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Research paper

The effect of systematic auditory stimuli micro-refresh on intellectual work performance and subjective measurement

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ABSTRACT

This study investigates the effect of auditory stimuli incorporated as a micro-refresh promoter during intellectual work by considering performance indicators and subjective measurement. A controlled laboratory experiment study was conducted with 47 participants performing a cognitive task under the conditions with and without auditory stimuli intervention. After data cleansing, 25 participants data were included in the analysis. Quantitative measurement of answering time and concentration time ratio resulted in no significant difference between conditions with and without auditory stimuli. Subjective ratings of NASA-TLX, subjective symptoms, and detachment factor found no significant difference among conditions with and without auditory stimuli. The recovery subjective questionnaire resulted in a significant difference in which participants felt more recovered when performing the task in auditory stimuli intervention. Regardless there are no statistically significant differences in several measurement indicators, there is a subjective indicator that auditory stimuli have an effect on intellectual work performance and it is worth considering for further research.

1. Introduction

In a current rapid and fast-moving work environment, workers are required to be able to complete their work quickly, precisely, and efficiently. The intellectual work performance is one of the important factors to be considered to achieve the expected work results [10,33]. However, the complex dynamic system of the work environment such as excessive stress and workload, can be an obstacle to achieving good work productivity in which further strategies for work recovery are needed [46,48].

Several theories have become the basis for topics related to work recovery. The effort-recovery model based on Meijman [56] in van Veldhoven [53] stated that the fatigue experience could be divided into four: the psychological pressure, weakening the desire to perform, dwindling performing capacity, and the state of exhaustion. Furthermore, van Veldhoven [53] also mentioned that based on Meijman [56], fatigue could be carried over or become a cumulative aftermath that can increase load consequences after work. Kaplan [22] proposed the attention restoration theory where this theory promotes the role of nature elements in creating recovery conditions from fatigue. Additionally, Ulrich et al. [52] composed the stress reduction theory which reveals that nature settings can strengthen the effect of restoration on attention.

1.1. Micro-refresh

Micro-refresh (MR) is a concept to promote an efficient recovery from fatigue and maintains work performance by giving a short stimulus or break within a few seconds without sacrificing excessive work productivity. MR adopted a very short-time stimuli inducement during work. The refresh stimuli in MR may have come in the form of object visualization, sound, air flows, lighting, and others.

Previous studies have investigated the MR's effect during the work. An experimental study by Kitayama et al. [23] shows that participants performing cognitive tasks under the condition with the grey screen micro-refresh intervention have a better performance compared to non-grey screen micro-refresh condition. The airflow modification as a micro-refresh mechanism was investigated and resulted that stimulated airflow with mild speed improved the cognitive performance [35].

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1.2. Auditory stimuli

Several works of literature mention the importance of auditory stimuli as a medium in promoting recovery enhancement and better performance. As described by Makov et al. [30], studies related to auditory selective attention support the process of explaining human's cognitive mechanism that mainly focuses on explaining its role as a stimulus. Acoustic environments could affect students' learning competence which could suggest a better acoustic environment to improve a better learning efficiency [27,55].

The type of sound related to the nature ambiance is more endorsed and has great potential for recovery enhancement effect. A review discussed by Pellegatti et al. [38] mentioned that the sound of nature has a good impact on student's performance and can be utilized to create a better classroom soundscape. Annerstedt et al. [4] found that the sounds of nature exert a positive influence to boost recovery from stress which was carried out on a group of participants after taking a stress test. Nature sounds effectively help to reduce stress and have proven to a better physiological aspects and mood responses through participants while performing attention experimental tasks [45]. Natural sound can be a therapeutic medium to help people with anxiety disorders with the proof of tranquility perceiving, emotional reactiveness, and arousal indicators [13]. Auditory stimuli deliver the greatest reduction in stress levels in the long run compared to visual stimuli [28].

This study aimed to investigate the potential of auditory stimuli as a micro-refresh intervention to enhance recovery during work. To achieve this, we systematically manipulated the duration and frequency of auditory stimuli presentation, which represents a novel approach compared to previous research primarily focused on absolute auditory stimuli during or post-work [4,14,26,45]. By incorporating quantitative measurements and conducting controlled experiments, this study offers a more objective and comprehensive analysis of the effects of auditory stimuli on intellectual work and recovery.

2. Materials and methods

2.1. Experiment procedure

In this study, repeated measures or within-group experiment design were applied. The participants conducted experiment tasks under both conditions with and without auditory stimuli intervention and their measurements were compared. The illustration of the experiment design is shown in Fig. 1. The experiment is divided into two days, where the first day is an explanation and practice day, meanwhile, the second day is the measurement day. We assume that by providing an explanation and practice day, participants will have quite similar understanding in carrying out the experimental test and minimize the learning curve in the second day.

In the first day (i.e., practice day), at the beginning of 30 min, the experimenter explained the experimental procedures and the consent form to participants. Then, simulate 3 sets of 25 min experiment task with 10 min break in between the set without auditory stimuli intervention. In the second day (i.e., mesurement day), participants performed 4 sets of experiment task for 25 min in each set, except set 4 for 10 min. Twenty minutes break were given in between sets. In set 1, the auditory stimuli were inserted. In set 2 and set 3, the auditory stimuli were given in a counterbalanced design. Then in the set 4, no auditory stimuli inserted. In a set with auditory stimuli intervention, the sound was played for 20 s every 7.5 min intervals from the start. Thus, for the 25 min task, the auditory stimuli will occur three times. Only the data from set 2 and set 3 on the second day will be used in the analysis where the intervention was given in a counterbalanced design, thus we assume that the ordering effect of auditory stimuli insertion in set 2 and set 3 can be minimized.

Before and after each set, the subjective symptoms questionnaire was given. NASA task load index (NASA-TLX) were given after each set. Lastly, the attentional control scale (ATTC) questionnaire and a survey interview were given at the end of the fourth set.

2.2. Auditory stimuli

In this study, the auditory stimuli constitute as a micro-refresh during the cognitive task performed by participants. The aim of inducing the auditory stimuli as a micro-refresh is to promote a short recovery improvement during the work and maintain work performance in the long run. Additionally, including natural elements in auditory stimuli could drive the restoration moments based on attention restoration theory [22].

Several elements of consideration in creating auditory stimuli as a micro-refresh are: (1) the element that signals the beginning of micro-

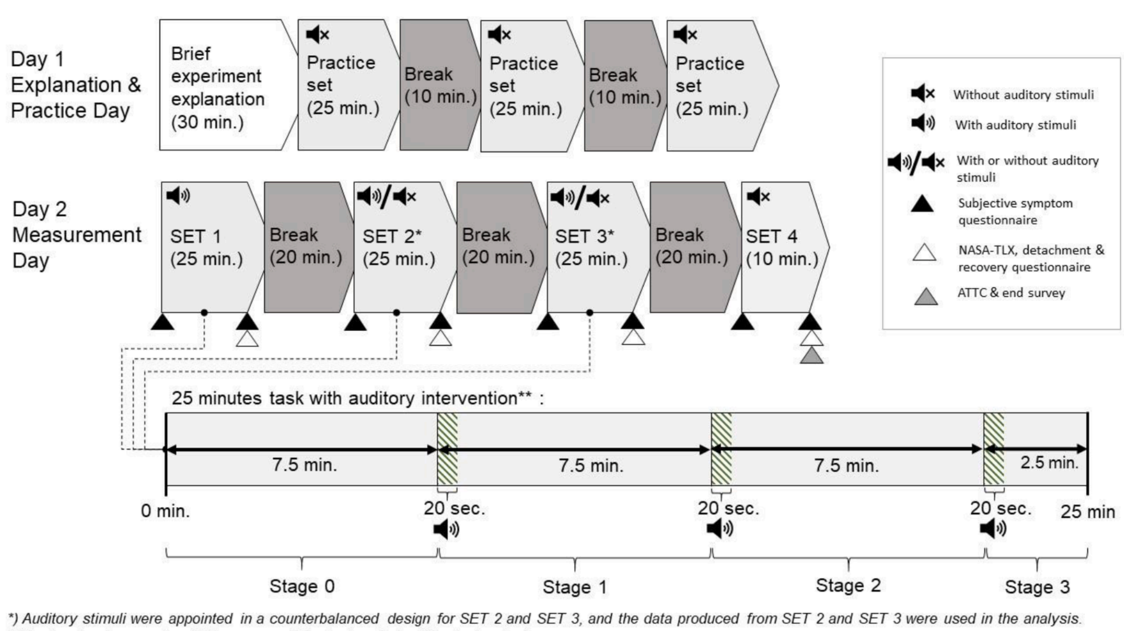

Fig. 1. Illustration of the experiment design.

refresh; (2) the element that promotes relaxation feeling; (3) the element that signals the end of micro-refresh. Considering the aforementioned elements, the natural sound of the waves and seagulls chirping at the beginning and end of the sound is chosen. The sound of waves and seagulls chirping which brings to mind a beachside situation hopefully could deliver a relaxing nuance.

The auditory stimuli were created using Studio One 5 Professional version 5.5.2.86528 with a Mac operating system [39]. The sound was created by combining several copyright-free sound sources included in the software. The sound pressure was set at 42 dBA and considered an appropriate level for the indoor area [50]. The auditory stimuli were played using the speaker [7]. There are four speakers placed in the corner of the experiment room. To create a monaural sound reproduction, an amplifier is utilized [54] and connected to a PC via a mixer audio interface [3].

The auditory stimuli were played for 20 s in every playback. Auditory stimuli were inserted in a condition with the micro-refresh intervention induced during the task. For one experiment task set of 25 min, there will be three times auditory stimuli inserted and given every 7.5 min. The duration of stimuli playback and intervals are adopted from previous methodological designs associated with the micro-refresh [23, 35].

2.3. Participants

Forty-seven Kyoto University students (undergraduates and master's degree students, aged 18–26) participated in the study. After applying exclusion criteria (discussed in the Data Analysis section), 25 participants were included in the analysis. The average age of the included participants was 21.6 years ($SD = 2.4$), with 17 males and 8 females. All participants' personal data is guaranteed to be kept confidential, and only data used in the analysis without mentioning the participant's identity will be displayed. Ethical approval was admitted by the Graduate School of Energy Science Ethics Committee at Kyoto University before the experiment.

2.4. Experiment task

In this study, participants were asked to answer questions within a predetermined period by experimental design procedures. The experiment tasks were adopted from Ueda et al., [51] which were then called comparison tasks. In the comparison tasks, two comparison statements will appear in the form of a comparison of two words and a comparison of two numbers.

The experimental task required participants to compare randomized pairs of words and numbers. Word pairs were drawn from various categories: plants, animals, inanimate objects, and place names. For example, participants might be asked to compare 'grasshopper' and 'Tokyo' and determine whether they belonged to the same category. Number pairs were presented with mathematical symbols (e.g., '4209 < 4092'), and participants were tasked with verifying the accuracy of the statement. To answer, participants selected the appropriate intersection on a 2 × 2 grid on display, choosing between the 'same words' or 'different words' category and 'correct math statement' or 'incorrect math statement'. After the participant answers the first task, the next task appears on the display with other random word categories and random numbers. Furthermore, answering time was measured to assess cognitive performance, providing insights into participants' information processing speed and decision-making abilities.

The comparison task was developed in a JavaScript program [21] and run on an iPad [1]. The answering time for each task was automatically recorded in the experiment program in a .csv format.

2.5. Experiment environment

The experiment was held in an experiment room at the Graduate School of Energy Science, Kyoto University. Fig. 2 shows its layout. The room temperature was adjusted around 21 °C–25 °C and the humidity level around 50 %–60 %. To ensure optimal air quality during the experiment, CO_2 levels were maintained below 1000 ppm, and VOC concentrations were kept within normal limits, posing minimal health risks. To minimize noise interference, the ventilation fan was switched off during the cognitive comparison task. Background noise levels were kept below 40 dBA throughout the experiment to ensure participants were not distracted. Each participant sat on a chair with a table set in front of them. An iPad with an iPad standing set on each table. The working area of each participant was separated by a partition in front of them and on the left and right sides of them. The speakers were positioned in the corners of the room. There are a total of four speakers in the room.

2.6. Outcome measurement

2.6.1. Answering time

The performance appraisal in completing comparison tasks is measured by the result of answering time. The answering time for each question was recorded automatically in the experiment program during 25 min tasks. The answering time for one question was constituted since the task' question appears on the screen until the participants answer that question by touching the screen in the specific designated answering box on the screen.

2.6.2. Concentration time ratio (CTR)

The concentration time ratio is a quantitative measurement approach of the proportion of actual time used in devoting concentration while working on a task compared to the total time completing the task [20,32,44]. The time devoting concentration is attained through the calculation of the average answering time when people devoted to the concentration state multiplied by the number of questions answered. Therefore, the CTR units appear in the form of percentages. Zero percentages indicate that an individual is not in a concentration state at all, and vice versa. The advantages of CTR compared to another quantitative measurement (e.g., answering time) as mentioned by Ishii et al. [20] are (1) CTR is less altered to learning effect due to its proportions measurement approach among actual concentration time towards total completion time; (2) CTR indirectly portrays intellectual productivity (i.e., a product of knowledge processing through period of time) instead of just a speed muscular response. An increase in the CTR score percentage indicates that the concentration phase is becoming more dominant during the total time span of completing the task.

2.6.3. Error rate

The error rate is one of the important considerations when evaluating human performance which could indicate an influence of interventions [11]. As mentioned by Dror [11], the error rate is essential to (1) evaluate how someone undergoes a task; (2) dispose of if an improvement might required; (3) amplify the effectiveness of intervention; (4) contribute to transparency of the ease of use. In this study, the error rate is measured to investigate how accurately participants perform the task in a condition with and without auditory stimuli intervention.

2.6.4. NASA task load index (NASA-TLX)

NASA task load index is a pluridimensional scale that measures a human's workload during work or after work [16]. The usage of NASA-TLX in a research field or organizational practices has been proven quite robust [15]. Six subscales consisted in the NASA-TLX questionnaire, namely effort (EF), frustration level (FL), mental demand (MD), physical demand (PD), overall performance (OP), and temporal demand (TD) [16]. In this study, we adopted the NASA-TLX questionnaire to measure participants' subjective mental workload after performing the task in a condition with and without auditory

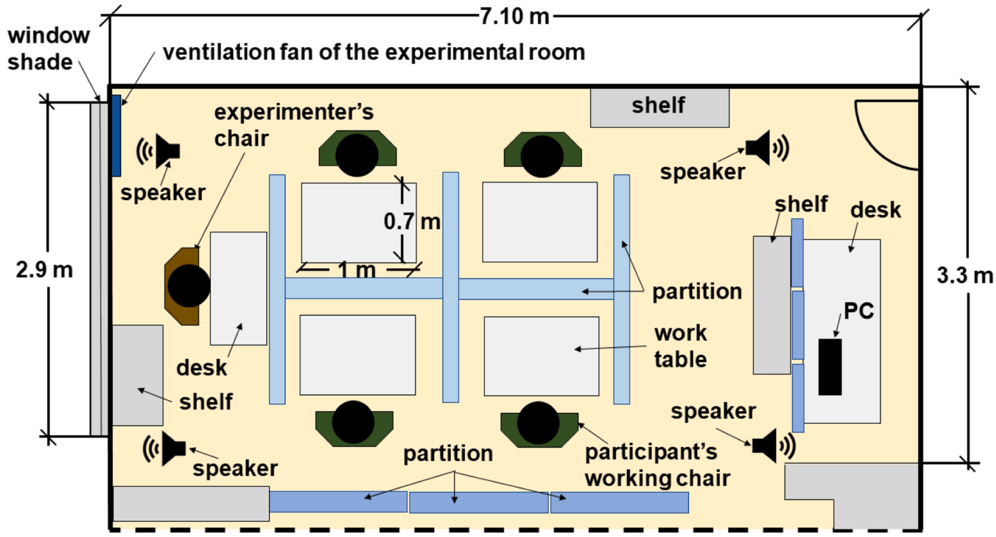

Fig. 2. Layout of the experiment room.

stimuli intervention. The NASA-TLX was measured at the end of each set on day 2 (the measurement day). The NASA-TLX questionnaire was displayed on the touchscreen, allowing participants to answer directly. Responses were automatically saved. The questionnaire used a 0–100 slider scale to assess workload, with 0 being the lowest and 100 the highest. Details of the NASA-TLX questions and response format are provided in the appendix.

2.6.5. Subjective symptoms questionnaire

The subjective symptoms questionnaire is a questionnaire to measure fatigue feelings developed by the Research Group of Industrial Fatigue in Japan Society for Occupational Health [43]. The questionnaire consists of five factors (i.e., drowsiness feeling, instability, uneasiness feeling, dullness feeling, and eyestrain), each factor being represented in five questions. In total, there are twenty-five questions listed in the subjective symptoms questionnaire. The answering options for each question are provided in a five-point Likert style with “strongly disagree” (1 point) to “strongly agree” (5 points). The subjective symptoms questionnaire was measured before and after each set on day 2 (the measurement day). The subjective symptoms utilized in this study to grasp participants’ feeling of physical symptoms that appear before and after performing the task based on self-report rating.

2.6.6. Detachment and recovery questionnaire

In this research, the role of audio stimuli to induce a micro-refresh is expected to have an effect on work performance. The presence of sound can cause alertness which changes cognitive performance or the emergence of refreshment feeling. The experience of recoveries can be discern into four particularly psychological detachment, relaxation, mastery experiences, and control during leisure [47]. Adapting to the research design of systematic auditory stimuli and experiment task, we suspect that the recovery experience that might occur could be caused by psychological detachment and relaxation feelings due to the presence of auditory stimuli. Meanwhile, mastery experience and leisure control are not suitable for this research because the recovery time has been determined systematically and no off-task activities to hone a mastering skill. Based on the aforementioned reason, we asked simple questions to measure the level of detachment and recovery experience, one question each with answer rated on a five-point Likert scale from “not happening at all” (1 point) to “very much happening” (5 point). The detachment and recovery questionnaire was questioned post set 1, set 2, set 3, and set 4.

2.6.7. Attentional control scale (ATTC)

The attentional control scale is an individual report to measure how well a person controls their attention where this will further influence their information processing [9]. The ATTC questionnaire consists of twenty questions and these questions fall into one of the categories of attentional shifting or attentional focusing. Each question in the ATTC questionnaire is rated using a four-point Likert style from “almost never” (1 point) to “always” (4 points). The ATTC questionnaire has proven reliable in measuring attentional control in individuals of various ages and backgrounds [2,12,31,36]. The results of ATTC questionnaire will complement the descriptive statistics of participants’ potential ability to control their attention.

2.7. Data analysis

The data of the quantitative measurement such as answering time is analyzed using the Analysis of Variance ANOVA methods. Furthermore, The participants’ data that satisfy one of the following criteria were excluded for the data cleansing; (1) misunderstood directed instructions and did not follow instructions correctly, (2) absent from one or several sessions of the scheduled experiment, (3) the concentration time ratio (CTR) score was below 40 % which set as the lower limit [23] where a value below 40 % indicates that those participant did not carry out the task earnestly, (4) the difference of CTR score between two sets with and without auditory stimuli intervention was fallen below 5 % in the lower threshold or above 5 % in the upper threshold of distribution where that area indicates as an outlier in which were eliminated from the data analysis to minimize bias and probability of Type-I errors [5]. The independent variables included are the intervention of auditory stimuli which is then divided into a condition with the intervention of auditory stimuli and a condition without the intervention of auditory stimuli. Other independent variables are the stages’ time which is divided into four stages named stage 0, stage 1, stage 2, and stage 3. The stage division is based on the time division with respect to the timing when the auditory stimuli were inserted. Stage 0 is a time period after the participants start the task until the period before the first auditory stimuli are played (0 to 450 s). Stage 1, Stage 2, and Stage 3 are periods when the participants perform the task at 451–900 s, 901–1350 s, and 1350–1500 s respectively. Subsequently, the paired t-test was utilized to analyze the response difference of concentration time ratio (CTR), error rate, subjective ratings of NASA Task Load Index (NASA-TLX), detachment, recovery, and subjective symptoms between conditions with auditory stimuli intervention and without auditory stimuli intervention.

3. Results

Of the 47 participants, 22 were excluded by the data cleansing criteria. The results shown below were extracted from the remaining 25 participants' data aged 18–26 years old ($M = 21.6$, $SD = 2.4$, male = 17 people, and female = 8 people). The statistical power for the 25 participants included in the analysis was 0.78.

3.1. Answering time

A mixed-model ANOVA was used to analyze the effects of intervention and stage on answering time. A significant main effect of the stage was found, $F(3, 25{,}992) = 52.25$, $p < .001$. However, there was no significant difference in the intervention (with and without the auditory stimuli), $F(1, 25{,}992) = 1.83$, $p = .176$, nor a significant interaction between intervention and stage, $F(3, 25{,}992) = 1.12$, $p = .338$. The *t-test* revealed no significant difference in answering time between the groups whose auditory stimuli presented in SET 2 and SET 3 ($p = .648$), indicating that the order of auditory presentation did not affect the answering time performance. Fig. 3 shows the graph of the average answering time in each stage between conditions with and without the auditory stimuli intervention.

3.2. Concentration time ratio (CTR)

An independent samples *t-test* was conducted to compare the concentration time ratio (CTR) scores between conditions under auditory stimuli intervention ($M = 62.99$, $SD = 11.32$) and without auditory stimuli intervention ($M = 62.23$, $SD = 11.97$). The results revealed no significant difference between the groups, $t(47) = -0.22$, $p = .828$, Cohen's $d = 0.631$. The *t-test* revealed no significant difference in CTR score between the groups whose auditory stimuli presented in SET 2 and SET 3 ($p = .261$), indicating that the order of auditory presentation did not affect the answering time performance. Fig. 4 shows the graph of the average CTR score between conditions with and without the auditory stimuli intervention.

3.3. Error rate

A statistical analysis *t*-test was conducted to compare the error rate between the no auditory stimuli condition and under auditory stimuli condition. The results revealed no significant difference between the groups, $t(46) = 0.13$, $p = .894$, Cohen's $d = 0.039$. The error rate in a condition with auditory stimuli is slightly lower ($M = 7.32$, $SD = 6.64$) compared to the error rate without the auditory stimuli intervention ($M = 7.60$, $SD = 8.08$).

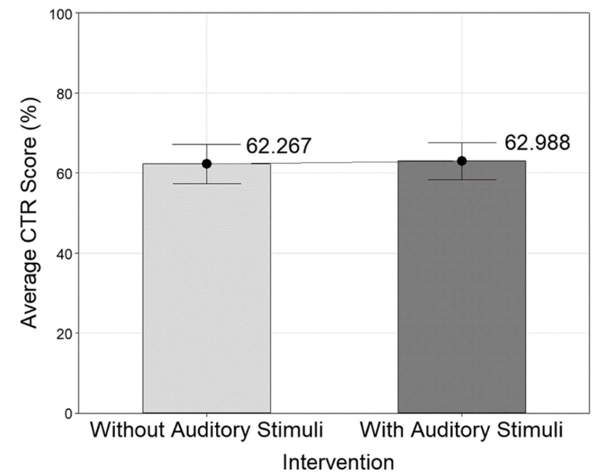

Fig. 4. Concentration time ratio (CTR) between conditions without auditory stimuli and with auditory stimuli.

3.4. Subjective ratings

3.4.1. NASA task load index (NASA-TLX)

An independent samples *t*-test was conducted to compare the NASA-TLX score between the no auditory stimuli group and the with auditory stimuli group. The *t*-test results revealed no significant difference between the groups, $t(46) = 0.03$, $p = .973$, Cohen's $d = 0.01$. The NASA-TLX score in a condition with auditory stimuli ($M = 53.3$, $SD = 18.5$) was quite similar to the score without auditory stimuli ($M = 53.4$, $SD = 15.6$). This result might indicate that in a condition with auditory stimuli, the participants felt their workload was almost the same as the condition without auditory stimuli.

3.4.2. Subjective symptoms

The subjective symptoms questionnaire scores were unity-based normalized by rescaling raw data values and then leading all values into the range between 0 and 1 to equalize the magnitudes on each

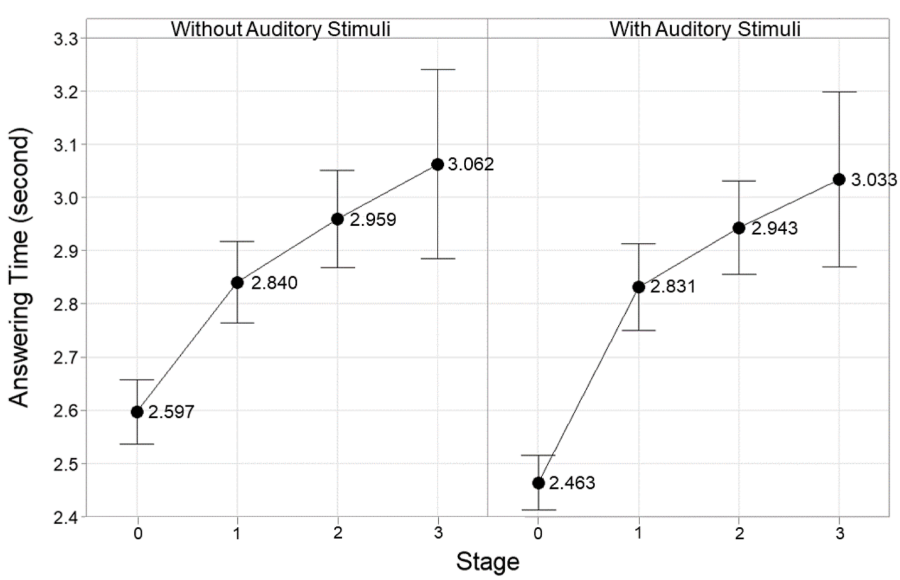

Fig. 3. Answering time between conditions without auditory stimuli and with auditory stimuli.

subscale as shown in Fig. 5. A mixed-model ANOVA was conducted to examine the effects of intervention (with and without the auditory stimuli) and questionnaire time (pre- and post-experiment) on subjective symptom scores in each subscale (concentration, fatigue, haziness, sleepiness, and sluggishness). The statistical results of the concentration subscale revealed a significant effect of questionnaire time, $F(1, 96) = 4.78$, $p = .031$. However, there was no significant effect of the intervention, $F(1, 96) = 2.03$, $p = .157$, nor a significant interaction between intervention and questionnaire time, $F(1, 96) = 0.07$, $p = .794$. The fatigue subscale exposed a significant effect of questionnaire time, $F(1, 96) = 20.38$, $p < .001$. However, there was no significant effect of the intervention, $F(1, 96) = 0.01$, $p = .903$, nor a significant interaction between intervention and questionnaire time, $F(1, 96) = 0.17$, $p = .678$. The haziness subscales statistical analysis results showed a significant effect of questionnaire time, $F(1, 96) = 4.07$, $p = .047$. However, there was no significant effect of the intervention, $F(1, 96) = 0.01$, $p = .970$, nor a significant interaction between intervention and questionnaire time, $F(1, 96) = 0.02$, $p = .902$. A statistical analysis indicated the nonsignificant effect of questionnaire time on the sleepiness subscale, $F(1, 96) = 2.03$, $p = .157$. Additionally, neither intervention ($F(1, 96) = 0.04$, $p = .833$) nor the interaction between intervention and questionnaire time ($F(1, 96) = 0.1$, $p = .758$) had a significant effect on the sleepiness subscale. A significant effect was revealed on the sluggishness subscale for the questionnaire time factor, $F(1, 96) = 3.79$, $p = .054$. On the other hand, neither the intervention factor ($F(1, 96) = 0.12$, $p = .727$) nor the interaction between intervention and questionnaire time ($F(1, 96) = 0.21$, $p = .647$) had a significant effect on the sluggishness subscale.

3.4.3. Detachment and recovery

3.4.3.1. Detachment. The detachment scores between conditions with and without auditory stimuli were analyzed using a *t*-test. The statistical analysis shows no significant difference between both conditions, $t(47) = -0.44$, $p = .661$, and Cohen's $d = 0.127$. The detachment score under the condition with auditory stimuli intervention ($M = 3.32$, $SD = 1.31$) was slightly higher compared to those with non-auditory stimuli intervention ($M = 3.16$, $SD = 0.25$). Fig. 6 shows the score of the average detachment ratings between conditions with and without auditory stimuli intervention.

3.4.3.2. Recovery. A statistical analysis *t*-test was conducted to compare

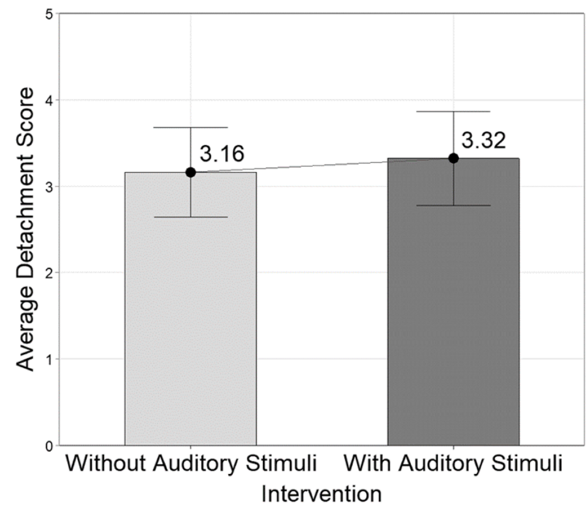

Fig. 6. Detachment score between conditions without auditory stimuli and with auditory stimuli.

the recovery score between conditions without the auditory stimuli intervention and with the auditory stimuli intervention. The score of recovery ratings shows a significant difference between conditions, $t(47)$, $p < .005$, Cohen's $d = 0.854$. The average score in a condition with auditory stimuli is higher ($M = 2.08$, $SD = 0.17$) compared to those without auditory stimuli ($M = 1.4$, $SD = 0.15$) and it indicates that the participants felt more recovered under the condition with auditory stimuli. Fig. 7 shows the graph of the average recovery score between conditions with and without the auditory stimuli intervention.

3.5. Attentional control scale (ATTC)

The results of the ATTC questionnaire total score resulted in 17 out of 25 participants, having a score between 20 and 50 (68 %) and can be classified into the medium score range. Meanwhile, the rest participants gained above 50 (32 %) and were classified into the high score range. In more detail, the ATTC score can be classified into ATTC focusing and ATTC shifting. Among 25 participants, 9 participants (36 %) gain a score between 9 and 22 and classified into medium focusing score range, while the rest 16 participants (64 %) laid above 22 and thus fall into high

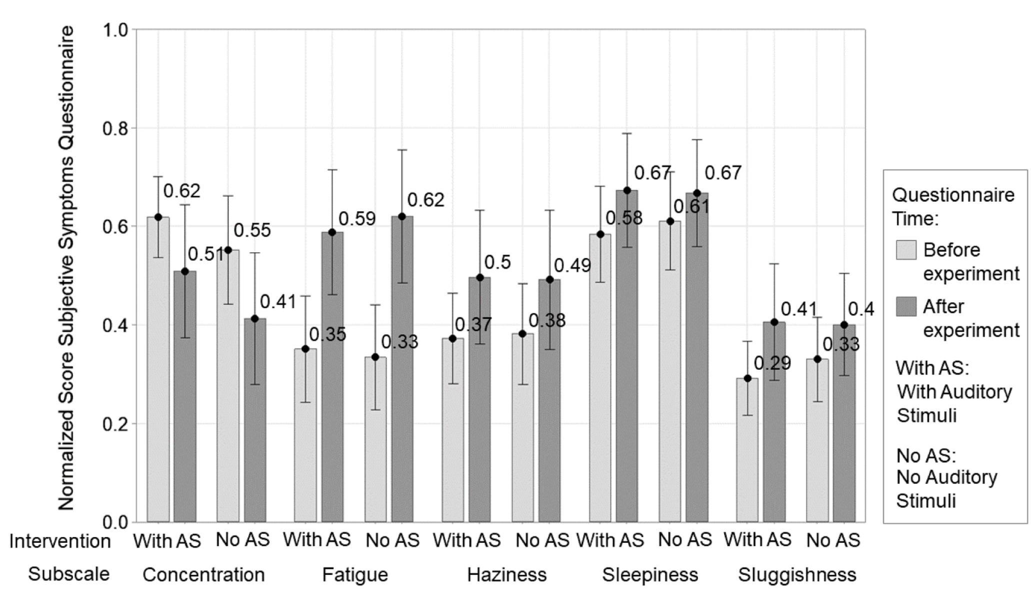

Fig. 5. Normalized score of subjective symptoms questionnaire.

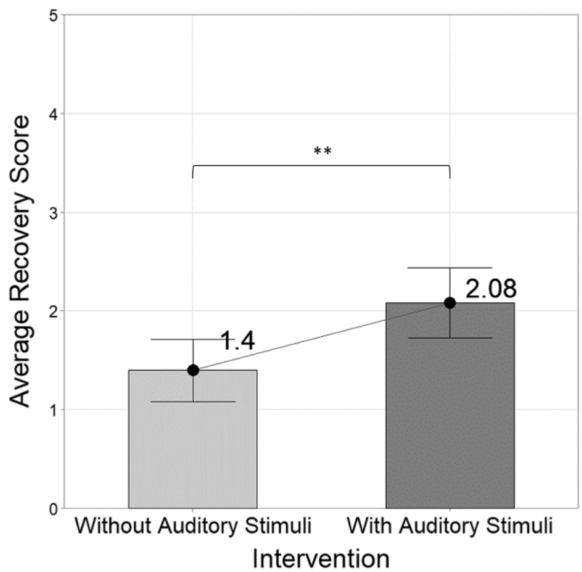

Fig. 7. Recovery score between conditions without auditory stimuli and with auditory stimuli. A significant statistical difference is shown in this figure $^{**}p < .005$.

focusing score range. Additionally, 17 participants got score between 11 and 27 of the ATTC shifting, where it can be classified into medium shifting score. Lastly, 8 participants got a score above 27 for the ATTC shifting and were categorized as high shifting score.

4. Discussion

This study aimed to investigate the effect of auditory stimuli to induce a micro-refresh during cognitive work while considering output performance and subjective measurements. Accordingly, quantitative indicator output named task answering time, concentration time ratio, error rate, and questionnaires (i.e., NASA-TLX, subjective symptoms, detachment, and recovery, ATTC) were measured.

The results of this study found that there is no significant difference between the answering time in a condition with and without auditory stimuli intervention. We suspect that the short time duration of providing the auditory stimuli of only 20 s at each 7.5 min interval is not effective and sufficient enough to provide a refreshing effect on work performance. Additionally, when the auditory stimuli were given, participants could still carry out their tasks concurrently. This intervention scheme is different from a previous study conducted by Kitayama et al. [23] where in his study when the stimulus was given, the workers also stopped performing their tasks. The CTR score between conditions with and without auditory stimuli showed no statistically significant difference even though the CTR score in a condition with an auditory stimuli intervention was slightly better compared to a non-auditory stimuli intervention. Similar to the findings of Song et al. [45], this study observed no significant difference in attentional task performance between different auditory stimuli conditions; however, a notable distinction emerged in subjective responses, with auditory stimuli of nature's sound demonstrating superior outcomes.

Subsequently, the error rate between conditions with and without the auditory stimuli showed no significant difference statistically. However, the performance under the auditory stimuli intervention shows a lower error rate. This result might indicate that the auditory stimuli micro-refresh have the potency to improve accuracy during the work. The subjective response of NASA-TLX showed no significant difference between conditions with and without auditory stimuli intervention. Several factors could explain the lack of significant differences in NASA-TLX scores and error rates. One possible explanation is the relatively short duration of the auditory stimuli (20 s in each induction), which may not have been sufficient to induce significant changes in performance, whereas other studies expose auditory stimuli for a longer period and in absolute conditions of complete exposure [14,29,40]. Additionally, the brief 25 min task duration may have limited the opportunity for fatigue to develop, resulting in consistent performance and minimal errors in both conditions. Furthermore, the simplicity of the cognitive task, while requiring prior knowledge, may have made it less demanding for participants, reducing the likelihood of errors and the need for increased mental effort, which could have impacted NASA-TLX scores. Previous studies that presented a duration two times longer than this research (51 min task) and included a response inhibition task of complex Sustained Attention Response Task (SART) could reduce commission errors by 4 % but also led to slower response times to target stimuli [17]. The subjective symptoms questionnaire showed a significant difference in the questionnaire time factor (i.e., pre-experiment and post-experiment) in the concentration subscale, fatigue subscale, and haziness subscale. These results indicate that the negative symptoms felt by individuals, mostly differ before and after carrying out the task. The detachment questionnaire resulted in no significant difference between conditions with and without auditory stimuli, however in a condition with auditory stimuli, the score was higher which participant felt more detached through the condition with auditory stimuli. Subsequently, the recovery questionnaire found a significant difference between conditions with and without auditory stimuli, and the score was higher in a condition with auditory stimuli. Attention Restoration Theory (ART) suggests that prolonged engagement in mentally demanding tasks can lead to directed attention fatigue [22]. The inherently engaging and less demanding nature of auditory stimuli from nature may facilitate attention recovery. Additionally, Stress Reduction Theory (SRT) proposes that exposure to natural environments can reduce stress levels, leading to physiological changes, relaxation, and improved emotional regulation [52]. These theories may explain why participants felt more recovered with auditory stimuli.

A positive response to the auditory stimuli intervention manifests its effect based on the recovery questionnaire. The results show a significant effect in which a restoration condition was felt by participants while performing tasks under auditory stimuli intervention. This result was in line with Song [45] and Ge [13], which found that psychological relaxation was improved after hearing a natural sound. Thus, auditory stimuli provide a subjective influence as a restorative replenishment. In addition, the attentional control scale provides a supplementary descriptive picture that the majority of participants recruited in this study have a good ability to control their attention. However, the findings of this study diverge from those of Hedblom et al. [18], who reported no significant difference in stress recovery between bird songs and traffic noise. This discrepancy may be attributed to the distinct nature of the auditory stimuli employed in the current study. While Hedbloom et al. [18] focused solely on bird songs, our research incorporated a combination of waves and seagull chirps to represent a more comprehensive seascape. The diversity of soundscapes in our study may have contributed to the observed differences in recovery outcomes, highlighting the potential influence of auditory stimulus complexity on individual responses.

Furthermore, previous research has demonstrated the significant influence of auditory stimuli, particularly nature sounds, on mood and stress levels [34]. These stimuli may reduce stress by promoting relaxation and emotional regulation, which aligns with current findings, potentially leading to improved cognitive function [29] and reduced feelings of overwhelm. Additionally, auditory stimuli of nature's sounds have been shown to enhance mood by evoking positive emotions [40] which is also similar to current findings of subjective response and the potential to reduce anxiety and depression [13].

4.1. Limitations

In this study, several facets might become the limitations. The auditory stimuli representation was limited to the sound of waves and seagulls chirping, where there are many variations of sound representation that could be explored. Ratcliffe et al. [42] mentioned that sound characteristics (e.g., sound level, harmonics, frequency) and individual perception (e.g., familiarity, perception complexity, pattern) influenced bird sound attractiveness towards humans that may arouse restorative feelings. Future research could explore a wider range of sounds to identify the most effective auditory stimuli for micro-refresh.

The auditory stimuli presentations were limited to 20 s every 7.5 min for a total of 25 min of task in each set. Our conjecture, there might be revamping needed in the experimental design, thus the role of auditory stimuli as a micro-refresh will arise more contrast compared to a condition without auditory stimuli. Future research could explore the effects of varying the duration and frequency of auditory stimuli presentation to determine the optimal parameters for micro-refresh. This could help to identify the most effective timing and intensity of auditory stimuli for promoting recovery and enhancing cognitive performance.

The cognitive task adopted in this study was limited to comparison tasks which were not broad enough to accommodate the various types of jobs. The arrangement of cognitive tasks will influence the competence of each individual [19]. To further explore the applicability of auditory stimuli micro-refresh, future research should investigate its effects on a broader range of cognitive tasks, encompassing various job types and requirements.

Subsequently, 25 participants' data were utilized for analysis, where the use of a larger amount of data is highly recommended to meet statistical needs. Our study recruited participants in a relatively similar cohort (i.e., university students). Different groups of participants (e.g., education level, type of job, work experience) might be important to be considered to represent a better work environment [25,41]. To enhance the generalizability of our findings, future research should investigate the effects of auditory stimuli micro-refresh on a more diverse population. This could include individuals with varying education levels, occupations, and work experiences. Additionally, this study did not investigate potential age or gender differences in the impact of auditory stimuli on intellectual performance. Previous research suggests that these factors may influence individual responses to sound stimuli [6] and nature-based stimuli [49].

Additionally, each individual might have a different sound preference which then can build an association of a favorite place or destination. As mentioned by Korpela et al. [24], recovery from stress is associated with respondents' cherished places and the effect is stronger when it is related to restorative experiences such as exercise and activity in an outdoor environment. In this study, micro-refresh is represented by auditory stimuli, which is a single sensory approach. The utilization of a multi-sensory approach to micro-refresh can be developed for further research. The multi-sensory approach is expected to boost the recovery enhancement process [8,37]. Future research is recommended to examine the potential advantages of integrating auditory stimuli with other sensory modalities for improved recovery outcomes.

Additionally, the current study focused on cognitive performance and subjective ratings but did not include physiological measures. Future research could explore the combined effects of auditory stimuli and physiological responses for a more comprehensive understanding of recovery. By measuring physiological parameters such as heart rate, blood pressure, or skin conductance, researchers could gain insights into the underlying mechanisms through which auditory stimuli influence relaxation and stress reduction.

5. Conclusion

In conclusion, the present study shows several effects of auditory stimuli on intellectual work performance. Even though there were no statistically significant differences found in several quantitative measurements, the recovery subjective feeling showed that participants felt more recovered when performing the task under auditory stimuli intervention, signaling a positive response to the intervention of auditory stimuli during the work. This study suggests several practical applications of auditory stimuli to enhance workplace performance and well-being. As an illustration, integrating auditory stimuli of nature's sounds into office design or educational settings creates more relaxing environments and promotes mental restoration during work breaks. Additionally, ambient nature sounds can be utilized to mask background noise to reduce distractions and improve focus. For remote workers, developing tools and applications that provide access to nature sounds to foster a more calming and productive work environment. Future research is expected to be able to explore more auditory stimuli potentials as micro-refresh during work (e.g., sound types, combination of multi-sensory approach, individual preferences, sound perceptions) holistically to enrich research related to recovery enhancement strategies.

Ethics approval and consent to participate

All methods were carried out in accordance with relevant guidelines and regulations. In compliance to Japan legislation this study design was submitted to an ethical board of the Graduate School of Energy Science Ethics Committee at Kyoto University. For the processing and storage of participant information, voluntary informed consent was obtained from all participants, in compliance with Regulations Concerning Protection of Personal Information at Kyoto University.

Availability of data and materials

The datasets used and analyzed in this study are available from the corresponding author upon reasonable request.

Declaration of generative AI and AI-assisted technologies in the writing process

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CRediT authorship contribution statement

Orchida Dianita: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Methodology, Formal analysis, Data curation. **Takuto Higashimaki:** Writing – original draft, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation. **Reika Abe:** Resources, Project administration, Methodology, Investigation. **Kimi Ueda:** Writing – review & editing, Validation, Supervision, Software, Methodology, Data curation, Conceptualization. **Hirotake Ishii:** Writing – review & editing, Validation, Supervision, Software, Methodology, Data curation, Conceptualization. **Hiroshi Shimoda:** Writing – review & editing, Validation, Supervision, Methodology, Funding acquisition, Data curation, Conceptualization. **Fumiaki Obayashi:** Writing – review & editing, Validation, Supervision, Methodology, Data curation, Conceptualization.

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.

Appendix A

Table A1

Table A1
The list of questions of the NASA task load index (NASA-TLX) and answering format scale from 0 to 100.

Mental Demand	
How mentally demanding was the task?	
0	100
Very Low	Very High
Physical Demand	
How physically demanding was the task?	
0	100
Very Low	Very High
Temporal Demand	
How hurried or rushed was the pace of the task?	
0	100
Very Low	Very High
Performance	
How successful were you in accomplishing what you were asked to do?	
0	100
Perfect	Failure
Effort	
How hard did you have to work to accomplish your level of performance?	
0	100
Very Low	Very High
Frustration	
How insecure, discouraged, irritated, stressed, and annoyed were you?	
0	100
Very Low	Very High

Data availability

Data will be made available on request.

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