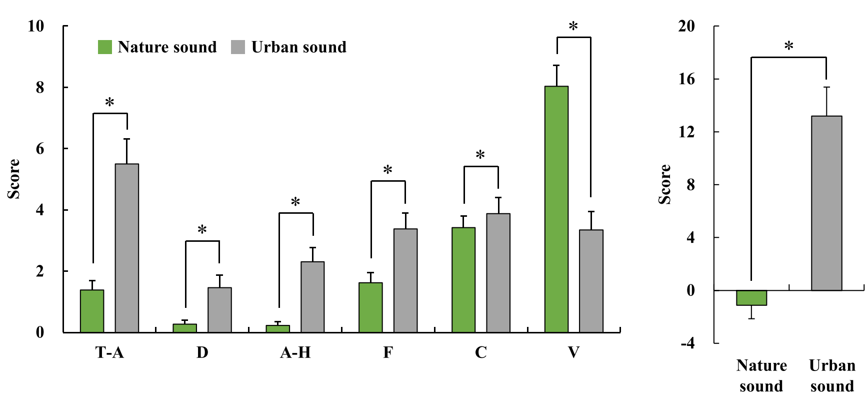

Fig. 12. Participants' mood states using the POMS after hearing the nature and urban sounds. **(Left)** The results of six subscales. (T-A: tension-anxiety; D: depression; A-H: anger-hostility; F: fatigue; C: confusion; V: vigor). **(Right)** The results of total mood disturbance (TMD). N = 26, mean ± standard error, * $p < 0.05$ using Wilcoxon signed-rank test (one-sided).

The experimental process of this study was similar to that of previous studies by Alvarsson et al. (2010) and Medvedev et al. (2015), who investigated the recovery effect while hearing nature sounds after work. However, this study supplemented the limitations of both studies in that only autonomic nervous system activity was measured by measuring prefrontal cortex activity using fNIRS and several subjective evaluations.

The results of this study can be summarized as follows. ① For the attention task, there was no significant difference between the nature and urban sounds; however, the score was slightly higher when hearing the nature sound. ② For the physiological indicators, the HbO concentration decreased, the ln(HF) values increased, and the heart rate decreased when hearing the nature sound. Additionally, in the Sound + Rest period, the HbO concentration was lower, the ln(HF) values were higher, and the heart rate was lower when hearing the nature sound than when hearing the urban sound. ③ For the psychological indicators, once the participants heard nature sound, they felt more comfortable, relaxed, and natural, and the negative mood state was lower, while the positive mood state was higher than the urban sound. These results were partially consistent with those of previous studies that confirmed that forest sounds can have a positive effect on physiological and psychological relaxation (Jo et al., 2019a; Ochiai et al., 2020).

This effect may be attributed to the fact that the human body is inherently well suited to natural environments (Miyazaki et al., 2011). Due to accelerated industrialization and urbanization since the 18th century, much of the population currently resides in urban areas. However, as humans have spent a significant portion of their evolutionary history in natural environments, they are inherently familiar with nature (Ulrich, 1983; Ulrich et al., 1991). Therefore, it is possible to experience comfort and attain physiological and psychological relaxation in natural environments (Song et al., 2016; Song et al., 2017). Kaplan and Kaplan (1989) proposed the Attention Restoration Theory (ART), which suggests that in environments where there is non-voluntary attention (fascination), distance from tasks that induce fatigue (being away), organic interconnectedness of environmental elements (extension), and provision of experiences that align with personal values and preferences (compatibility), mental fatigue and attention can be restored (Hartig and Jahncke, 2017; Kaplan, 1995). Because natural environments fulfill these conditions, we can expect restoration effects in such settings. These effects are more efficient when experiencing actual natural environments or perceiving a combination of stimuli that constitute the environment through multiple senses (Sun et al., 2018; Van Renterghem, 2019). However, various indoor studies have revealed that even single stimuli or indirect experiences in nature can enable the perception of natural environments and the relaxation of the human body (Aletta et al., 2018; Jo et al., 2019a; Ratcliffe, 2021). The finding in this study, which reveals that "nature sound actually relaxes people" seems to be consistent with this fact.

On the other hand, no significant difference was found in the attention task, this could be attributed to the extremely short test time (1 min), and the Harris & Harris grid was not adequately challenging for the university students to have a significant effect by sounds. In future studies, it will be necessary to increase the number of samples and test time or use a test method that requires greater attention.

However, this study revealed that the brain and body awakened by the attention task became more relaxed by resting with nature sounds and that nature sounds gave a positive impression and improved the mood states of the listener. This highlights the possibility that nature sounds can be utilized to relax the body and mind of modern people awakened by many mental tasks from studies and/or work. The sounds of nature are thought to be extremely useful as a healing resource in daily life because it can be easily accessed through Internet media, even if one cannot visit a natural environment.

Following the outbreak of the COVID-19 pandemic, there is an increasing desire among modern people to visit natural environments (da Schio et al., 2021; Jarský et al., 2022; Weinbrenner et al., 2021). If the urban green space to be created in the future is designed to naturally generate nature sounds, such as the sounds of birds, wind, and water, it is believed that it can be used as an important healing space for stress management and improving the health of modern people.

The limitations of this study are as follows: First, it is difficult to generalize the results because the participants only included university students in their early 20 s attending a specific university. In the future, more extensive research should be conducted that considers the characteristics of the participants. In particular, it has been revealed that perceptions of the environment can differ based on gender and cultural backgrounds (Bord and O'Connor, 1997; Momsen, 2000), highlighting the need for examination of these aspects as well. Second, the periods of 'Rest', 'Sound + Task', and 'Sound + Rest' for measuring physiological indicators are as short as 1 min. Future studies should verify the effects of long-term sound hearing. Third, it was challenging to completely block the participants' sound exposure. In auditory experiments, the management of external noise is very important. However, because the NIRSIT LITE device used in this study covers both the forehead and the sides of the head, it was not feasible to use headphones, which are more effective for noise control. Consequently, we had to resort to presenting sounds through speakers. To compensate for this, we selected a period with low visitor traffic (vacation season) as the experimental period and restricted access to the laboratory. However, in future studies, these aspects should be carefully considered during the experimental design phase.

Furthermore, even the same sound may elicit different responses depending on individual characteristics and subjective impressions for the sound. Medvedev et al. (2015) performed two experiments to investigate the effects of soundscape on stress recovery: ① Following exposure to stress stimuli, hearing four sounds (birdsong, ocean, road noise, and construction), and ② hearing six sounds (construction, birdsong, motorbike racing, heavy aircraft, breaking waves on calm day, and orchestra playing) at rest. Skin conductance and heart rate were measured while hearing the sounds, and subjective evaluations for five soundscapes (pleasantness, arousal, familiarity, eventfulness, and dominance) were performed after hearing each sound. As a result of comparing the recovery speed of skin conductivity, it was confirmed that ① the most pleasant and familiar, and the least eventful sounds exhibited a faster recovery rate than the least pleasant and familiar, and the most eventful sounds, and ② the least pleasant and familiar, and the most dominant sounds exhibited a slower recovery rate than the most pleasant and familiar, and the least dominant sounds. The sound that induced a positive impression had a more positive effect on stress recovery than the sound that gave a negative impression. Jo et al. (2020) divided 29 female university students into two groups according to behavior patterns (Type A and Type B) (Yamasaki, 1992) and analyzed the differences in psychological responses after hearing forest and city sounds. As a result, after hearing forest sound, the Type A group felt more comfortable, relaxed, and natural, and the tension-anxiety score was lower than the Type B group. Upon hearing the city sound, the anger-hostility score was lower in the Type A group than the Type B group. Through both studies, it was found that subjective impressions of sound affect physiological responses and that individual characteristics, such as behavior patterns, influence psychological responses. In the future, an in-depth study should be conducted to analyze the recovery effect of sound in connection with the subjective impression of sound and individual characteristics.

8. Conclusions

The findings of the present work show that resting with nature sounds after an attention task is more effective on physiologically and psychologically relaxation than urban sounds. In conclusion, hearing nature sounds may be an effective way to relieve stress in everyday life.

CRediT authorship contribution statement

Chorong Song: Conceptualization, Data curation, Investigation, Methodology, Writing – review & editing, Funding acquisition, Project administration, Supervision. **Injoon Song:** Data curation, Formal analysis, Investigation, Visualization, Writing – original draft. **Kwangsik Beak**: Conceptualization, Data curation, Formal analysis, Investigation, Methodology. **Choyun Kim:** Data curation, Investigation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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