

Experimental Study on the Effect of Systematic
Micro-refresh by Office Environment Control on
the Workers' Intellectual Concentration

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Abstract

The increasing demands of modern work environments necessitate strategies to enhance employee productivity and well-being while maintaining energy efficiency. This dissertation investigates the potential of systematic micro-refresh interventions to address these competing demands.

By incorporating brief, strategic breaks into the work time, we aimed to improve cognitive performance, reduce stress, and enhance overall well-being. To achieve this, we conducted a series of controlled experiments that involved exposing participants to various micro-refresh interventions, including auditory and visual stimuli.

Our findings demonstrate that systematic micro-refresh interventions can significantly improve cognitive performance, particularly during extended tasks. These interventions not only enhance task accuracy and efficiency but also contribute to a more positive work experience. By reducing perceived workload and promoting feelings of recovery and relaxation, micro-refresh strategies can help mitigate the adverse effects of prolonged work.

Furthermore, the timing of micro-refresh interventions plays a crucial role in maximizing their benefits. Strategic placement of these breaks can help prevent performance decline and maintain sustained attention.

The results of this dissertation have important implications for workplace design, employee well-being, and organizational productivity. By incorporating micro-refresh strategies into daily work routines, organizations can create more supportive and efficient work environments. Future research should explore the optimal implementation of micro-refresh interventions, including the ideal duration, frequency, and content of stim-

uli. Additionally, investigating the long-term effects of these interventions on cognitive performance, well-being, and job satisfaction is essential.

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Chapter 1

Introduction

1.1 Background

In a current modern work environment, prioritizing both environmental responsibility by incorporating energy-efficient acts and workers' well-being becomes crucial. Several actions to save energy, such as designing energy-efficient buildings or energy-efficient smart appliances in the office, often utilize strategies like reducing excessive energy use, such as reducing the energy consumption of electronic devices used when working. However, these actions in which are aimed at minimizing energy consumption, could also become a drawback to workers' cognitive performance or might be harnessed to intensify their performance. Therefore, it is still unclear whether several actions correlated with energy efficiency practices, especially in the workplace, might hinder or enhance the potential benefits for human cognition in the workplace.

The International Energy Agency (IEA) in their report for future "Buildings" highlights the importance of following energy efficiency acts in buildings, as their emissions have increased 1% per year since 2015 on average and contribute to around a third of overall energy emissions [1]. Figure 1.1 shows the "Net Zero Scenario 2010-2030" correlates to the global CO₂ emissions from the operation of buildings.

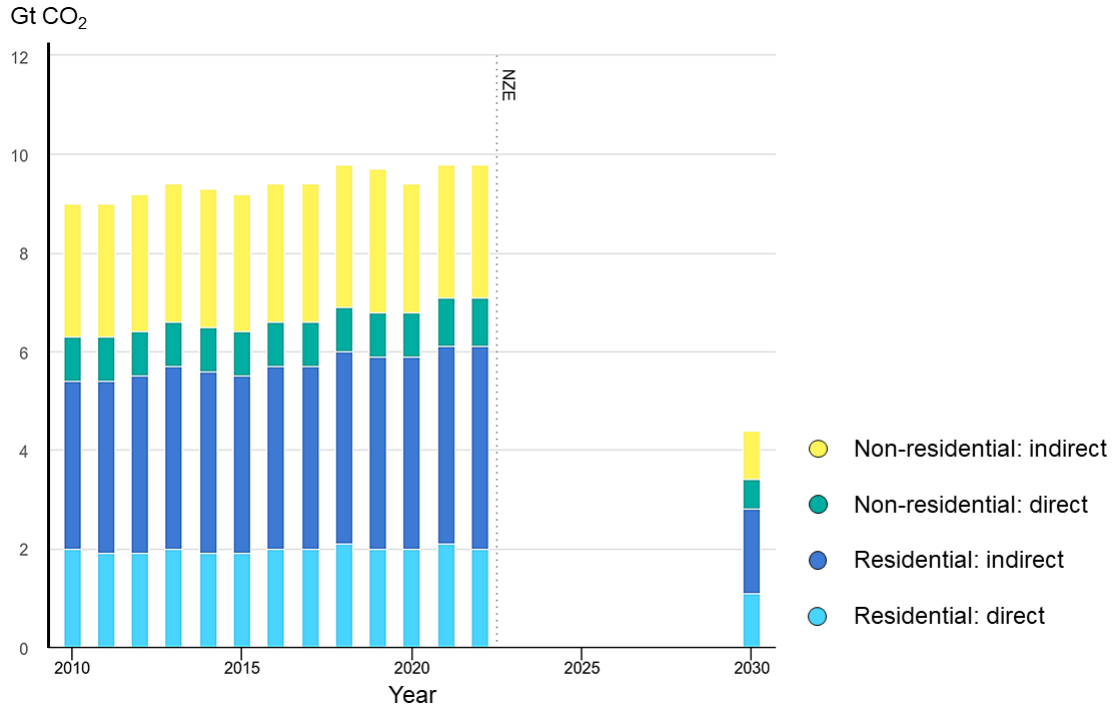


Figure 1.1: IEA Net Zero Scenario 2010-2030 for global CO₂ emissions from the operation of buildings [1]

Therefore, massive acts promoting “Green Buildings” such as “Net Zero Buildings” (i.e. efficient energy operations in buildings to become zero energy consumption), “Electrification of Buildings” (i.e. buildings powered by sustainable energy, shifting from fossil fuel to more renewable energy-based) and Smart Building Technologies (i.e., utilizing automation systems to optimize energy usage) are intensively implemented and will become a trend for the future [2,3].

The growing promotion of designing and constructing energy-efficient buildings could impact the occupants or workers who live or work inside the buildings. The implementation of energy-saving measures in the design of a room can correlate with the workers’ performance, and thus needs to be investigated further. Will this positively or negatively impact the workers who work in it.

The reverse approach is also imperatively implemented. By increasing the productivity performance of workers, it’s expected that workers can complete their work faster

and optimally, thus the energy consumption in the office can be saved. In addition, approximately a third of the current workforce in progressive economies is employed in the office and has become a significant asset for organizations and companies [4].

Workers are important assets in an organization and company, and their well-being must be considered. In a fast-paced work environment in which workers are required to be productive despite many factors that could become their stressors, it becomes challenging to maintain their productivity and well-being. Several related works and theories describe things that correlate to human performance management during work which are explained in the following section.

1.2 Related Works and Theories

1.2.1 Intellectual Performance

Intellectual abilities carried several properties that were taken into account at their level, stimulation, and potential development capabilities in the psychology domain. In connection with intellectual terms, intellectual concentration is attributed to the ability of an individual to think, understand things, and focus attention on some tasks or information. Although it is difficult to quantify intellectual concentration quantitatively, one of the quantitative approaches to measure intellectual concentration is called the concentration time ratio (CTR) [5–7].

In the CTR, the three states model is considered: the working state, short-term rest state, and long-term rest state. A working state is defined as the working condition for performing a task without problems. In the working state condition, as the task takes place during the time the mental fatigue escalates. Short-term rest is determined as a very short pause during cognitive work. In the short-term rest state, the task does not progress and increases mental fatigue. The condition in the short-term state might also be called blocking in mental work, which refers to short termination during mental work when people cannot perform the cognitive task for a short period of time [8]. As the

number of the task increased or continued over time, the appearance of the “blocking” assured more frequently especially if the task was considered homogenous and constant, however individual differences might be influenced in terms of blocking duration and frequencies during the mental work [8]. The long-term rest state is defined as a condition when people consciously take a long time break and then terminate the cognitive task, which then can reduce mental fatigue. Figure 1.2 illustrates the three states in the CTR model.

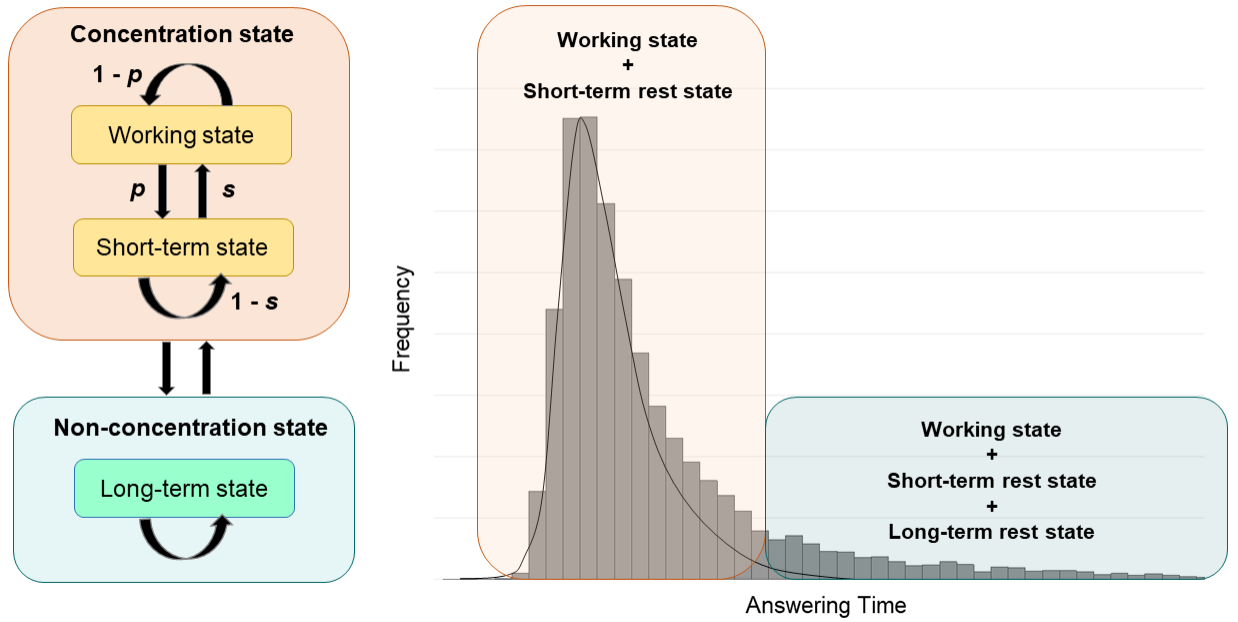


Figure 1.2: The three-state concentration model.

Mental fatigue influenced the probability of the transition state between the working state and the long-term rest state, while the transition between the working state and the short-term rest state transition is a fixed value [7]. The distribution of the cognitive work which correlates with the concentration states and rest cognitive states follows the log-normal distribution as described in Figure 1.3 [5–7, 9]. The parameters of the cognitive states are obtained from the sum of two log-normal distributions of the working state

and the short-term rest state (concentration state) and the working state, short-term rest state, and long-term rest state (non-concentration state).

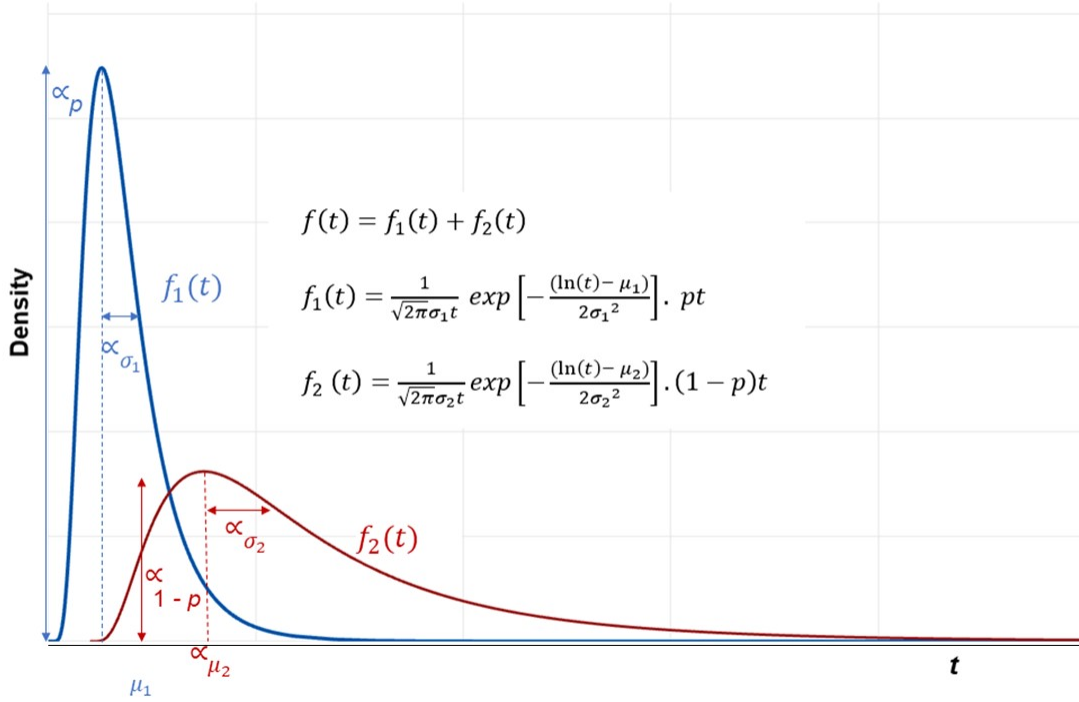


Figure 1.3: The distribution of concentration state.

1.2.2 Recovery Enhancement Theory

In the work environment, constant stimulation, distractions, and workloads could degrade the cognitive performance of workers, and in the long run, it could affect the well-being of workers leading to more serious problems such as health problems and burnout. In the following sections, several key theories correlated to cognitive restoration and enhancement will be describes. By understanding the cognitive function that helps workers recover, a work environment that supports workers' focus, productivity, and well-being is expected to be more easily achieved.

Effort Recovery Model

The effort recovery model describes the harmony between job demands and recovery sources [10]. Degradation in working performance occurs due to lacking recovery, which could lead to further compensatory work effort resulting in stress and fatigue [10]. Thus, when workers do some recovery acts and the workload are non exist, the recovery potency could occur as a form of break [11]. Based on the effort recovery model, it is important to provide recovery elements in the workplace to forbid workers' stress, fatigue, and burnout.

Attention Restoration Theory (ART)

The attention restoration theory emphasizes the importance of nature elements to promote recovery from fatigue and stress, thus restoring the directed attention capacity [12]. Based on the attention restoration theory, there are four fundamental elements of restorative settings of nature: 1) Being away (i.e., detaching from attention loads), 2) Fascination (i.e., enthusiasm features), 3) Extent (i.e., a sense of broader aspects that still connected), 4) Compatibility (i.e., harmony between natural elements and human affection) [12]. Furthermore, it can be said that ART is a model of psycho-sociological that most importantly recovery is not just simply a matter of time, but also determined by the place ambience [13].

Stress Reduction Theory (SRT)

The stress reduction theory highlights the importance of nature environments to stress recovery by activating the parasympathetic nervous system to promote relaxation feeling [14]. The important points of SRT encompass the evolutionary connection to nature and its calming nuance, the stress minimization effects, and psychological advantages (e.g., lift the mood, diminish anxiety, and amplify further well-being) [14]. SRT is one of the

main theories that correlate to relaxation and restoration improvement that become a track to link urban green space to human health and well-being enhancement [15].

Conservation of Resources Theory (COR)

The conservation of Resources (COR) theory assumes that individuals are motivated to acquire, protect, and sustain resources [16]. These resources can be tangible factors (e.g., money, possessions things, valuable objects) or intangible (e.g., self-esteem, social status, work position, social support).

A fundamental assumption of COR theory is that individuals aim to maintain and grow their resource assets. When resources are threatened or lost, stress and adverse psychological outcomes can appear. Reciprocally, gaining or building resources can promote individual well-being and resilience.

Building upon COR theory, the strategies to improve workplace well-being and productivity could be achieved by implementing several strategies such as:

- Resource arrangement: The organization or company can provide resources such as training, opportunities for growth, and supportive work environments to help employees maintain and build their resource assets.
- Job design: Designing challenging but not overwhelming jobs can help employees feel a sense of accomplishment and avoid resource depletion.
- Work stress management: Implementing work stress management programs and promoting work-life balance can help employees cope with potential resource loss and prevent burnout.
- Social support: Encouraging social interaction and fostering positive relationships among employees can provide a valuable source of social support.

Transactional Model of Stress and Coping

The Transactional Model of Stress and Coping proposes that stress is a dynamic process involving a transaction between an individual and their environment [17,18]. This

transaction is influenced by the individual's appraisal of the situation and their coping strategies. The model emphasizes the role of cognitive processes in shaping emotional responses and subsequent coping behaviors.

The important components of appraisal steps can be distinguished into three main parts:

1. Primary Appraisal: In the initial appraisal stage, individuals assess the significance of events, determining whether they are harmful, demanding, or inconsequential. For example, several appraisals such as:

- Irrelevant situation: The situation is deemed unimportant or irrelevant to the individual.
- Favorable situation: The situation is perceived as positive or beneficial.
- Stressful situation: The situation is perceived as harmful, threatening, or challenging.

2. Secondary Appraisal: In the second appraisal stage, individuals assess their ability to handle the situation, considering their available resources and coping mechanisms. For example, several assessments such as:

- Evaluation of coping resources: Assessing one's ability to cope with the stressful situation.
- Selection of coping strategies: Choosing appropriate coping strategies, such as problem-focused coping (e.g., seeking information, taking action) or emotion-focused coping (e.g., seeking social support, relaxation techniques).

3. Reappraisal: The process of altering one's interpretation of a stressful event to minimize its negative consequences. Reappraisal involves changing the way a situation is perceived, from a negative to a more positive or neutral perspective. This can help individuals cope with stress more effectively and reduce the negative impact of challenging situations.

1.3 Proposal of the Experimental Study on the Effect of Systematic Micro-refresh by Office Environment Control on the Workers' Intellectual Concentration

1.3.1 Systematic Micro-refresh during Work

Micro-refresh (MR) was proposed as one of the methodologies to improve intellectual cognitive performance during work by giving a very short stimulant non-voluntarily within a few seconds with environmental stimuli [19]. The term micro-refresh is different from conventional micro-break during work. While the micro-break refers to the initial break intentionally initiated or voluntarily done by the worker which might last for minutes with several options of restoration activities such as stretching activities, taking a coffee break, strolling around, and others [20–22], the micro-refresh has a different concept. MR has a very short time intervention during the works compared to the usual micro break. The refresh stimuli in a micro-refresh mainly come from external factors such as air flows, lighting, sounds, and others.

The idea of systematic micro-refresh appears as a way to induce the micro-refresh for a short time to become more organized. The systematic micro-refresh during several intervals of working time appears without sacrificing too much working time and preventing goof-off acts so that the goal of achieving workers' productivity is maintained. Figure 1.4 illustrates the concept of systematic micro-refresh.

1.3.2 Micro-refresh as Recovery Enhancement Strategy

During the work, several challenges could affect workers' cognitive performance (e.g., job demands, workload, stressors) [23, 24]. Especially for a certain job that demands workers' intellectual concentration, during a longer period, there will be a higher potential for decreasing the workers' attention. Thus, the concept of attention fatigue becomes a com-

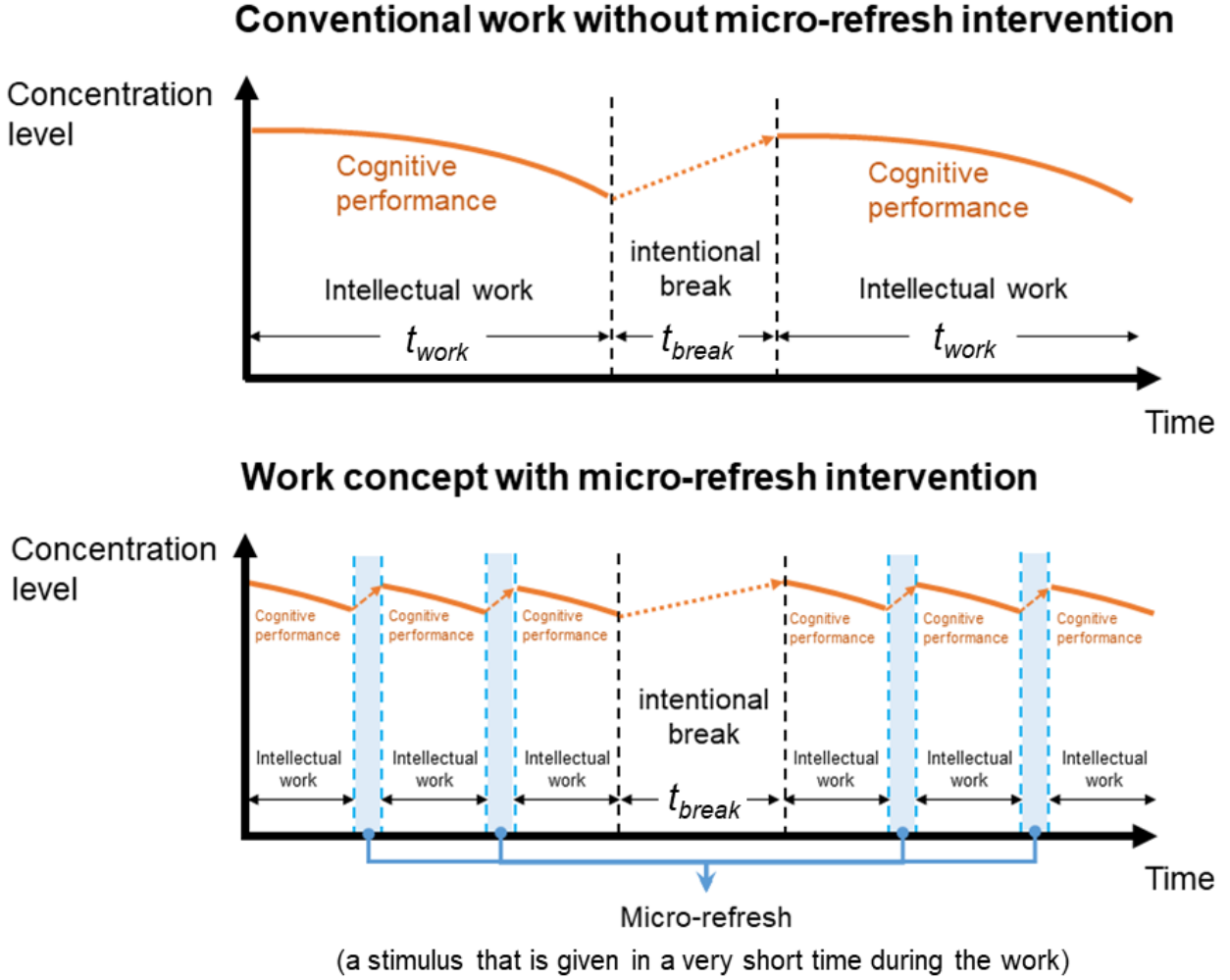


Figure 1.4: The micro-refresh concept.

mon finite nature of human attentional resources. Therefore, the recovery enhancement strategy appears as a compound act to restore human cognitive performance.

Micro-refresh appears as one of the potential recovery enhancement strategies during the work. The concept of micro-refresh aligns and becomes the manifestation of theories of focused attention restoration [12] and part of the job control (i.e., the ability to manage the allocation of attentional resources) [25,26]. An inducement of micro-refresh during the work for a short amount of time will trigger an attentional shifting mechanism, in which, there will be a short time of shifting attention from work focus to something less demanding. Subsequently, it will influence the load effect which refers to the circumstances where the capability to pick relevant information decreases along with the

increasing of the number of information to be processed [27]. The micro-refresh inducement might indirectly influence the load effect by stimulating psychological detachment (i.e., detached from current work demands) and recovery feelings. Previous studies correlated to psychological detachment from work highlighting its association with recovery experience [28–30]. As a consequence, it will affect the worker’s performance output, fatigue, and workload perceptions. Ultimately, by embracing the gleaned from the micro-refresh concept, it is expected the creation of a productive working environment that also supports workers’ optimized performance, and promotes their well-being by minimizing fatigue and workload could be consistently created. Figure 1.5 shows the framework of micro-refresh as a recovery enhancement strategy.

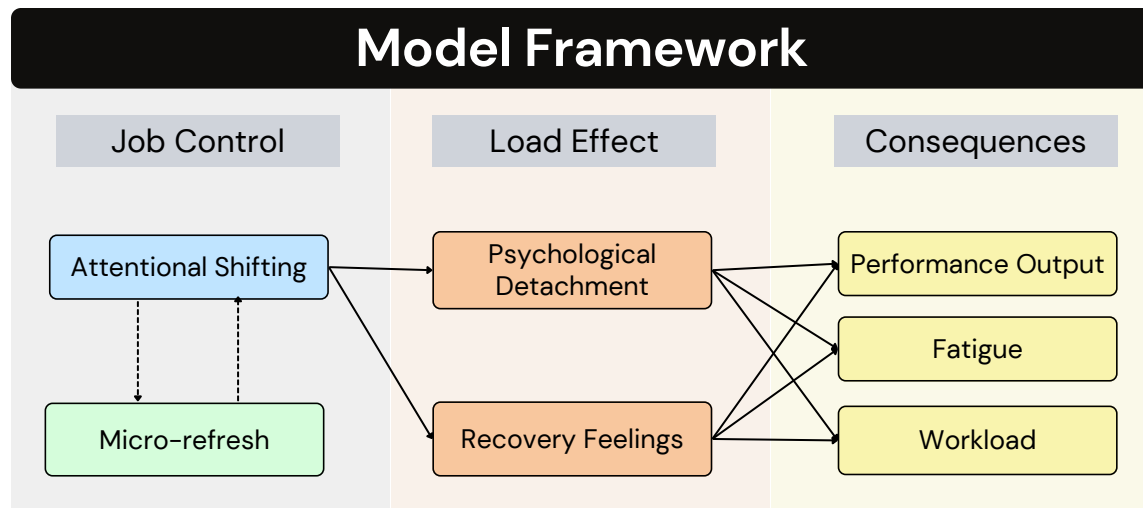


Figure 1.5: The recovery enhancement micro-refresh model framework.

1.4 Objective

This research aims to investigate the possibility of employing energy-efficient practices to maintain human cognitive performance in the workplace. Identifying specific design and operational strategies within workplaces that can optimize workers’ performance could lead to further workers’ well-being and environmental or energy responsibility. By conducting experiment-based and data analysis-driven links between these goals, this

research could bridge the gap in the design of future workspaces that promote both productivity and sustainability.

First, this study explores the effects of applying micro-breaks during the work. This action could halt the task by a short break which is inserted systematically within several seconds during the work.

Secondly, this study explores the impact of incorporating several stimuli as a micro-refresher during the work. Additionally, the stimuli induced in this study also incorporate natural elements by adopting the biophilic design and natural soundscape (for the audio stimuli experiment). In the second study, one candidate stimuli were investigated, namely the audio stimuli. The audio stimuli were induced systematically during the work for several seconds.

Thirdly, other potential stimuli are being investigated as a micro-refresh, the visual stimuli. The visual stimuli being induced several times during the work systematically. The visual stimuli adopted also incorporate the natural elements as part of the biophilic design concept.

By delving into these areas, this study strives to bridge the gap between a sustainable future and a workforce productivity that thrives in the modern era. Furthermore, this study aspires to contribute to enriching productivity research areas and integrate it through sustainable practices (e.g., creating energy-efficient workplaces) which further strengthen the productivity-sustainability loop cycle.

1.5 Structure of this Paper

This dissertation consists of five chapters. Chapter 1 introduces the research, providing background, objectives, and a literature review. Chapter 2 presents the initial investigation of systematic micro-breaks, focusing on timing and intervals. Chapter 3 explores the effects of auditory stimuli, building upon the previous study. Chapter 4 extends the research further by incorporating visual stimuli and longer task durations. Finally, Chapter

5 summarizes the findings and suggests directions for future research. Figure 1.6 illustrates the overall structure and relationships between these chapters.

The detailed summary of each chapter is explained below:

Chapter 1 : Introduction

This chapter provides a brief overview of the background and problems found that motivate the implementation correlates to the topics in this study. Several literatures correlate to the previous work and theories that underlie this research are also presented in this chapter. Additionally, the study proposal correlates to the micro-refresh concept described in this chapter, along with the research objectives. Subsequently, several measurement methods utilized in this study were specified.

Chapter 2 : Effect of Systematic Micro-break on Intellectual Work

This chapter describes the initial study that correlates to the investigation of systematic micro-refresh. As the initial study, a systematic investigation of micro-refresh induction during cognitive tasks within a certain duration and interval range becomes a special concern. With a predetermined experimental design, involving some participants, tasks, and methods, the performance output data in two different conditions (without micro refresh and with micro refresh) are compared. Furthermore, the results of the data in two different conditions are compared and analyzed to then draw objective conclusions.

Chapter 3 : Effect of Systematic Micro-refresh Auditory Stimuli on Intellectual Work

This chapter follows up on the subsequent study of the micro-refresh investigation. In this study, auditory stimuli micro-refresh were employed following established timing protocols. By adopting the concept of biophilic and soundscapes, the nature sound is chosen as the micro-refreshing auditory stimuli. Experimental studies involving several participants, utilizing some measurement methods, and following certain designs of experiments were described in this chapter. The output results of two conditions with the micro-refresh and without micro-refresh were compared and analyzed. Conclusion cor-

relates to the investigation of auditory stimuli micro-refresh and its effect on intellectual concentration performance is generated and described.

Chapter 4 : Effect of Systematic Micro-refresh Visual Stimuli on Intellectual Work

In this chapter, to further investigate the effects of micro-refresh stimuli, the third study extended the previous experimental design. Visual micro-refresh stimuli were employed, and the cognitive task duration was prolonged to incorporate multiple micro-refresh inductions. This modification allowed for a more comprehensive evaluation of the impact of visual micro-refresh on cognitive performance. The visual stimuli utilized in this study adopt the biophilic concept of nature visualization and are induced several times during the work. The design of the experiment, the participants recruited, and the methods and data analysis methods are described. The analysis involving the data collected from two different experimental conditions (i.e., with visual stimuli micro-refresh and without visual stimuli micro-refresh). The discussion and conclusion obtained from the experiment are discussed in the following section.

Chapter 5 : Conclusion

This chapter summarizes the general conclusions drawn from the study in Chapter 2, Chapter 3, and Chapter 4. This chapter also discusses the limitations, implications, and prospects for future research, where this study still has the potential to be developed in the future.

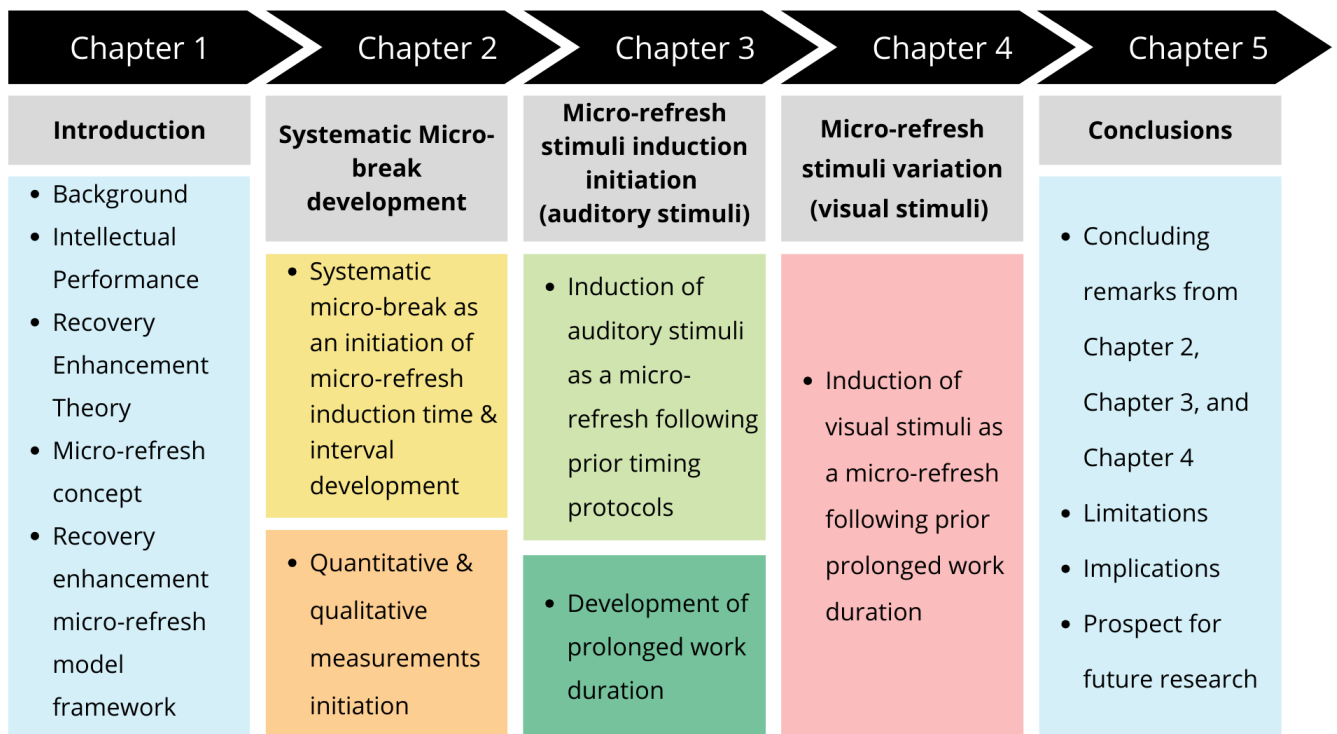


Figure 1.6: The summary and its connection between the chapters.

Chapter 2

Effect of Systematic Micro-break on Intellectual Work

The contents of this chapter are published on:

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<https://doi.org/10.1007/s43674-024-00074-6>.

2.1 Introduction

Improving human intellectual attributes becomes an important concern in a fast pacing work environment [31,32]. The complex work environment factors (e.g., stressors, workload, conflicts) should be balanced by a recovery-enhancing process to create employee well-being within the company [33,34]. In general, some organizations and companies apply the lunch break time during more than 6 hours to 8 hours of daily work [35–37]. However, it is hard to maintain optimal working performance for the 3-4 hours period before and after the lunch break time. Thus, the micro-breaks concept is offered to maintain stable work performance without taking excessive working time.

Micro-breaks are defined as short time breaks from work as a momentary work recovery [38]. Micro-breaks appear as an individual strategy to maintain or improved occupational well-being during work [22]. Even though there is no exact standard on how long the duration of micro-breaks should occur [39], several literatures suggest a short amount of time for a few seconds or minutes is sufficient for the micro-breaks duration without countering the productivity [19, 40, 41]. Several activities can be referred to as micro-breaks such as relaxation activities (e.g., listening to music, meditating, taking a short nap), nutrition-intake activities (e.g., drinking water, snacking), socialization (e.g., chatting, contacting friends or family), and others activities (e.g., look outside the window, walking, stretching) [39, 42].

Previous studies investigated the micro-breaks impact on working performance. A survey study involving 71 call operators resulted that cognitive micro-breaks improved their positive affect which resulted in higher sales achievement [39]. Other survey studies involving 120 respondents show the desire for self-reward triggers the individual to take the micro-breaks [20]. The attention of assembly workers improved by taking micro-breaks during work shown by the EEG analysis [43]. Previous preliminary study showed that on average the condition with systematic micro-break during work, gives a positive impact on the performance of 3 participants compared to the condition without break [19]. Previous study mentioned that a systematic break during work resulted in more efficient in terms of work completion and has advantages to restore the mood compared to self-regulated break [44]. Other studies supported the advantage result of taking a micro-break during the work to restore the performance for both relaxation and expertized activity than no micro-break condition [45]. Additionally, previous work of study mentioned that utilizing the pause in a computerized simulation game for the medical students resulted in a higher cognitive load and performance than without the pause [46]. It was also mentioned that without taking frequent break could accumulate the fatigue symptom in the work-from-home officer cases [47]. Previous literature also suggest that

taking more frequent short breaks than postponing the break to later time could promote recovery better [48].

However, the investigation on systematic micro-break intervention in a cognitive work under controlled experimental with quantitative and qualitative measurement condition was rarely done. Thus, this study aims to contribute in the investigation of systematic micro-breaks on intellectual concentration within intellectual work by controlled laboratory experiment objectively.

2.1.1 Systematic Micro-break and Micro-refresh

Micro-refresh (MR) is a concept to promote efficient recovery from fatigue and maintain 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. 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 [19] 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. Airflow modification as a microrefresh mechanism was investigated and the result showed that stimulated airflow with mild speed improved cognitive performance [9].

2.2 Investigation of Systematic Micro-break

To examine the effect of microbreaks (MB) on intellectual concentration work, a controlled laboratory experiment was conducted with experiment participants. Two types of measurement evaluations were employed (i.e., quantitative and qualitative) as mentioned [49] that the combination of quantitative and qualitative measurement is effective in detecting the shift correlates to the cognitive work task. The experiment was designed with certain

procedures, specific tasks, and equipment. The details of the experiment procedure, cognitive tasks, measurement, experiment environment, participants, and data analysis are described in the following paragraph.

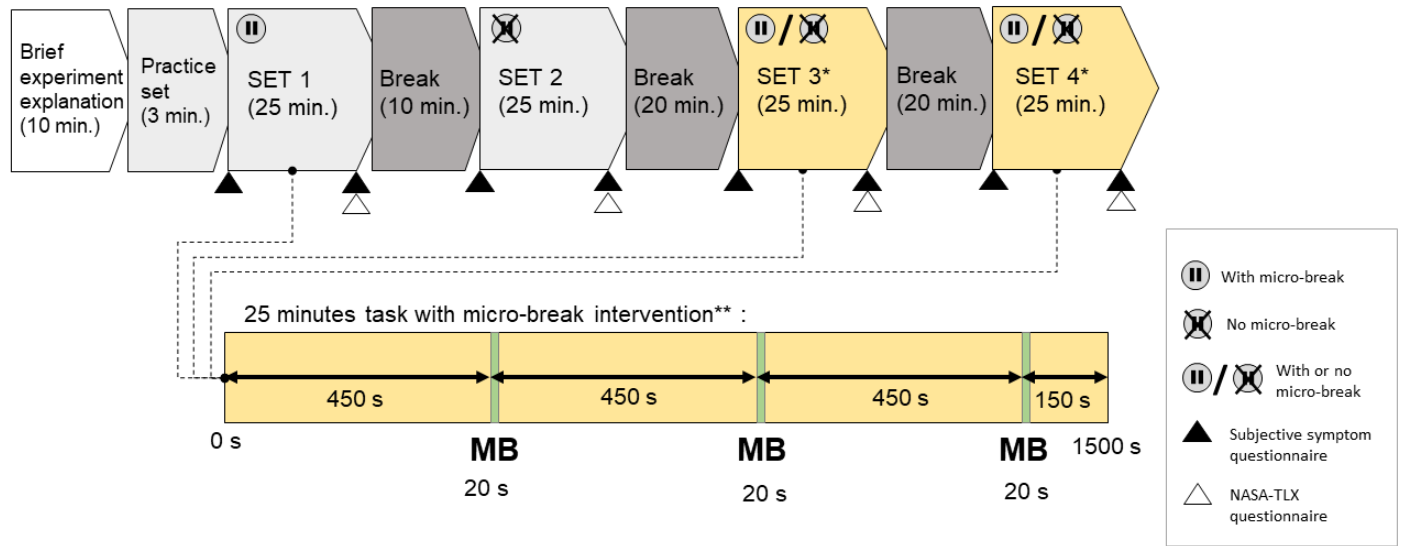
2.3 Methods

2.3.1 Experimental Procedure

In this study, the independent variable was the systematic MB intervention during cognitive tasks. Answering time in each question, the intellectual concentration performance such as CTR score, and the subjective rating questionnaire were set as the dependent variables. As the MB intervention, a blank grey screen appeared for 20 seconds repeatedly just after answering the problem after 7.5 minute task, which pause the cognitive task. All participants performed cognitive tasks under two conditions with the MB intervention and without the MB intervention.

Figure 2.1 illustrates the experimental procedures. The experiment was conducted where four sets of cognitive comparison tasks with 25 minutes duration were given to all the participants. Set I and set II were executed in the same order for each participant, with MB intervention in set I, then without MB intervention in the set II. Additionally, set III and set IV are arranged with a counterbalanced design of the MB intervention between all participants to minimize the ordering effect. Additionally, the learning effect considered to have been reduced assumed that all the participants were already familiar with the task after conducting set I and set II. Later, in the data analysis, only the data from the set III and set IV were used.

Before and after each task set, the participants were given a subjective symptom questionnaire to measure subjective ratings for their level of fatigue, concentration, sleepiness, blur, and dullness. Additionally, the participants also answered the NASA Task Load Index (NASA-TLX) questionnaire after each set.



*) Micro-breaks were appointed in a counterbalanced design for SET 3 and SET 4, and the data produced from SET 3 and SET 4 were used in the analysis.
 **) Three 20-second micro-breaks were administered at 7.5-minute intervals during the 25-minute cognitive task.

Figure 2.1: The experimental procedures.

2.3.2 Cognitive Comparison Task

Previous studies used comparison tasks in human reasoning research that emphasized similarities and differences between pairing words [50, 51]. The cognitive comparison tasks [52] were utilized in this experimental study. The characteristics of cognitive comparison tasks are suitable in the aims to measure the intellectual concentration properties due to its unified level of difficulties for each question and unobtainable to change the answering strategies, and approximately portrays cognitive tasks during the work or study.

Figure 2.2 shows an example screen of the cognitive comparison task [52]. The half-left sides of the screen show the task questions and the half-right sides of the screen show the answering buttons. In the cognitive comparison task, two comparison categories should be solved for each question which are semantic words comparison and numerical comparison. The semantic word comparison is given in a way of two different words being compared whether these two words are classified into the same category or not. There are four categories determined for each word that appears such as place name, animal, plant, and artificial objects. For example, when given two words “dog” and “cat” it should be

responded as the “same” category as the “cat” and “dog” both belong to the animal category. In the numerical comparison, two numbers with an inequality mathematical sign between them are logically compared, whether the inequality formula is correct or false. For example, given two numbers “2543” and “2354” connected with the “<” (less than) sign of the math symbol, then it should answer as a “false” statement. Combining the answer of semantic words comparison which is “same” and numerical comparison which is “false”, the answer box should be tapped in the “same” – “false” intersection area. After tapping the answer box, the next question appears. All the questions were designed to have the same level of difficulty and presented in a pseudorandom order.

The cognitive comparison task was developed in the JavaScript software program [53] and run on an iPad 2 tablet [54]. The answering time for each question was automatically recorded in the program.

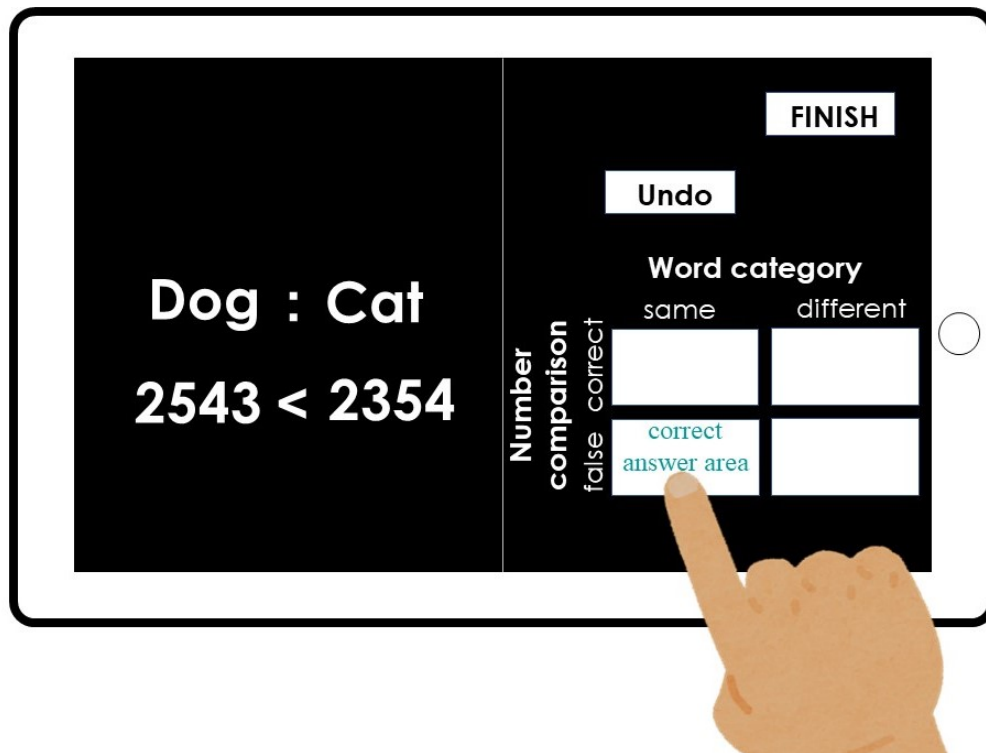


Figure 2.2: Illustration of the cognitive comparison task.

2.3.3 Measurements

Answering Time

The performance output is measured in the form of answering time for each question task. The answering time was recorded automatically in an experimental program and can be downloaded in a .csv file at the end of the task. The answer time for each counted question starts when the question appears until the participants touch the square box of an answer area on the screen. The unit digit of answering time in the experimental program is set in milliseconds denomination.

Concentration Time Ratio (CTR)

Intellectual abilities carry several properties given due consideration at their level, stimulation, and potential capabilities of development in the psychology domain. In connection with intellectual terms, intellectual concentration is attributed to the ability of an individual to think, understand things, and focus attention on some tasks or information. Although it is difficult to quantify intellectual concentration quantitatively, one of the quantitative approaches to measure intellectual concentration is called the concentration time ratio (CTR), which represents the proportion of actual concentration time for total task completion time [5–7].

The CTR obtained from the average response time of concentration state functions multiplied by the number of task questions answered, divided by the total response time from cognitive task work. In the CTR, three states model is considered which are the working state, short-term rest state, and long-term rest state [5–7].

Subjective Ratings

The workload assessment instrument utilized in this study are the subjective symptoms questionnaire [55], time lapse questionnaire and the NASA task load index (NASA-TLX) questionnaire [56]. The subjective symptoms questionnaire was adopted in this study

according to the research needs to grasp the distinction in the qualitative measurements of the subjective alertness feeling during the work. On the symptom questionnaire, five subscales were listed i.e. concentration, sleepiness, blurriness, dullness, and fatigue. The concentration scores measure the ability to focus on one's attention during the work. The sleepiness scores measure the drowsiness level or the tendency to feel sleepy. The blurriness scores grasp the perception of the vision's haziness. The level of boredom is adapted from the dull scores. Fatigue scores distinguish the weariness condition.

In the progress questionnaire, the sleepiness, blurriness, and dullness subscale contain five question points ranging from 1 "low" to 5 "high". The total score of sleepiness, blurriness, and dullness subscale was obtained from the sum-up score from the question points. The time lapse questionnaire includes subjective fatigue and concentration subscale as scores ranging from 0 "low" to 100 "high". The NASA-TLX questionnaire consists of six subscales or load dimensions i.e. effort (EF), frustration level (FR), mental demand (MD), physical demand (PD), the overall performance (OP), and temporal demand (TD) [56,57]. NASA-TLX brings an adequate sensitive index that could diversify cognitive tasks and physical tasks of the overall workload [58] as cited in [59].

2.3.4 Experimental Environment

The experiment was conducted in an experimental room in Graduate School of Energy Science, Kyoto University. A table was set in front of the participants with an iPad on top of the table and a stand behind the iPad. A chair is placed in front of the table, where the participants could perform the task while sitting. Figure 2.3 shows the layout of the experimental room. Boards of partition were placed in front of the table, on the left and right sides of the table to minimize distraction while participants performing the task. The experimental room temperature was set around $23 \pm 2^{\circ}\text{C}$, with humidity level $50 \pm 10\%$ RH. The lighting level was set at 500 ± 50 lux. Additionally, the CO_2 concentration was around 550 ppm.

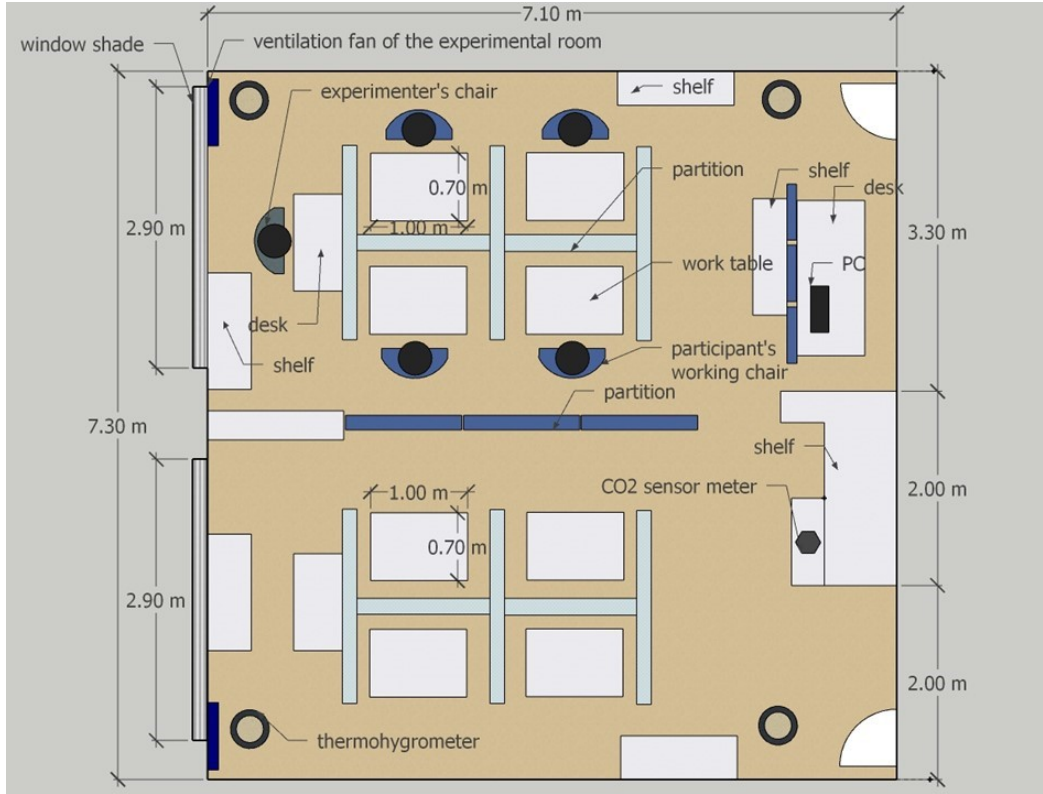


Figure 2.3: Layout of the experimental room.

2.3.5 Participants

In this study, fifty-two participants were recruited. All the participants are Kyoto University students with a range of ages between 18–28 years old. From a total of fifty-two participants recruited, thirty-one participants' data (male = 20, average age = 21.2 ± 2.54 years old) were used in the analysis procedures who followed the experimenter's instruction without slacking off and completed all four sets of the experimental procedures, while twenty-one participants' data were excluded. The data from 31 participants performing 2 conditions in a set with MB intervention and no MB intervention resulted in a statistical power of 0.97, $\alpha = 0.05$ and $\sigma = 5$ which fulfilled the statistical sufficiency. For this experiment, ethical approval was granted by the Graduate School of Energy Science Ethics Committee at Kyoto University. Figure 2.4 shows a scene when participants were performing the experiment task.



Figure 2.4: Participants performing the experiment task.

2.4 Data Analysis

The quantitative data from the cognitive comparison task to be analyzed is the answering time collected by the task software and the CTR score. The data to be analyzed were extracted from set III and set IV which portrays the condition with MB intervention and without MB intervention sets in counterbalanced design.

The CTR scores were calculated by the CTR analyzing software from answering time data in each set. In the analysis, the CTR score in set III and set IV are being compared to discover the effect of MB intervention in intellectual concentration performance.

To grasp more intuitive accuracy for the cognitive performance in each set, and to facilitate more details comparable performances in a set with MB intervention and without MB intervention, the answering time was divided into seven time blocks for every four minutes in a time series horizon. Figure 2.5 shows the detailed time frame grouping in a set with MB intervention and without MB intervention. Later in the analysis section, these four minutes time frame grouping then stated as the phase factors. In the phase factor, to grasp the intuitive comparable data align with the MB effect, the phase included starts from the block number 3 until 7 for the condition with MB intervention and block number 3 to 7 in no MB condition. The actions to correct the previous answer by partici-

pants which indicated by the undo movements were removed in the answering time data analysis.

Time Window (seconds)	0–240	241–480	481–720	721–960	961–1200	1201–1440	1440–1500
Block Number	1	2	3	4	5	6	7
SET no Micro-breaks	Performing the task	Performing the task	Performing the task	Performing the task	Performing the task	Performing the task	Performing the task
SET with Micro-breaks	Performing the task	Performing the task	Performing the task	Performing the task	Performing the task	Performing the task	Performing the task

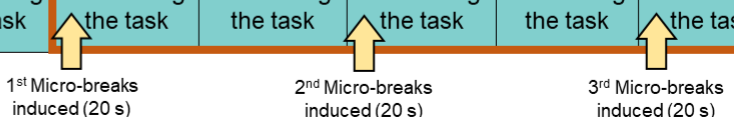


Figure 2.5: Time frame grouping for set with micro-break and without micro-break intervention.

Statistical analysis was used to compare the quantitative data of the answering time and the qualitative data from the questionnaire results. The *Repeated Measures ANOVA* (RM-ANOVA) was performed to analyze each factor's significance in the quantitative data and qualitative data. Minitab statistical software is utilized for the analysis tools [60].

2.5 Results

2.5.1 Analysis of Answering Time

The answering time in each block shows a significant difference in the condition with MB and without MB intervention ($p < 0.001$). The details of answering time in each block and statistically significant difference indicators are shown in Figure 2.6. *Tukey's post-hoc* analysis was performed to indicate which block contributes to the significant difference. The contrast significant difference was found in block 3 with micro-breaks condition to block 4 with no micro-breaks condition. This result indicates that the first micro-break induction for 20 seconds after 7.5 minutes of intellectual work could help to improve the

performance and result in contrasting performance after 12 minutes of work without the micro-break condition. A significant difference was also found in block 5 with micro-breaks condition to block 5-7 with no micro-breaks condition. In block 5 with micro-breaks, the second micro-break was induced for 20 seconds. It restored the intellectual performance and resulted in a significant difference in answering time after 16 minutes of intellectual work without micro-breaks.

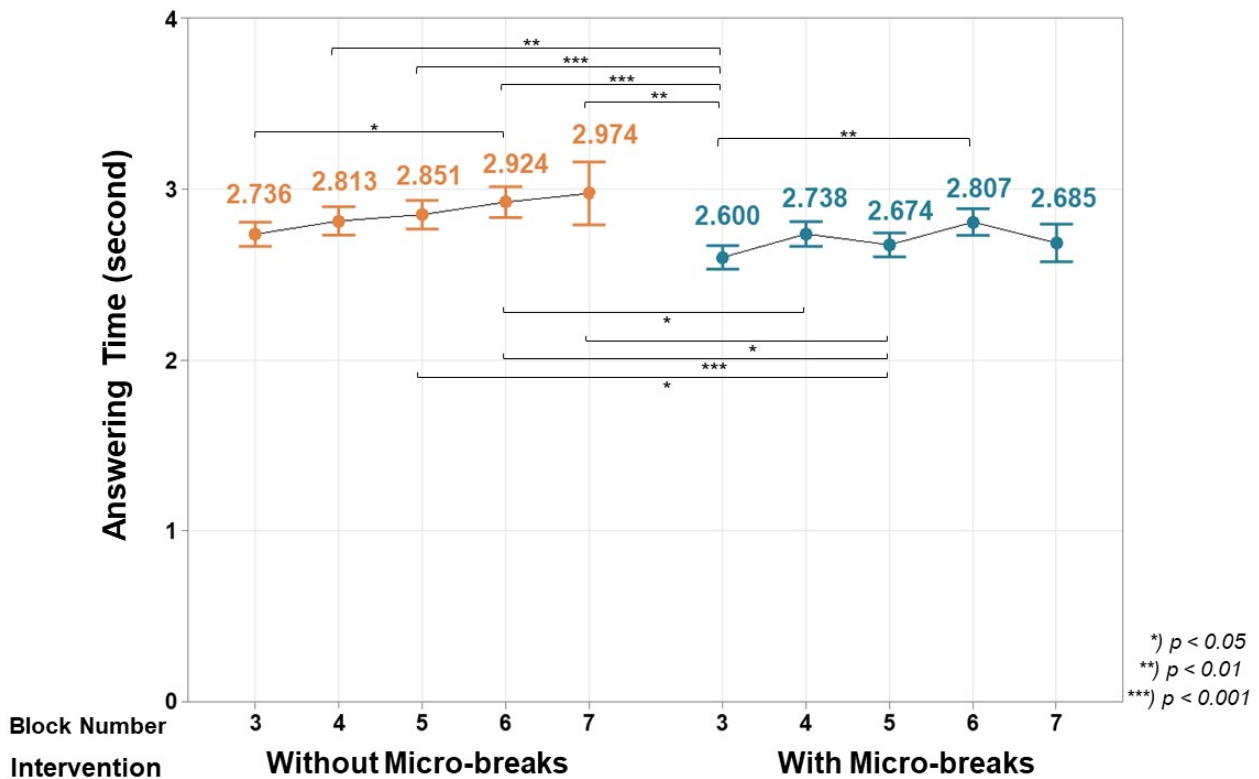


Figure 2.6: The average answering time for each block and indicators of significant difference.

2.5.2 Analysis of Concentration Time Ratio

The CTR score in the condition with MB intervention then being compared with the condition without MB. Figure 2.7 shows the average CTR score of 31 participants' data with MB intervention and without MB intervention. The CTR scores in a set with MB intervention and in a set without MB intervention follow the normal distribution based on the

Anderson-Darling normality test with follow *p-value* 0.076 in a MB condition and 0.254 in a condition without MB. As the CTR score for both conditions follows the normal distribution, the statistical two-sample *t-test* was conducted. The *t-test* resulted there was no significant difference between the set with MB intervention and the set without MB intervention ($p = 0.721$). Even though there was no significant difference comparing the CTR scores in both conditions, the CTR score with MB was not reduced despite it taking a total 1-minute break under MB condition.

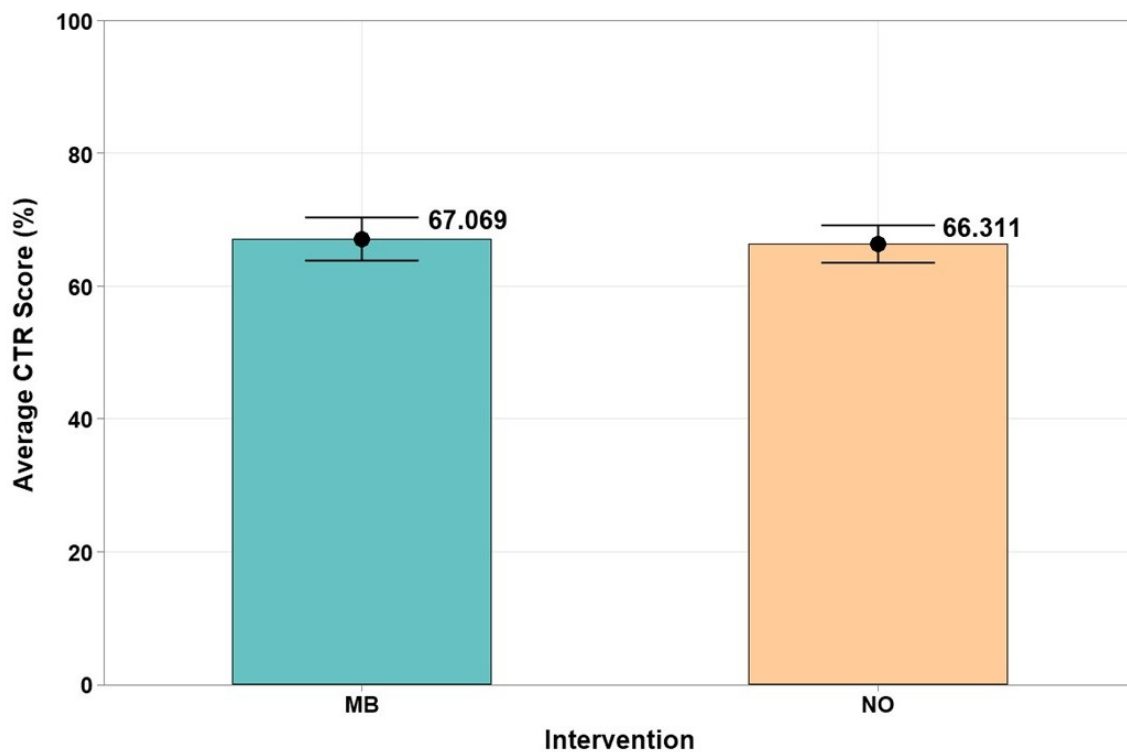


Figure 2.7: The average CTR scores of 31 participants' data in a set with MB intervention and a set without MB intervention.

From 31 participants' data, 17 participants showed better CTR scores in a condition with MB intervention compared to the no MB intervention. The results showed that more than half of the participants obtained a higher concentration level in a condition with MB intervention.

2.5.3 Subjective Ratings

Subjective Symptoms Questionnaire

The subjective symptoms questionnaire scores are shown in Figure 2.8 and Figure 2.9. The ANOVA analysis shows a significant difference for the questionnaire time factor ($p < 0.001$). Meanwhile, the intervention factor has no significant difference ($p = 0.773$), as well as the interaction between factors (intervention*questionnaire time, $p = 0.962$).

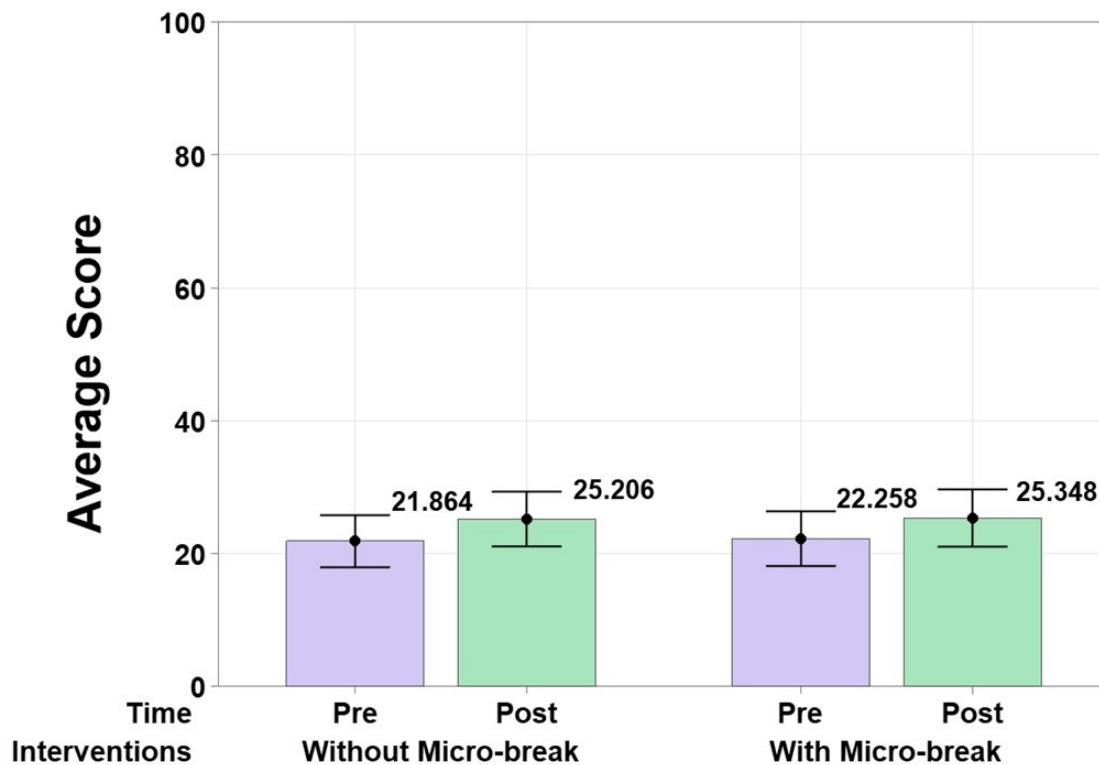


Figure 2.8: Subjective symptoms questionnaire pre- and post-task in both conditions with and without MB.

NASA Task Load Index (NASA-TLX)

The average of NASA-TLX weighted scores are shown in Figure 2.10. The *paired t-test* analysis indicates that there is a significant difference between conditions with MB intervention and without MB intervention ($p < 0.05$). This result has pinpointed the partic-

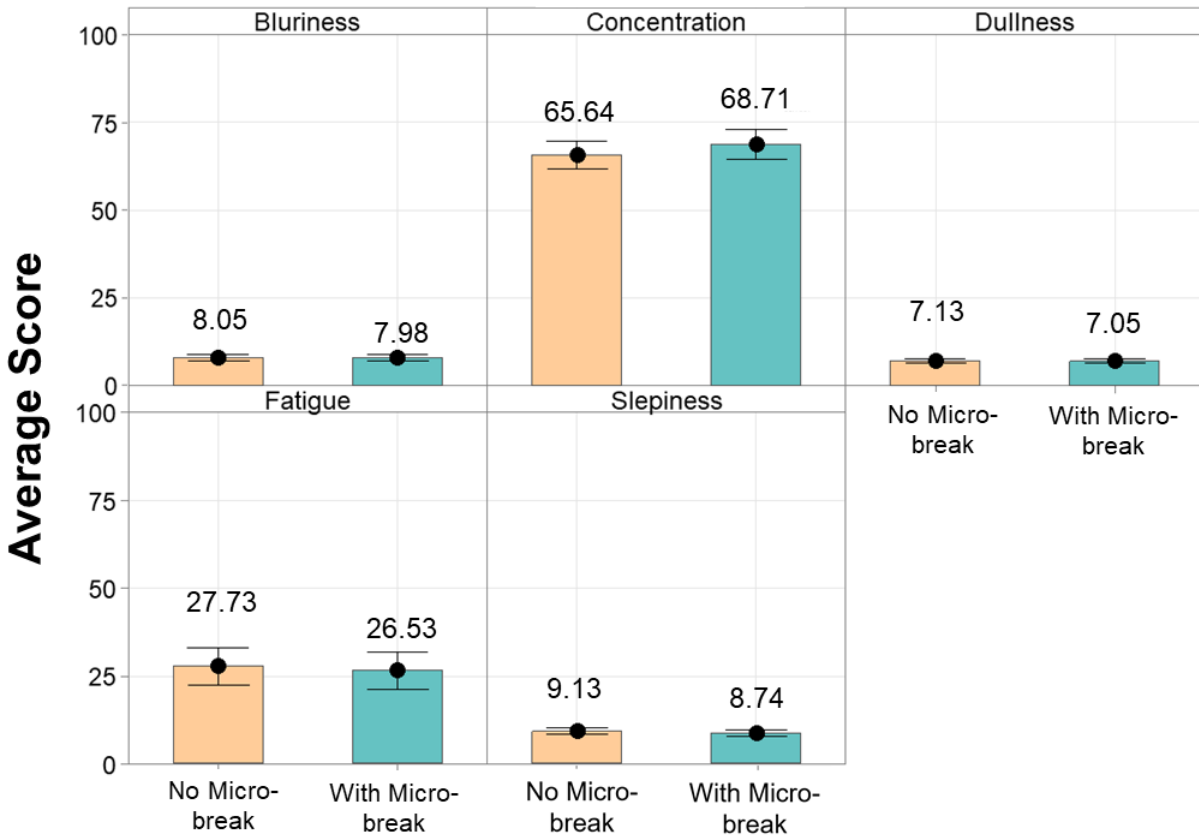


Figure 2.9: Subjective symptoms questionnaire results for each subscale.

ipants' feeling that in the cognitive comparison task, the mental workload was significantly higher in the condition without MB intervention.

2.6 Discussion and Conclusion

In terms of the answering time analysis, the intellectual performance between the intervention with MB and without MB showed a significant difference ($p < 0.001$). On average, the performance under MB intervention demonstrates lesser performance degradation compared to the performance without MB intervention shown by the sequences of answering time pattern. When the MB was induced, the performance slightly improved from the previous block (e.g. answering time was improved in block 5 in the MB condition compared to block 3 in the MB condition and block 7 in the MB condition compared

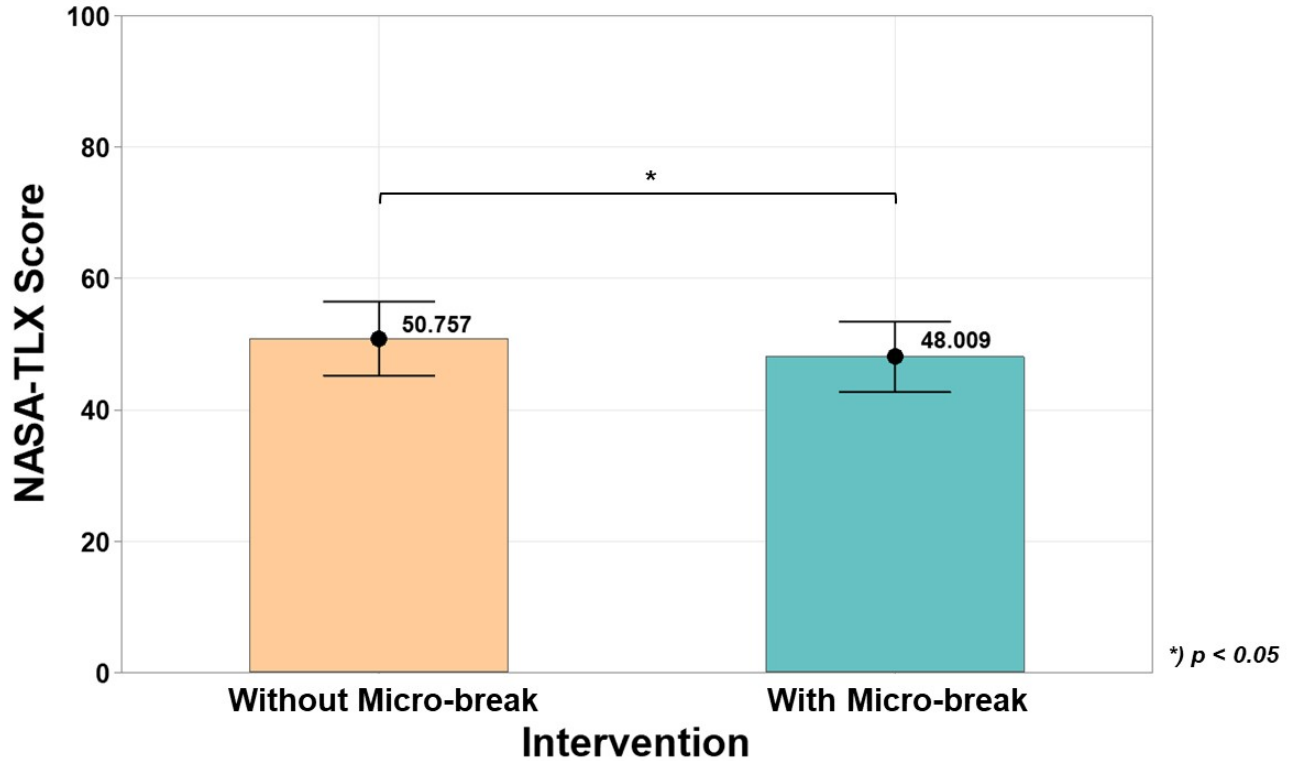


Figure 2.10: The NASA-TLX score between conditions with and without micro-break.

to block 6 in the MB intervention). However, the improvement effect might decay over time. On the other hand, the set without MB intervention showed an increasing trend of the answering time gradually from block 3 to block 7 which indicates a cognitive performance degradation throughout the time.

Nonetheless, there was no significant difference in the CTR scores in the set with MB intervention and without MB intervention, the scores were slightly higher for a condition with MB than without MB. Additionally, more than half of the participants show higher CTR scores in the condition with MB intervention than without MB intervention. The difference in significant results between the total 31 participants' data in CTR analysis and answering time analysis could be due to the indulgence of micro-breaks time in the formulation. While answering time analysis, does not include the pause break time in the MB condition calculation, CTR is obtained from the average answering time of the concentration state multiplied by the number of questions answered divided by total time.

However, the CTR score under the MB condition was not decreased regardless of the inclusion of a total break time of 1 minute (i.e., 3 times MB was given with 20 seconds each).

Generally, the performance during the time was 25-minute more stable in a condition with MB intervention, compared to the condition without MB. In the 25 minutes task set, the answering time performance under the MB intervention resulted in slight improvement after the MB induced in block 3, block 5, and block 7. On the other hand, the performance in a condition without the MB intervention was getting slower gradually from block 3 to block 7.

The contrast significant difference was found between block 3 in the condition with MB condition to block 4, block 5, block 6, and block 7 in the condition without MB. There is a possibility that the first intervention of MB was too early to be induced after a 7.5-minute task. It is advisable to start inducing an MB after the minute of thirteenth at the start of block 4 in a condition without MB intervention, which might obstruct the performance degradation.

The questionnaire results have shown a significant difference in terms of the MB intervention factor for the NASA-TLX with a tendency that in a condition without the MB intervention, the mental workload was higher than the condition with MB intervention. However, generally, the subjective symptom questionnaire did not show a significant difference between conditions with MB and without MB intervention. It might be that the insertion of 20 seconds MB 3 times during the task, did not significantly affect the subjective symptoms feeling among the participants. Whereas, the pre and post-questionnaire have significant differences which indicate that the participants were more likely to feel the symptoms effect of before and after taking 25 minutes cognitive task.

To conclude, this study showed that a systematic MB has the potential benefit of stabilizing worker performance and hindering performance degradation over time. A quantitative result from the answering time analysis portrayed the significant difference in various time blocks concerning the induction of systematic MB in the 25-minute cognitive

task. Additionally, a qualitative result of the NASA-TLX showed the mental workload in the conditions with MB was significantly lower than that without MB. As further studies, it is necessary to investigate various types of stimuli for MB intervention has potential benefits as a way to improve intellectual concentration. Additionally, incorporating the assorted possibilities of MB duration and interval might enrich the exploration of research correlates to the resource replenishment strategy.

Chapter 3

Effect of Systematic Micro-refresh Auditory Stimuli on Intellectual Work

The contents of Study 1 in this chapter are published on:

Dianita, O., Higashimaki, T., Abe, R., Ueda, K., Ishii, H., Shimoda, H., & Obayashi, F. (2024). The effect of systematic auditory stimuli micro-refresh on intellectual work performance and subjective measurement. *Results in Engineering*, 24, 1—10.

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3.1 Study 1: Effect of Systematic Micro-refresh Auditory Stimuli on 25 Minutes Intellectual Work

3.1.1 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 [61, 62]. 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 [33,34].

Several theories have become the basis for topics related to work recovery. The effort-recovery model 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 [63,64]. Furthermore, fatigue could be carried over or become a cumulative aftermath that can increase load consequences after work [63,64]. Previous study proposed the attention restoration theory where this theory promotes the role of nature elements in creating recovery conditions from fatigue [12]. Additionally, previous work of study composed the stress reduction theory which reveals that nature settings can strengthen the effect of restoration on attention [65].

Micro-refresh

Micro-refresh (MR) is a concept to promote an efficient recovery from fatigue and maintain 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. Previous work of study 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 [19]. The airflow modification as a micro-refresh mechanism was investigated and resulted that stimulated airflow with mild speed improved the cognitive performance [9].

Auditory Stimulation on Cognitive Functions

Several works of literature mention the importance of auditory stimuli as a medium in promoting recovery enhancement and better performance. Auditory selective attention supports the process of explaining a human's cognitive mechanism that mainly focuses on explaining its role as a stimulus [66]. Acoustic environments could affect students'

learning competence which could suggest a better acoustic environment to improve a better learning efficiency [67,68].

The type of sound related to the nature ambiance is more endorsed and has great potential for recovery enhancement effect. A review study mentioned that the sound of nature has a good impact on student performance and can be utilized to create a better classroom soundscape [69]. The sounds of nature also exert a positive influence to boost recovery from stress which was carried out on a group of participants after taking a stress test [70]. Nature sounds effectively help reduce stress and have been proven to better physiological aspects and mood responses through participants while performing an experimental task of attention [71]. Natural sound can be a therapeutic medium to help people with anxiety disorders with the proof of tranquility perceiving, emotional reactivity, and arousal indicators [72]. Auditory stimuli deliver the greatest long-term reduction in stress levels compared to visual stimuli [73].

3.1.2 Investigation of Systematic Micro-refresh Auditory Stimuli

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 [70,71,74,75]. 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.

The experiment was divided into two primary studies. Study 1 investigated the induction of auditory stimuli as a micro-refresh technique following the established timing protocol of the experiment design from the previous study. Study 2, on the other hand, focused on the effectiveness of auditory stimuli micro-refresh during prolonged work durations.

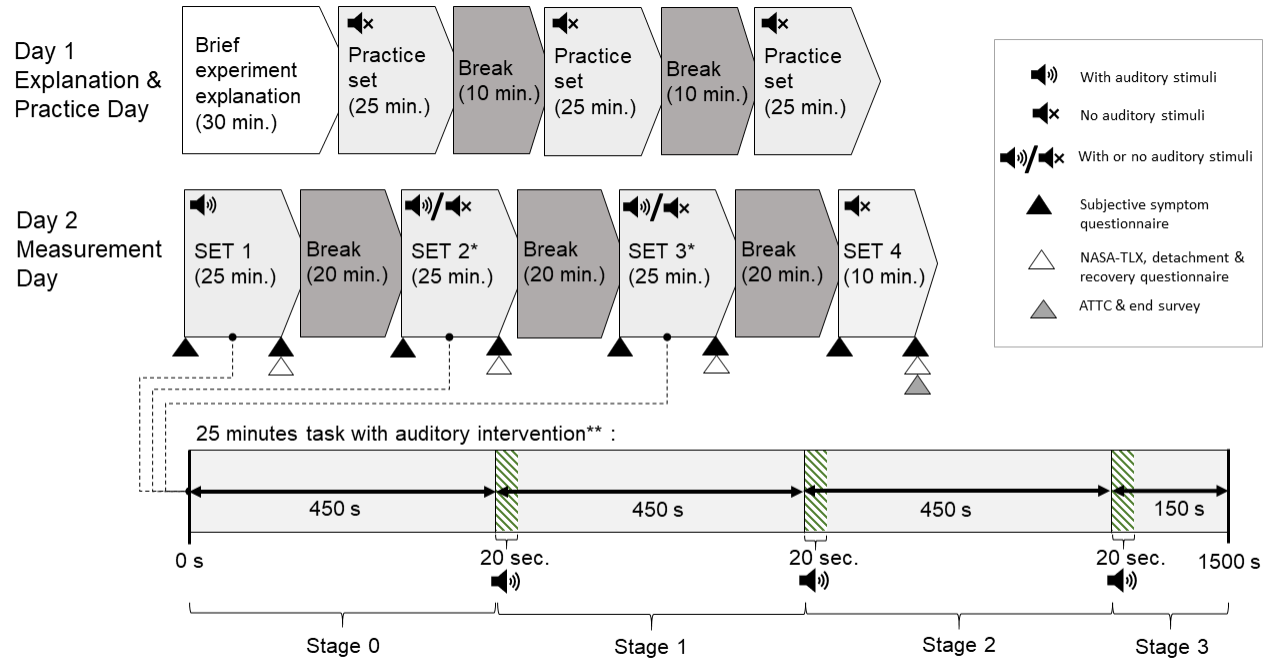
3.1.3 Methods

Experiment Procedure

In this study, repeated measures or within-group experiment design were applied. The participants performed 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 Figure 3.1. 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 a similar understanding in carrying out the experimental test and minimize the learning curve on the second day.

On the first day (i.e., practice day), at the beginning of 30 minutes, the experimenter explained the experimental procedures and the consent form to the participants. Then, simulate 3 sets of 25-minute experiment task with 10 minutes breaks in between the sets without auditory stimuli intervention. On the second day (i.e., measurement day), participants performed 4 sets of experiment tasks for 25 minutes in each set, except set 4 for 10 minutes. Twenty-minute breaks 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 were inserted. In a set with auditory stimuli intervention, the sound was played for 20 seconds every 7.5-minute intervals from the start. Thus, for the 25-minute 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) was given after each set. Lastly, the attentional control scale (ATTC) questionnaire and a survey interview were given at the end of the fourth set.



*) Auditory stimuli were appointed in a counterbalanced design for SET 2 and SET 3, and the data produced from SET 2 and SET 3 were used in the analysis.

**) Three 20-second auditory stimuli were administered at 7.5-minute intervals during the 25-minute cognitive task.

Figure 3.1: The illustration of the experiment design.

Auditory Stimuli in Experimental Design

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 [12].

Several elements of consideration in creating auditory stimuli as a micro-refresh are: 1) the element that signals the beginning of micro-refresh; 2) the element that promotes relaxation feeling; and 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 [76]. 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 [77]. The auditory stimuli were played using the speaker [78]. There are four speakers placed in the corner of the experiment room. To create a monaural sound reproduction, an amplifier is utilized [79] and connected to a PC via a mixer audio interface [80].

The auditory stimuli were played for 20 seconds 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 minutes, there will be three times auditory stimuli inserted and given every 7.5-minutes. The duration of stimuli playback and intervals are adopted from previous methodological designs associated with the micro-refresh [9, 19].

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.

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. [52] 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 [53] and run on an iPad [81]. The answering time for each task was automatically recorded in the experiment program in a *.csv* format.

Experiment Environment

The experiment was carried out in an experiment room at the Graduate School of Energy Science, Kyoto University. Figure 3.2 shows its layout. The room temperature was adjusted around $23 \pm 2^\circ\text{C}$ and the humidity level around 50%–60%. 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.

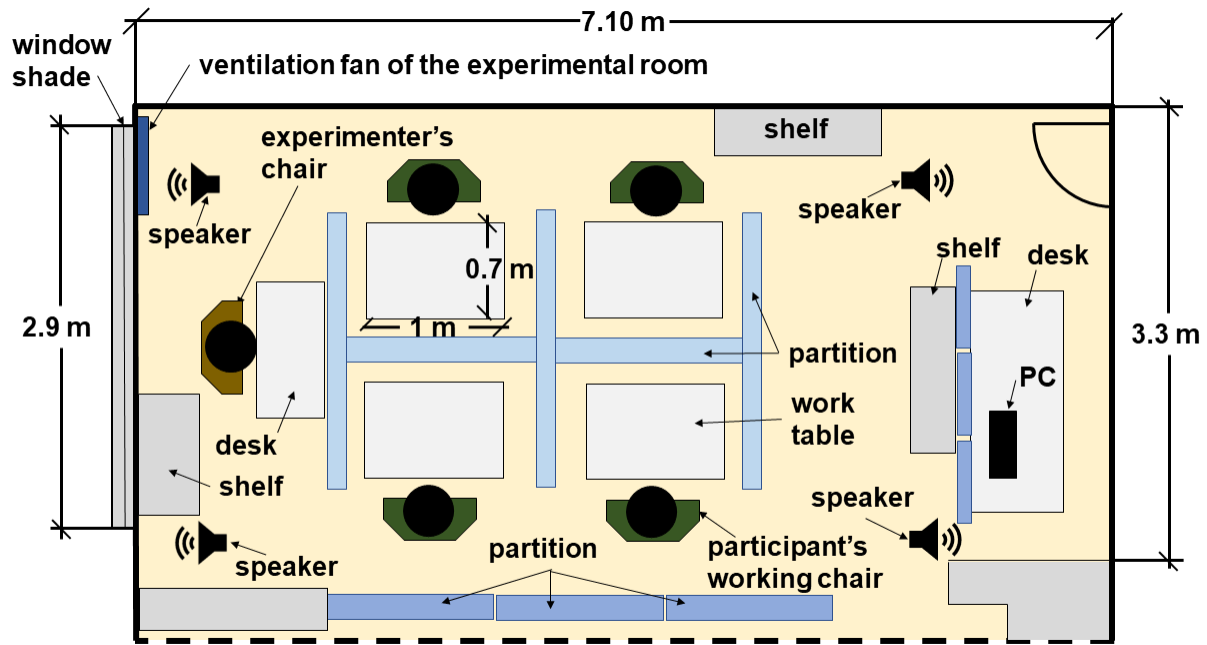


Figure 3.2: Layout of the experiment room.

3.1.4 Outcome Measurement

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-minute tasks. The answering time for one question was constituted since the task' question appeared on the screen until the participants answered that question by touching the screen in the specific designated answering box on the screen.

Concentration Time Ratio (CTR)

The concentration time ratio is a quantitative measurement approach of the proportion of actual time used to devote concentration while working on a task compared to the total time to complete the task [5–7]. The time of concentration that is dedicated is attained by

calculating the average response time when people are 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) [7] are 1) CTR is less altered to learning effect due to its proportions measurement approach among actual concentration time toward 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 percentage of the CTR score indicates that the concentration phase is becoming more dominant during the total time span to complete the task.

Error Rate

The error rate is one of the important considerations when evaluating human performance that could indicate the influence of interventions [82]. 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 [82].

NASA Task Load Index (NASA-TLX)

The NASA task load index is a pluridimensional scale that measures a human's workload during or after work [58]. The usage of NASA-TLX in a research field or organizational practice has been proven to be quite robust [56]. 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) [58]. In this study, we adopted the NASA-TLX questionnaire to measure the subjective mental workload of the participants after performing the task under a condition with and without auditory 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.

Subjective Symptoms Questionnaire

The subjective symptoms questionnaire is a questionnaire to measure fatigue feelings developed by the Industrial Fatigue Research Group of the Japan Society for Occupational Health [55]. The questionnaire consists of five factors (drowsiness feeling, instability, unease feeling, dullness feeling, and eyestrain), each represented in five questions. In total, there are twenty-five questions listed in the subjective symptoms questionnaire. The answer 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). Subjective symptoms were used in this study to understand the feeling of physical symptoms of the participants that appeared before and after performing the task according to the self-report rating.

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 [83]. 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, each question with an answer rated on a five-point Likert scale from “not happening at all” (1 point) to “very much happening” (5 points). The detachment and recovery questionnaire was questioned post set 1, set 2, set 3, and set 4.

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 [84]. 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 [85–88]. The results of the ATTC questionnaire will complement the descriptive statistics of the potential ability of the participants to control their attention.

3.1.5 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 [19] where a value below 40% indicates that those participants did not carry out the task earnestly, 4) the difference of CTR score between two sets with and without auditory stimuli intervention was falling 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 [89]. 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 concerning 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 seconds). Stage 1, stage 2, and stage 3 are periods when the participants perform the task at 451–900 seconds, 901–1350 seconds, and 1350–1500 seconds respectively. Subsequently, the paired t-test was used to analyze the response difference of the 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.

3.1.6 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.

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, $F(3, 25992) = 52.25$, $p < 0.001$. However, there was no significant difference in the intervention (with and without the auditory stimuli), $F(1, 25992) = 1.83$, $p = 0.176$, nor a significant interaction between intervention and stage, $F(3, 25992) = 1.12$, $p = 0.338$. The *t-test* revealed no significant difference in answering time between the groups whose auditory stimuli presented in SET 2

and SET 3 ($p = 0.648$), indicating that the order of auditory presentation did not affect the answering time performance. Figure 3.3 shows the graph of the average answering time in each stage between conditions with and without the auditory stimuli intervention.

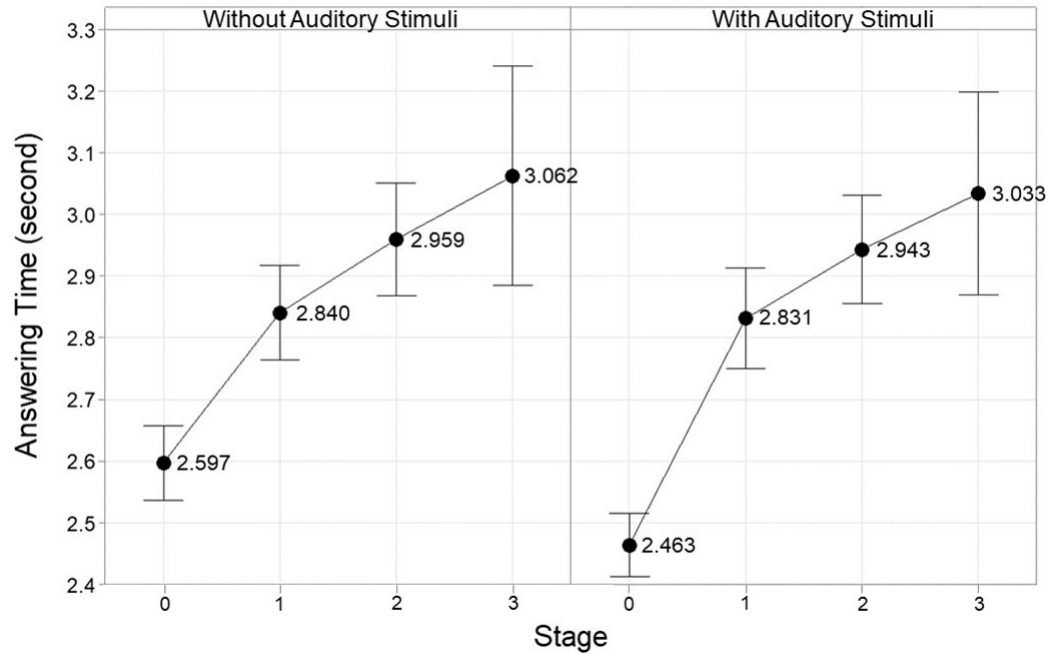


Figure 3.3: The answering time between conditions without auditory stimuli and with auditory stimuli.

Concentration Time Ratio (CTR)

An independent sample *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 ($M = 62.27$, $SD = 11.97$). The results revealed no significant difference between the groups, $t(47) = -0.22$, $p = 0.828$, *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 ($p = 0.261$), indicating that the order of auditory presentation did not affect the CTR performance. Figure 3.4 shows the graph

of the average CTR score between conditions with and without the auditory stimuli intervention.

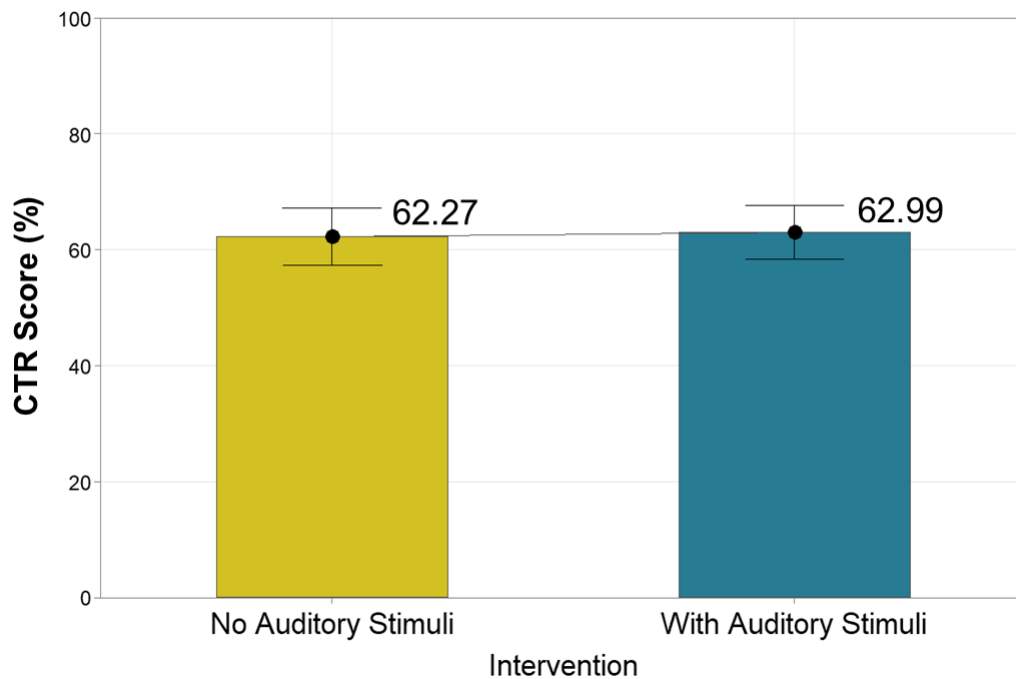


Figure 3.4: The concentration time ratio (CTR) between conditions without auditory stimuli and with auditory stimuli.

Error Rate

A statistical analysis *t-test* was conducted to compare the error rate between the no auditory stimuli condition and the under auditory stimuli condition. The results revealed no significant difference between the groups, $t(46) = 0.13$, $p = 0.894$, *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 ($M = 7.60$, $SD = 8.08$).

Subjective Ratings

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, $t(46) = 0.03$, $p = 0.973$, *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.

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 0–1 to equalize the magnitudes on each subscale as shown in Figure 3.5. 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, $F(1, 96) = 4.78$, $p = 0.031$. However, there was no significant effect of the intervention, $F(1, 96) = 2.03$, $p = 0.157$, nor a significant interaction between intervention and questionnaire time, $F(1, 96) = 0.07$, $p = 0.794$. The fatigue subscale exposed a significant effect of questionnaire time, $F(1, 96) = 20.38$, $p < 0.001$. However, there was no significant effect of the intervention, $F(1, 96) = 0.01$, $p = 0.903$, nor a significant interaction between intervention and questionnaire time, $F(1, 96) = 0.17$, $p = 0.678$. The haziness subscales statistical analysis results showed a significant effect of questionnaire time, $F(1, 96) = 4.07$, $p = 0.047$. However, there was no significant effect of the intervention, $F(1, 96) = 0.01$, $p = 0.970$, nor a significant interaction between intervention and questionnaire time, $F(1, 96) = 0.02$, $p =$

0.902. A statistical analysis indicated the non-significant effect of questionnaire time on the sleepiness subscale, $F(1, 96) = 2.03, p = 0.157$. Additionally, neither intervention ($F(1, 96) = 0.04, p = 0.833$) nor the interaction between intervention and questionnaire time ($F(1, 96) = 0.1, p = 0.758$) had a significant effect on the sleepiness subscale. A significant effect was revealed on the sluggishness subscale for the questionnaire time factor, $F(1, 96) = 3.79, p = 0.054$. On the other hand, neither the intervention factor ($F(1, 96) = 0.12, p = 0.727$) nor the interaction between intervention and questionnaire time ($F(1, 96) = 0.21, p = 0.647$) had a significant effect on the sluggishness subscale. Table 3.1 shows the ANOVA analysis for each subscale of the subjective symptoms questionnaire.

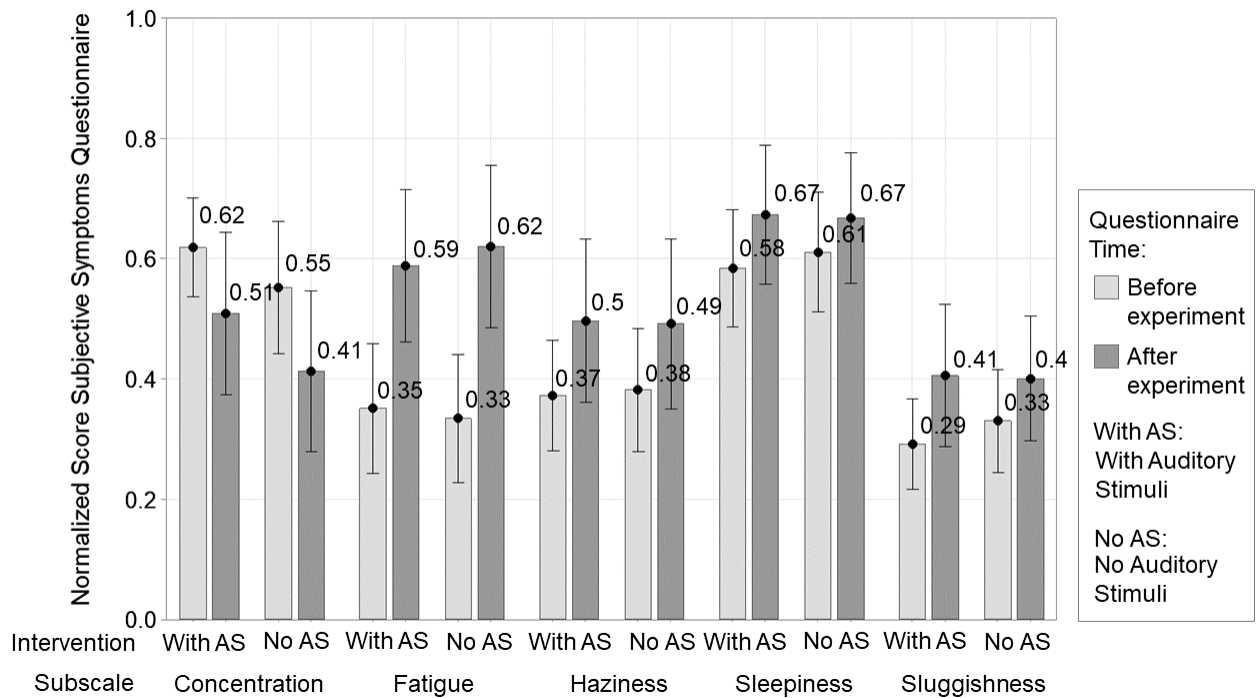


Figure 3.5: The normalized score of subjective symptoms questionnaire.

Detachment and Recovery Questionnaire

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

Table 3.1. The ANOVA analysis for each subscale of the subjective symptoms questionnaire.

Subscale	Factor	<i>p-value</i>
Concentration	Intervention	0.157
	Questionnaire Time	0.031*
	Intervention*Questionnaire Time	0.794
Fatigue	Intervention	0.903
	Questionnaire Time	< 0.001***
	Intervention*Questionnaire Time	0.678
Haziness (Blurriness)	Intervention	0.970
	Questionnaire Time	< 0.047*
	Intervention*Questionnaire Time	0.902
Sleepiness	Intervention	0.833
	Questionnaire Time	0.157
	Intervention*Questionnaire Time	0.758
Sluggishness	Intervention	0.727
	Questionnaire Time	0.054
	Intervention*Questionnaire Time	0.647

(*: $p < 0.05$, ***: $p < 0.001$)

Intervention: With auditory stimuli, Non-auditory stimuli

Questionnaire: Pre-experiment, Post-experiment

conditions, $t(47) = -0.44$, $p = 0.661$, 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 ($M = 3.16$, $SD = 0.25$). Figure 3.6 shows the score of the average detachment ratings between conditions with and without auditory stimuli intervention.

Recovery

A statistical analysis *t-test* was conducted to compare 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, $t(47)$, $p < 0.005$, *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

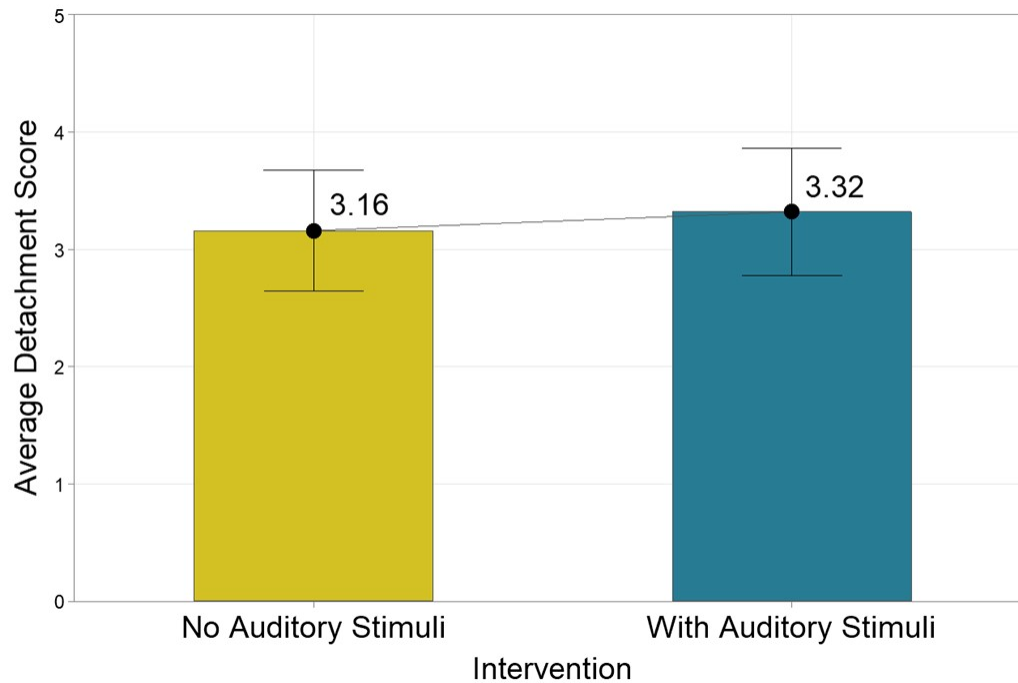


Figure 3.6: The detachment score between conditions without auditory stimuli and with auditory stimuli.

with auditory stimuli. Figure 3.7 shows the graph of the average recovery score between conditions with and without the auditory stimuli intervention.

Attentional Control Scale (ATTC)

The results of the ATTC questionnaire total score resulted in 17 out of 25 participants, having a score between 20–50 (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%) gained a score between 9–22 and classified into medium focusing score range, while the rest 16 participants (64%) laid above 22 and thus fell into the high focusing score range. Additionally, 17 participants got scores between 11–27 of the ATTC shifting, which can be classified as medium shifting

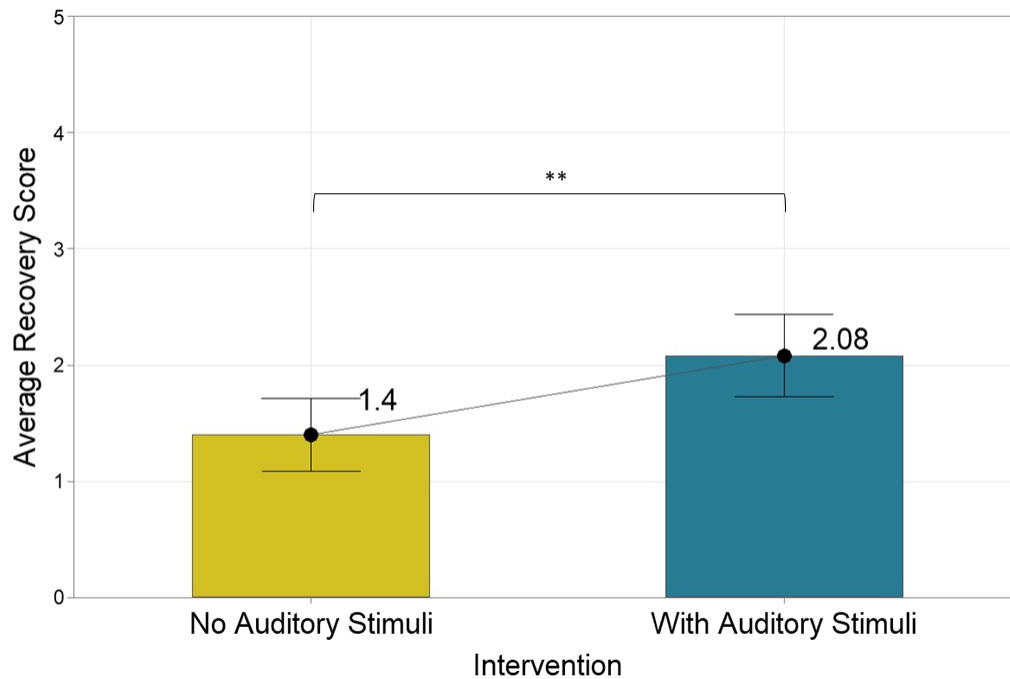


Figure 3.7: The recovery score between conditions without auditory stimuli and with auditory stimuli. A significant statistical difference is shown in this figure $**p < 0.01$.

score. Lastly, eight participants scored above 27 for the ATTC shifting and were categorized as high shifting score.

3.1.7 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 seconds at each 7.5-minute 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 [19] 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 previous research findings [71], 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 seconds 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 [74, 90, 91]. Additionally, the brief 25-minute 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 minutes 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 [92]. 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 [12]. 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 [65]. 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 previous studies [71,72], 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 previous study [93], 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 the previous study [93] 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 [94]. These stimuli may reduce stress by promoting relaxation and emotional regulation, which aligns with current findings, potentially leading to improved cognitive function [90] and reduced feelings of overwhelm. Additionally, auditory stimuli of nature's sounds have been shown to enhance mood by evoking positive emotions [91] which is also similar to current findings of subjective response and the potential to reduce anxiety and depression [72].

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. Previous studies 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 [95]. 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 seconds every 7.5 minutes for a total of 25 minutes 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 [96]. 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 [97, 98]. 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 [99] and nature-based stimuli [100].

Additionally, each individual might have a different sound preference which then can build an association of a favorite place or destination. As mentioned by a previous study [101], 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 [102, 103]. 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.

3.1.8 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.

3.2 Study 2: Effect of Systematic Micro-refresh Auditory Stimuli on 45 Minutes Intellectual Work

3.2.1 Introduction

In today's taxing work environment requiring intensive attention, recovery strategies during working hours are necessary to maintain workers' productivity and preserve their well-being. Previous studies described recovery as "a process of psychophysiological unwinding after effort expenditure", which is a key intermediary between the stress mechanism and a worker's health over an extended period [104]. Deficiency in recovery during working hours (i.e., internal recovery) then leads to the necessity of recovery after work (i.e., external recovery) [104]. Previous studies mentioned in the research through path analysis methods that strong evidence for their theoretical model proposes that recovery experiences have distinct positive influences on job and health outcomes [105].

The important factor in effective recovery during working hours is ensuring that workers can detach themselves from the work stressors. If not, there is a risk that workers will fall into the condition of affective rumination, which a previous study mentioned as a key predictor that causes the escalation of exhaustion over an extended period [106]. Previous work mentioned, "affective rumination refers to pervasive, recurrent negative thoughts about work", and in their study, they found a strong link between affective rumination and burnout [107]. Affective rumination, a form of perseverative cognition where a person ponders on anxieties and distressing feelings, is a thriving interest in mental and physical health [108].

Incorporating the principle of biophilics in the work environment has become a promising and recommended way to tackle the negative consequence of affective rumination. The biophilic concept adopts some natural elements approach (e.g., nature visualization, nature ambiance, nature vegetation, nature audio) to create an atmosphere that evokes positive emotional feelings that could support restorative practices [109–113]. The calm-

ing effect of nature, evident in both visual and auditory, is expected to enhance well-being through arousal reduction [114]. Through their empirical study, previous studies mentioned several cognitive advantages of embracing the natural world and discussed several theories that explain the natural environment effects [115]. Additionally, it noted some features that substantially could affect people's evaluation of how natural environments are perceived, such as minimum color saturation, fewer hues, and non-linear edges for visual features and spectral entropy, prominent frequency, noisiness for acoustic features [115].

Biophilic concepts can be implemented in real or virtual environments, and biophilic adoption results in positive physiological and psychological impacts compared to non-biophilic environments [116]. Additionally, previous work found that immersive virtual environments with biophilic enforcement were shown as effective as real-nature environments in reducing negative mood despite no similar effect being found in the case of other psychological parameters (i.e., positive affect, visual working memory, and stress level) [117]. Moreover, an immersive virtual environment can replace in-person nature experiences when circumstances prevent real-world contact with nature [118].

Research on biophilics has mainly focused on visuo-spatial aspects (e.g., nature visualization, dynamic video content, digital display). However, the experience of nature goes beyond just sight, and paying attention to other senses is worth considering. Beyond sight, previous work of study highlight the importance of non-visual factors in biophilic design, measuring their effect on various facets of human performance and well-being [109]. Additionally, considering non-visual stimuli such as sound could help individuals with visual impairment benefit from a restoration experience through the constructed natural environment [119,120]. Moreover, sound elements can be a valuable medium for visually demanding tasks such as screen-based tasks to promote restorative experience and well-being without altering visual attention.

Fields of study related to sound and acoustics frequently utilize soundscapes broadly. Based on the International Organization for Standardization (ISO) in Acoustic Sound-

scape Part 1: Definition and Conceptual Framework, the soundscape is defined as an “acoustic environment as perceived or experienced and understood by a person or people, in context”. Additionally, soundscape perception is demonstrably influenced by contextual factors [121]. According to ISO [121], these factors include: “(1) the auditory sensation, (2) the interpretation of auditory sensation, and (3) the responses to the acoustic environment.” The World Health Organization (WHO) also mentioned the soundscape importance concerning health perspective and noise from the environment [122].

Nature’s Sound Stimulus

Modern urban living and work environments make it difficult to contact with the natural environment directly. Armed with a background that highlights the importance of the restorative power of nature to human well-being, previous studies have tried to answer the challenges of the urban work environment by bringing the concept of nature into it. One of the mediums utilized is the nature sounds stimulus to promote a stimulating restorative effect toward individuals.

Previous work of study mentioned that not all nature’s sounds are perceived as pleasurable [123]. Nonetheless, several nature sounds could bring tranquility and pleasantness, such as sounds of water, birdsongs, and wind. Previous literatures identified the critical natural elements (i.e., biotic and abiotic) that shape natural land-based soundscapes based on a source-filter model to specify sound generation (i.e., sources), how sound travels (i.e., propagation), and how we perceive it (i.e., receivers) [128]. Additionally, functional block diagram analysis from the previous work led to a categorization of soundscapes into three types: distal (i.e., distant sounds), proximal (i.e., nearby sounds), and perceptual or how we experience the soundscape [128].

Nature sounds could boost the immersive feeling of a natural environment through the artificial setting area (e.g., workplace, residency) and enhance positive valuation [123]. Perceptions of bird sound that correlate to positive appraisals, restoration feeling possibility, and detachment feeling correlate to several strong predictors (i.e., sound level,

frequency, harmony, aesthetics equity of familiarity, pattern, and complexity) [95]. Previous literature mentioned that water soundscapes categorized as low and high-decibel offer distinct benefits [125]. High-decibel sounds have a more significant physiological impact, while low-decibel sounds provide more psychological advantages. Additionally, in an actual environmental study, the sounds of birds and water substantially lower the perceived loudness of traffic [126]. Previous work of study found that nature's sounds of fountains and tweeting birds help individuals recover from stress observed in participants' skin conductance levels, which returned to normal faster after exposure to nature sounds [127].

Despite the growing studies in biophilic design and soundscapes for improving human well-being, research on their combined effects, specifically in work environments, still needs to be conducted. A key question is whether nature's sound stimulus can enhance or hinder workers' performance. This study addresses this gap by examining how incorporating biophilic design elements alongside a specific nature's sound stimulus can influence workers' intellectual work and subjective assessment.

Study 2 extended the duration of the cognitive task to 45 minutes to investigate the potential impact of systematic micro-refresh auditory stimuli on prolonged cognitive performance. By increasing the task duration, we hypothesized that participants would experience increased fatigue, making the benefits of auditory interventions more pronounced. Additionally, we adjusted the frequency of micro-refresh interventions to optimize their effectiveness within the extended timeframe. The specific modifications to the intervention protocol will be detailed in the subsequent methodology section.

3.2.2 Methods

Experimental Procedure

In study 2, the experiment was designed to assess the impact of auditory stimuli on cognitive performance over an extended duration. A controlled laboratory experiment was

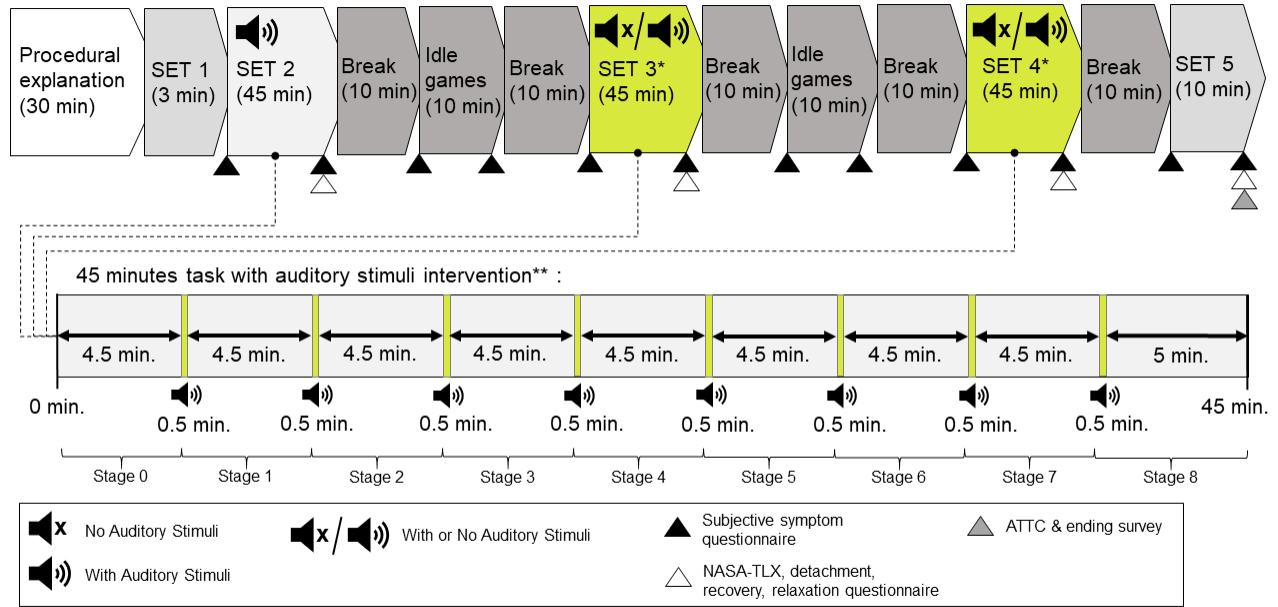
conducted with a within-group experiment design adopted. Two experiment conditions are being set: the control condition (i.e., no nature sound stimulus applied) and the treatment condition (i.e., nature sound stimulus played in the middle of task work).

Each consecutive task completion was considered a 'SET'. Five sets were conducted throughout the experiment. The experiment begins with a brief explanation of the procedure, which lasts around thirty minutes. After the explanation, participants completed a three-minute practice task (SET 1). Continued SET 1, participants engaged in a forty-five-minute task (SET 2) aimed to familiarize them with the main tasks and duration of the task, also minimize potential learning effects. Following the completion of SET 2, a 10-minute break was implemented, followed by a 10-minute idle game session to mitigate boredom during the experimental sequence. Subsequently, another 10-minute break was provided. Following the break, SET 3 commenced, lasting for 45 minutes. This was followed by another 10-minute break, an idle game session, and another 10-minute break. SET 4, also lasting 45 minutes, was initiated after the preceding break. A final 10-minute break was provided before concluding the experiment with SET 5. To minimize the potential impact of ordering effects, a counterbalanced design was implemented for SETs 3 and 4. This involved alternating the presentation of nature's sound stimulus between the two sets. Consequently, only the data from SETs 3 and 4 were included in the subsequent analysis.

Nature's sound stimuli were presented for 30 seconds during each micro-refresh intervention, which was integrated into the 45-minute cognitive task. This resulted in eight nature sound stimuli presentations per task set, occurring approximately every 4.5 minutes. The illustration of the experiment design in Study 2 is shown in Figure 3.8.

Auditory Stimuli in Experimental Design

In this study, micro-refresh is represented as a sound stimulus for a short period during the work. Sound stimuli chosen as micro-refreshers have nature's elements. Adopting nature's elements as a sound stimulus has the objective of creating a restored feeling,



*) Auditory stimuli were appointed in a counterbalanced design for SET 3 and SET 4, and the data produced from SET 3 and SET 4 were used in the analysis.
 **) Eight 30-second auditory stimuli were administered every 4.5-minute during the 45-minute cognitive task.

Figure 3.8: Illustration of the experiment design.

which is conveyed by the attention restoration theory (ART) [12] and stress reduction theory (SRT) [65]. This approach is relatively modest to implement, yet it carries a potential way to deliver the elements of a restorative nature and is expected to enhance work performance.

In selecting the type of nature sound as a micro-refresher, several considerations are applied as follows: 1) the elements to be played should indicate a signal of the starting point when the micro-refresh begins; 2) the restoration elements can be aroused when the sound stimuli are sounded; 3) the elements played should indicate a signal of the finishing point (i.e., the end of the micro-refresh). Besides considering the former elements, the typical nature's sound elements could be biotic and abiotic [128]. Combining the sound elements of biotic and abiotic nature is better for representing the more comprehensive nuances of the natural environment. Thus, the sound stimuli appear as the sound of seagulls chirping and the waves sound so that it brings the shore ambiance.

Auditory stimuli were generated using Studio One 5 Professional (version 5.5.2.86528) on a Mac operating system [76]. The stimuli consisted of a combination of copyright-free sound sources in the software. The sound pressure level was set at 42 dBA, considered appropriate for indoor environments [77]. The auditory stimuli were delivered through Dali Zensor 1 speaker [78], with four speakers strategically placed in the corners of the experiment room. An amplifier [79] was connected to a PC via a Yamaha AG06MK2 audio interface to ensure monoaural sound reproduction.

Participants

A total of ten Kyoto University students (aged 19–25, $M = 22.4$, $SD = 2.3$) participated in this study. The participants were comprised of seven males and three females. Each participant completed both conditions (with and without auditory stimuli) during a 45-minute cognitive task for each condition, resulting in a total of 14715 answering data points from 10 participants. A power analysis using G*Power, with an alpha level of 0.05, effect size of 0.1, and a desired power of 0.8, indicated that the sample size was sufficient. This suggests that the study had adequate statistical power to identify significant differences between the two conditions (with and without auditory stimuli). Before the experiment, all participants provided informed consent, ensuring the confidentiality of their data. Only anonymized data was used in the analysis, and ethical approval was obtained from the Graduate School of Energy Science Ethics Committee at Kyoto University.

Cognitive Comparison Task

Participants were required to answer questions within a predetermined timeframe, following established experimental procedures. The comparison tasks used in this study were adapted from previous study [52]. These tasks presented participants with two items for comparison: two words and two numbers. The comparison tasks were de-

veloped using JavaScript [53] and administered on iPads [81]. The experiment program automatically recorded the time to answer each question in a *.csv* format.

Experiment Environment

The experiment was conducted in a dedicated room at the Graduate School of Energy Science, Kyoto University. The room was maintained at a comfortable temperature of $23 \pm 2^{\circ}\text{C}$ and a humidity level of 50%–60%. The CO_2 levels were kept below 1000 ppm to ensure optimal air quality. Participants sat at individual workstations, each equipped with a table and iPad. Partitions were placed between participants to minimize distractions. Four speakers were strategically positioned in the corners of the room. The ventilation fan was turned off during the cognitive comparison task to reduce background noise, and it was maintained below 40 dBA throughout the experiment.

3.2.3 Outcome Measurement

Answering Time

Performance in the comparison tasks was evaluated based on answering time. The experiment program automatically recorded the time taken to answer each question, from the moment the question appeared on the screen until the participant selected the correct answer by touching the designated area.

Concentration Time Ratio (CTR)

The concentration time ratio (CTR) is a quantitative measure that assesses the proportion of time devoted to concentration during a task [5–7]. It is calculated by multiplying the average answering time during periods of concentration by the number of questions answered. CTR is expressed as a percentage, with 0% indicating no concentration and higher percentages indicating greater concentration. Unlike other measures, CTR is less susceptible to learning effects due to its focus on the proportion of time spent in con-

centration [7]. Additionally, CTR indirectly reflects intellectual productivity, considering both knowledge processing and time, rather than solely measuring speed. An increase in CTR indicates that concentration is becoming more prominent during the task.

Error Rate

The error rate is a crucial metric for evaluating human performance, as it can indicate the impact of interventions [82]. Error rate is essential for assessing task performance, identifying areas for improvement, enhancing intervention effectiveness, and ensuring transparency regarding ease of use [82]. In this study, error rate was measured to evaluate the accuracy of participant performance in conditions with and without nature's sound stimuli.

Subjective Ratings

NASA Task Load Index (NASA-TLX)

The NASA Task Load Index (NASA-TLX) is a multidimensional scale used to assess human workload during or after tasks [58]. The NASA-TLX has been widely adopted in research and organizational settings due to its robustness [56]. The NASA-TLX questionnaire consists of six subscales: Effort (EF), Frustration Level (FL), Mental Demand (MD), Physical Demand (PD), Overall Performance (OP), and Temporal Demand (TD) [58]. The NASA-TLX was administered in this study to measure participants' subjective mental workload after they completed the task under both auditory stimuli and no auditory stimuli conditions.

Subjective Symptoms Questionnaire (SSQ)

The Subjective Symptoms Questionnaire (SSQ) is a validated tool developed to assess fatigue [55]. The SSQ consists of five factors: drowsiness, instability, uneasiness, dullness, and eyestrain. Each factor is measured using five Likert-scale items, resulting in a total

of 25 questions. In this study, the SSQ was administered pre- and post-task to measure participants' self-reported physical symptoms. Responses were rated on a 5-point Likert scale ranging from "strongly disagree" to "strongly agree". The SSQ data was used to understand participants' subjective experiences of fatigue and discomfort before and after performing the task.

Detachment Recovery Relaxation (DRR) Questionnaire

This study hypothesized that nature's sound stimuli could serve as a micro-refresh intervention, influencing work performance. Previous research suggests that sound can induce alertness, potentially altering cognitive performance or evoking feelings of refreshment. Previous studies identified four key psychological elements of recovery: detachment, relaxation, mastery experiences, and control during leisure [129]. Given the systematic nature of our sound stimuli and the experimental task design, it was anticipated that psychological detachment and relaxation might be the primary mechanisms underlying recovery.

To measure detachment, recovery, and relaxation experiences, a questionnaire was administered after each set (1, 2, 3, and 4). The questionnaire consisted of two items, each rated on a 5-point Likert scale from "not happening at all" to "very much happening". These items assessed the extent to which participants felt detached and experienced relaxation during the micro-refresh intervals.

Attentional Control Scale (ATTC)

The Attentional Control Scale (ATTC) is a self-report measure designed to assess an individual's ability to control their attention, which can influence information processing [84]. The ATTC consists of twenty questions categorized as either attentional shifting or attentional focusing. Each question is rated on a 4-point Likert scale from "almost never" to "always".

The ATTC has demonstrated reliability in measuring attentional control across various age groups and backgrounds [85–88]. In this study, the ATTC results will provide valuable insights into participants’ attentional control abilities, complementing the descriptive statistics and further understanding their potential to effectively manage cognitive resources.

3.2.4 Data Analysis

Minitab statistical software [60] was employed to conduct a comprehensive statistical analysis of the quantitative data. The *ANOVA* methods were applied to the answering time raw data after a *Box-Cox* transformation. The *paired t-test* was utilized to analyze the response difference of concentration time ratio (CTR) and error rate. A non-parametric test (i.e., *Mann-Whitney U test*, *Kruskal-Wallis test*) is utilized to analyze the 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. Data cleaning procedures excluded participants who met any of the following criteria: misunderstood instructions, missed one or more sessions, had a CTR score below 40% [19], or exhibited a CTR difference between conditions that fell outside of a predetermined threshold (5%). These exclusion criteria were implemented to minimize bias and the risk of Type I errors [89].

The independent variables in this study were intervention (with or without nature’s sound stimuli) and stage. The stage was divided into nine levels: Stage 0 (0–270 seconds), Stage 1 (271–570 seconds), Stage 2 (571–870 seconds), Stage 3 (871–1170 seconds), Stage 4 (1171–1470 seconds), Stage 5 (1471–1770 seconds), Stage 6 (1771–2070 seconds), Stage 7 (2071–2370 seconds), and Stage 8 (2371–2770 seconds). The stages were divided based on the timing of nature’s sound stimuli presentation.

3.2.5 Results

The results from 10 participants recruited in this study are shown below. The results show from the analysis of the average answering time between each stage in conditions with and without the sound stimuli, the average concentration time ratio (CTR), the average error rate, the subjective ratings of NASA task load index, the detachment and recovery questionnaire, the attentional control scale and post-experiment interview.

Answering Time

The *Anderson-Darling* test indicated a non-normal distribution of answering time data both in the dataset in the control condition and the dataset under nature's sound stimuli condition ($p < 0.005$). The *Levene's* test confirmed the homogeneity of variance ($p = 0.726$). Statistical analysis of variance (ANOVA) was applied after the *Box-Cox* transformation data with approximately equal to -0.84. A significant main effect of auditory stimuli intervention on answering time was observed ($p < 0.001$). Additionally, a significant interaction between auditory stimuli and experimental stages was found ($p < 0.001$). *Bonferroni post-hoc* tests revealed that the interaction effect was primarily driven by differences at stages 0–stages 6 ($p = 0.013$), stages 0–stages 8 ($p = 0.006$), stages 1–stages 8 ($p = 0.042$) under the auditory stimuli condition. Furthermore, significant differences emerged between stages 6, 7, and 8 when comparing the control condition (without auditory stimuli) to the auditory stimuli condition. Specifically, participants in the auditory stimuli condition exhibited significantly faster response in answering time at stages 6, 7, and 8 compared to those in the control condition. The details of significant differences between stages in the control condition and stages in auditory stimuli condition are non-stimuli stage 6–with stimuli stage 6 ($p = 0.027$), non-stimuli stage 7–with stimuli stage 6 ($p = 0.001$), non-stimuli stage 8–with stimuli stage 6 ($p = 0.015$), non-stimuli stage 7–with stimuli stage 7 ($p = 0.015$), non-stimuli stage 6–with stimuli stage 8 ($p = 0.013$), non-stimuli stage 7–with stimuli stage 8 ($p < 0.001$), and non-stimuli stage 8–with stimuli stage 8 ($p = 0.007$). Figure 3.9 illustrates these findings graphically.

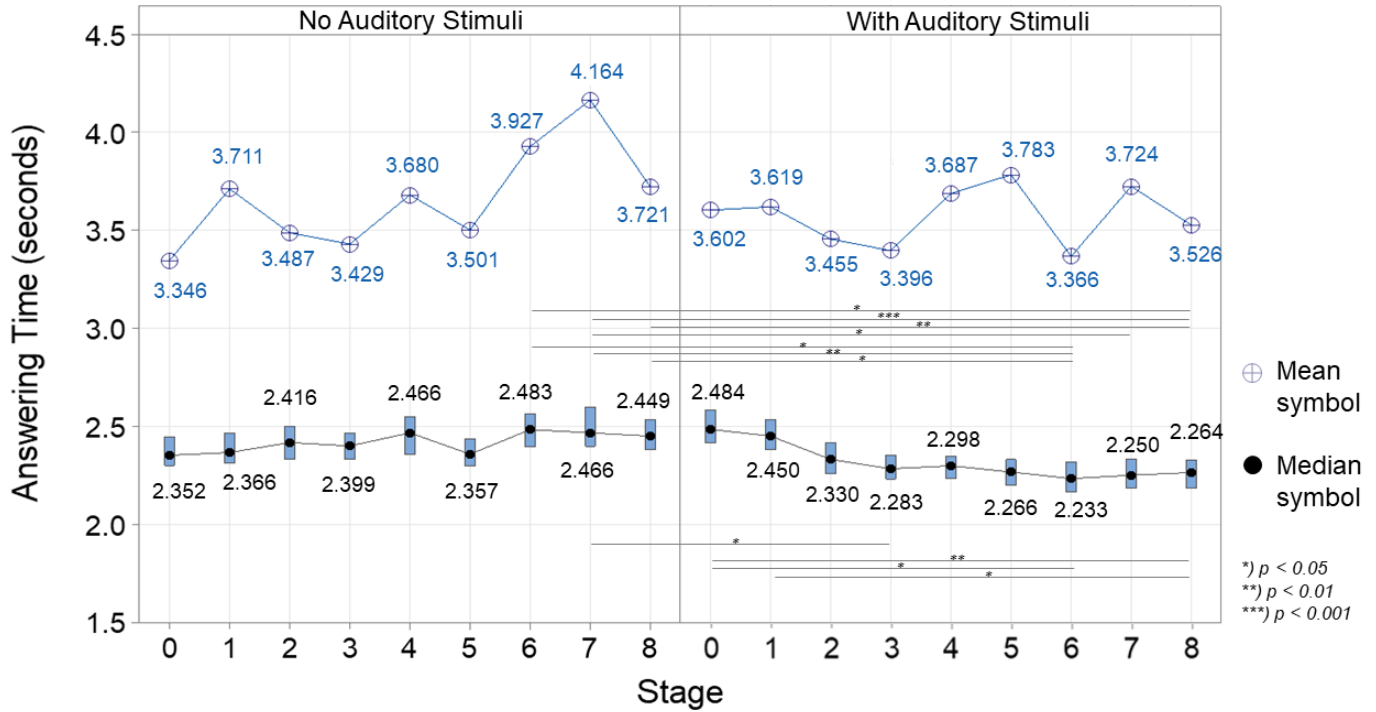


Figure 3.9: The mean and median of answering time in each stage between conditions with and without the auditory stimuli. A statistically significant difference is shown in this figure $*p < 0.05$, $**p < 0.01$, $***p < 0.001$.

Concentration Time Ratio (CTR)

The *Anderson-Darling* test revealed a non-normal distribution of the CTR dataset in the control condition ($p = 0.18$). The *Levene's* test confirmed the homogeneity of variance ($p = 0.464$). The non-parametric test *Mann-Whitney U* test revealed no significant difference in CTR between the control condition and under nature's sound stimuli condition ($p = 0.791$). Figure 3.10 shows the CTR score between conditions with auditory stimuli and control conditions.

Error Rate

The *Anderson-Darling* test revealed a normal distribution of error rate in both groups with and without auditory stimuli intervention ($p = 0.07$ and $p = 0.74$). The *Levene's* test resulted

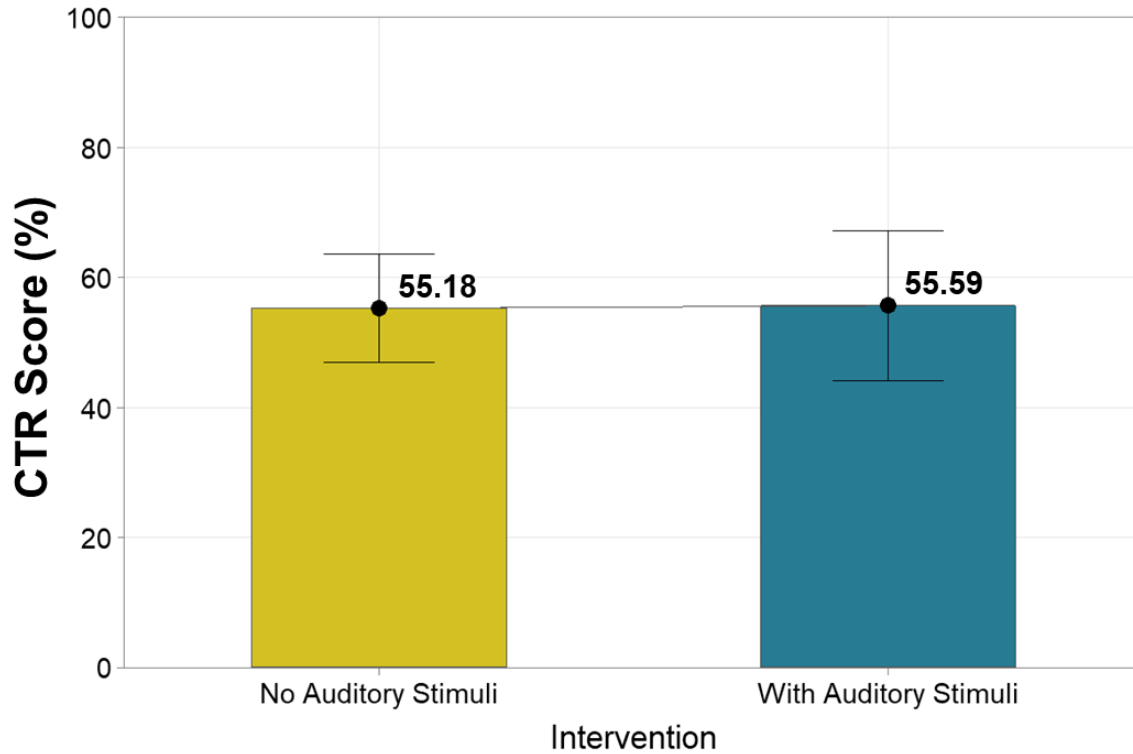


Figure 3.10: The CTR score between conditions no and with auditory stimuli conditions.

in non-homogenous variance ($p = 0.04$). The *Mann-Whitney U* test found no significant difference ($p = 0.084$) between the condition with and without auditory stimuli with effect size *Cohen's d* 0.36. Figure 3.11 shows the error rate between conditions with and without auditory stimuli.

Subjective Ratings

NASA Task Load Index (NASA-TLX)

The *Anderson-Darling* test revealed a normal distribution of NASA-TLX scores for both groups with and without auditory stimuli intervention ($p = 0.5$ and $p = 0.307$). Both groups of NASA-TLX score with and without auditory stimuli had equal variances showed by the *Levene's* test ($p = 0.762$). The parametric *t-test* found no significant difference between the control condition and treatment condition with nature's sound stimuli ($p = 0.94$). The average NASA-TLX total score in the control condition is 52.96 ± 10.3 , fol-

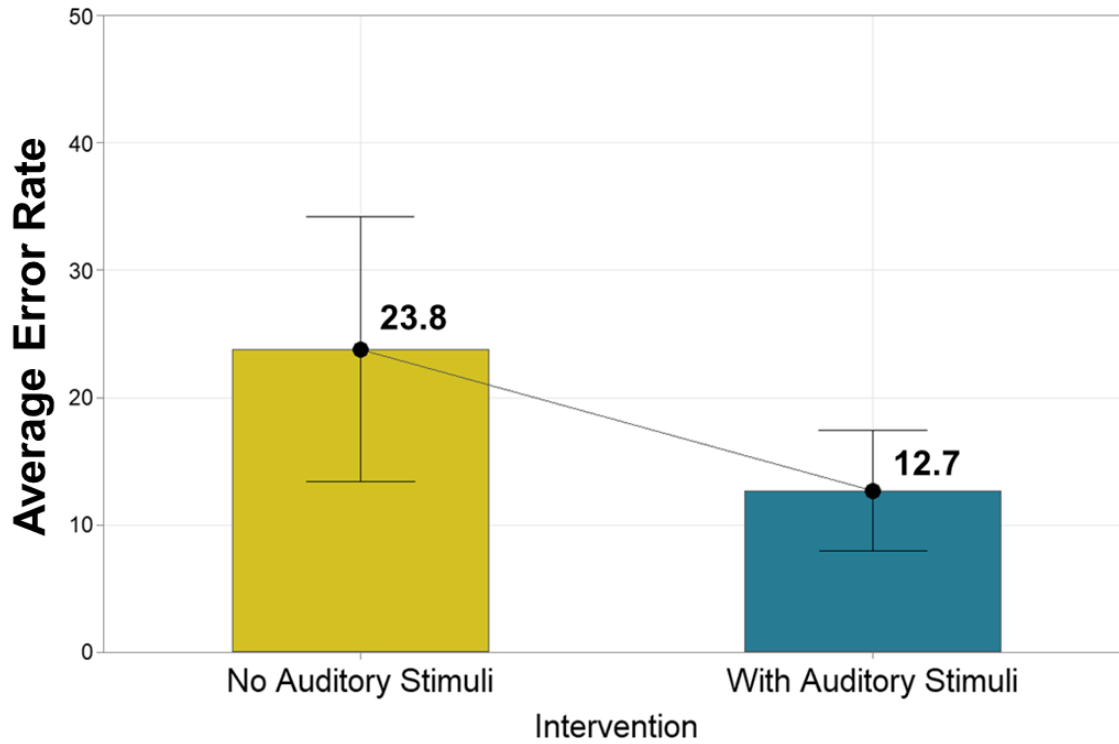


Figure 3.11: The error rate between conditions no and with auditory stimuli conditions.

lowed by the treatment condition 53.34 ± 11.5 . Figure 3.12 shows the total average score of NASA-TLX in both conditions.

Subjective Symptoms Questionnaire

The subjective symptoms questionnaire data were non-normally distributed for the concentration (C) subscale under auditory stimuli intervention post-experiment questionnaire ($p = 0.026$) and blurriness (B) subscale without nature's sound stimuli pre-experiment questionnaire ($p = 0.013$). Meanwhile, other subscales (i.e., fatigue, sleepiness, sluggishness) were normally distributed ($p > 0.05$). All the subscale scores had homogeneous variances shown by the sphericity test ($p > 0.05$). The *Kruskal-Wallis* test revealed no significant differences in concentration and blurriness subscale ($p = 0.252$ and $p = 0.921$). Furthermore, parametric test analysis of variance revealed no significant differences in fatigue (F), sleepiness (Sp), and sluggishness (Sg) subscales ($p > 0.05$). The subjective

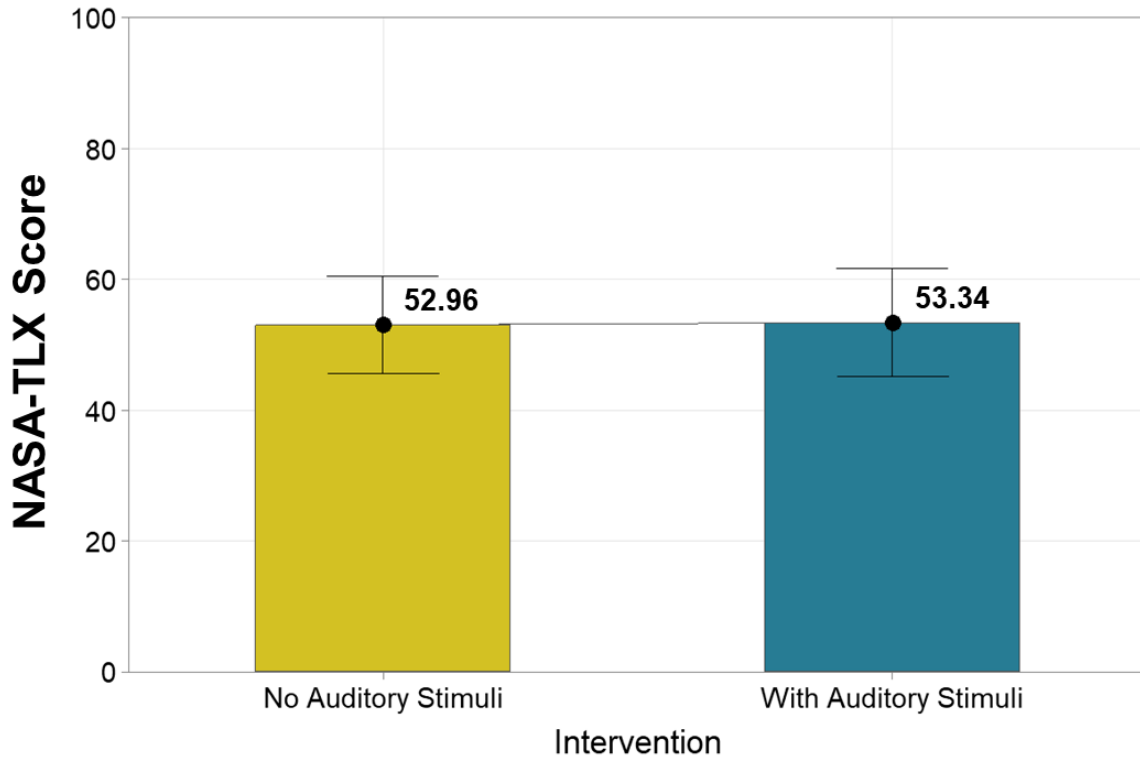


Figure 3.12: The NASA-TLX score in both conditions with and without auditory stimuli.

symptoms questionnaire score in each subscale: blurriness (B), concentration (C), fatigue (F), sleepiness (Sp), and sluggishness (Sg) is shown in Figure 3.13.

Detachment Recovery Relaxation Questionnaire

The *Anderson-Darling* test revealed non-normally distributed data among detachment, recovery, and relaxation scores ($p < 0.05$). The sphericity test revealed non-homogeneous data of recovery score ($p = 0.044$), meanwhile detachment score and relaxation score were classified as homogeneous data ($p = 0.217$ and $p = 0.172$). The *Mann-Whitney U* test revealed a significant difference in detachment, recovery, and relaxation scores with significant differences in the *p-values* respectively $p = 0.013$, $p = 0.002$, and $p = 0.001$. The score of detachment, recovery, and relaxation scores between conditions are shown in Figure 3.14.

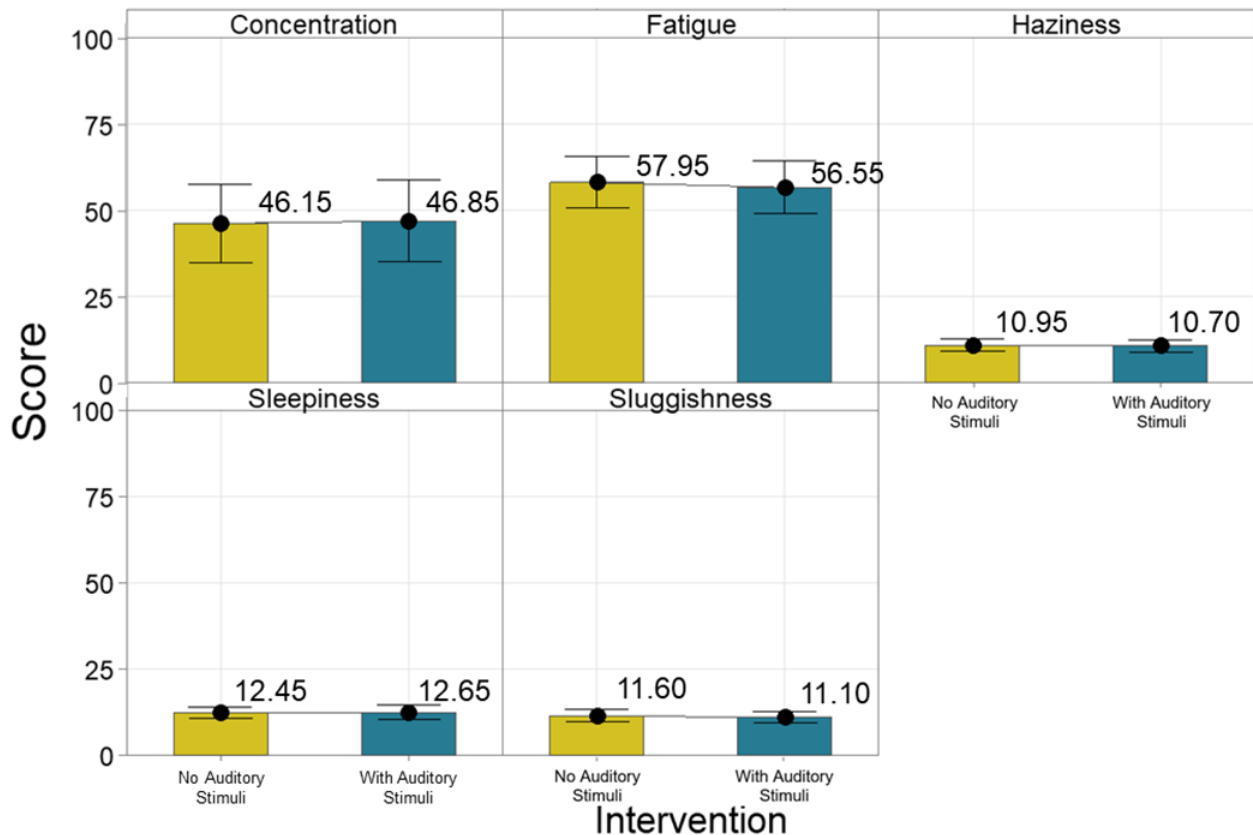


Figure 3.13: The subjective symptoms questionnaire scores for each subscale.

Attentional Control Scale (ATTC)

Analysis of the ATTC questionnaire revealed that 60% of participants scored between 20 and 50, falling into the medium range. The remaining 40% scored above 50, indicating a high level of attentional control. When examining ATTC focusing and shifting scores separately, 30% of participants demonstrated medium focusing scores (9–22), while 70% exhibited high focusing scores (above 22). For ATTC shifting, 60% of participants scored between 11 and 27 (medium shifting), and 40% scored above 27 (high shifting). These findings suggest that while a majority of participants demonstrated high levels of attentional focusing, shifting abilities were more evenly distributed. The score of ATTC are shown in Figure 3.15.

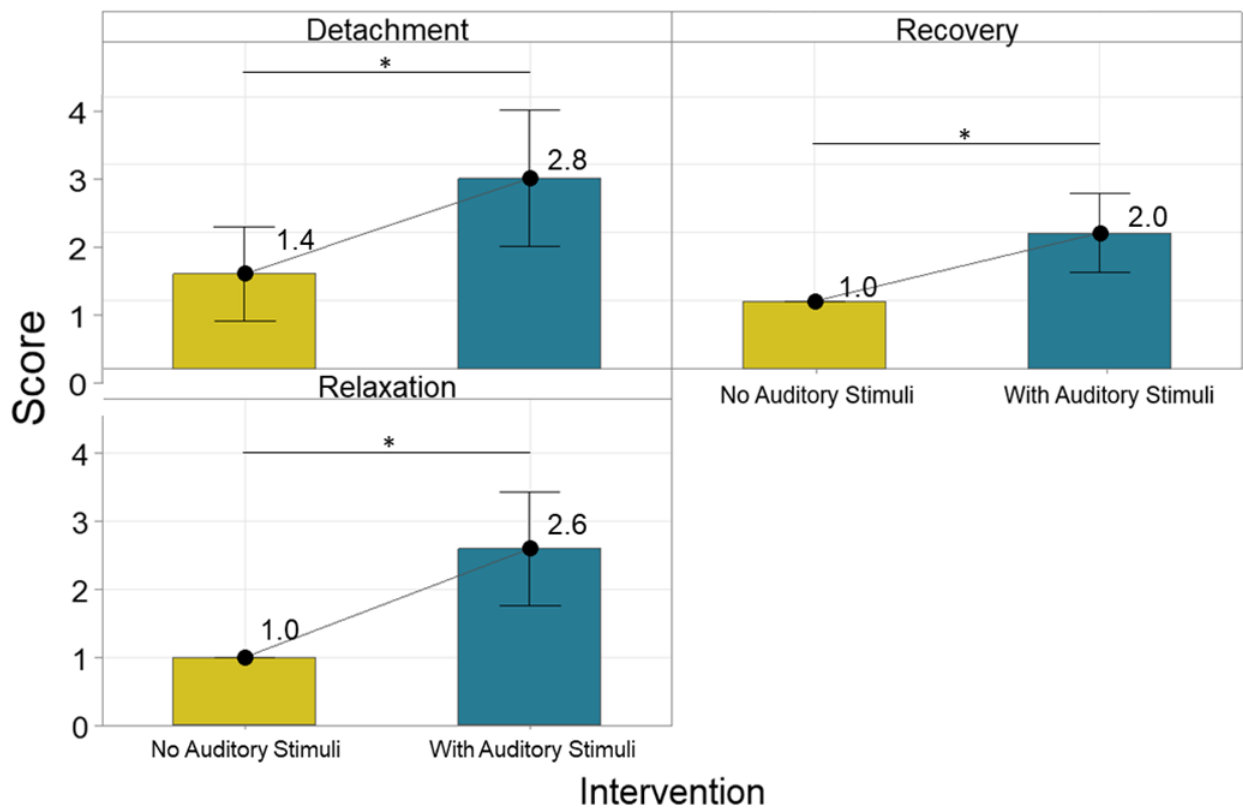


Figure 3.14: The score of the detachment, recovery, and relaxation questionnaire between conditions. A statistically significant difference is shown in this figure $*p < 0.05$

3.2.6 Discussion

A significant finding of this study 2 is the positive impact of strategically timed auditory stimuli on cognitive performance. Participants in the auditory stimuli condition exhibited significantly faster answering times, particularly during the latter stages of the 45-minute cognitive task (Stages 6 to 8). This suggests that the timely delivery of auditory stimuli can effectively mitigate cognitive decline and enhance sustained attention.

However, while auditory stimuli positively influenced cognitive performance, it did not significantly affect other performance metrics, such as accuracy. This suggests that the primary benefit of auditory stimuli may be in reducing cognitive decline and improving attention, rather than enhancing accuracy.

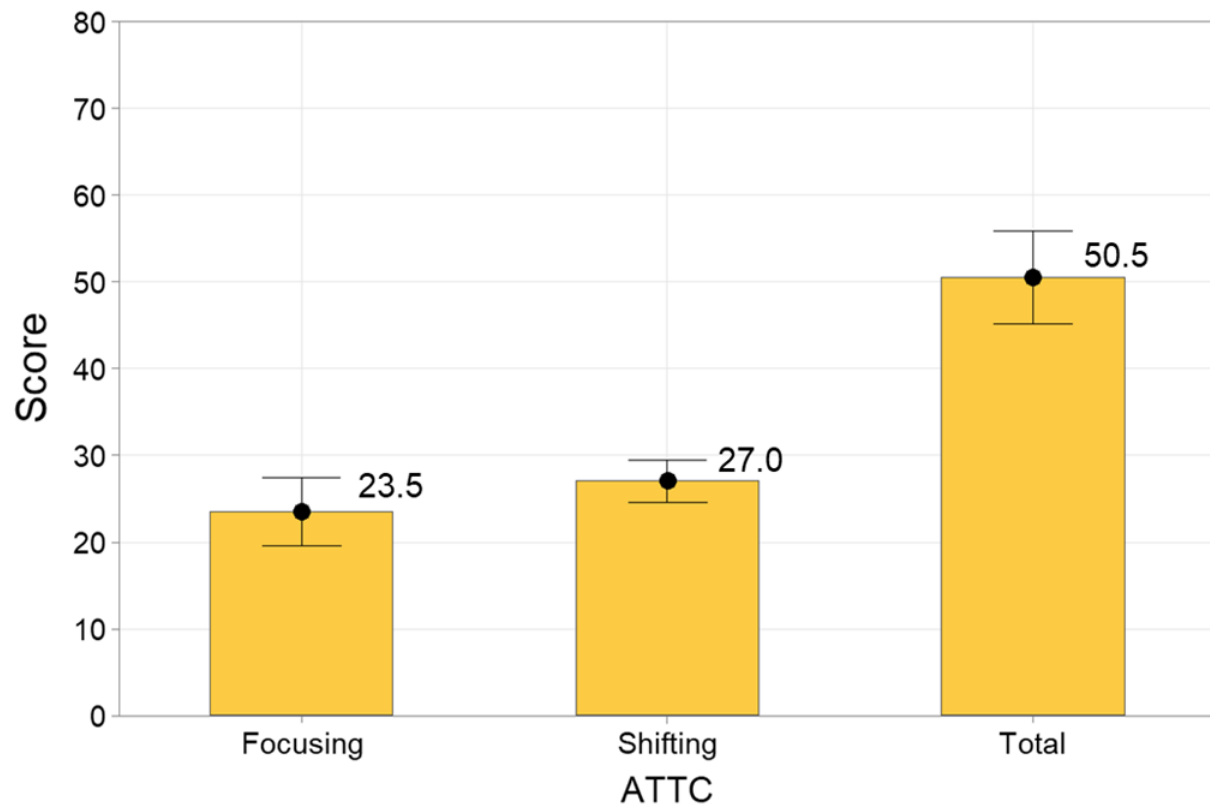


Figure 3.15: The ATTC score of focusing criteria, shifting criteria, and total score.

Additionally, the NASA-TLX questionnaire revealed no significant differences in perceived workload between the two conditions. Furthermore, subjective measures of symptoms state, including concentration, fatigue, haziness, sleepiness, and sluggishness did not show significant differences between conditions. These findings suggest that while auditory stimuli may improve certain aspects of cognitive performance, they do not have a significant impact on overall perceived workload or subjective feelings of fatigue.

Furthermore, study 2 revealed a significant increase in feelings of detachment, recovery, and relaxation among participants in the auditory stimuli conditions. This suggests that auditory stimuli may have a positive impact on subjective well-being by increasing the level of detachment, recovery, and relaxation.

A comparison of Study 1 and Study 2 reveals distinct findings. While both studies employed similar cognitive tasks, Study 2 extended the duration to 45 minutes to investi-

gate the impact of micro-refresh auditory stimuli on prolonged performance. This longer duration allowed for a more pronounced demonstration of the effectiveness of auditory interventions, particularly in the latter stages of the task.

Interestingly, while both studies showed no significant differences in terms of accuracy or perceived workload, Study 2 revealed significant improvements in detachment, recovery, and relaxation. This suggests that auditory stimuli may be more beneficial for longer tasks, potentially aiding in stress reduction and cognitive restoration. In contrast, Study 1, with a shorter task duration, did not exhibit significant differences in these subjective measures. These findings highlight the potential time-dependent effects of auditory interventions.

3.2.7 Conclusion

In conclusion, this study provides compelling evidence for the effectiveness of systematic micro-refresh auditory stimuli in enhancing cognitive performance and subjective well-being during prolonged cognitive tasks. By strategically timing auditory interventions, it is possible to mitigate cognitive decline.

Furthermore, auditory stimuli can positively influence mental states, promoting feelings of detachment, recovery, and relaxation. These findings have significant implications for workplace design and employee well-being, suggesting that incorporating auditory interventions into work routines can enhance productivity and job satisfaction.

Chapter 4

Effect of Systematic Micro-refresh Visual Stimuli on Intellectual Work

The contents of this chapter is based on :

Dianita, O., Nomura, K., Higashimaki, T., Abe, R., Ueda, K., Ishii, H., Shimoda, H., Obayashi, F. (2024). Systematic visual stimuli micro-refresh evaluation on cognitive work performance. *Displays*.

4.1 Introduction

Amidst the high work demands and rapid work environments, office workers are required to maintain high work productivity. Maintaining high work productivity, whether in the short or long term, remains a challenge. Workers often face a variety of stressors that can affect their performance and result in negative physical and psychological effects, such as high workloads, tight deadlines, unclear job expectations, interpersonal conflict, and organizational change [130–132]. The dynamics of workers and the complexity of stressors can hinder work productivity. Therefore, several steps are necessary to sustain workers' high performance.

Recovery strategies are presented as one way to maintain employee performance in the short and long term. Effective recovery strategies can help to alleviate the negative

consequences of stress and burnout, thereby supporting employee productivity [39]. By providing employees with opportunities to rest, relax, and recharge, recovery strategies can help prevent mental and physical exhaustion, improve job satisfaction, and enhance overall well-being [133]. Additionally, effective and sufficient recovery can contribute to workers' productivity and well-being, ultimately benefiting both employees and the organization [134].

Existing research on work recovery often focuses on specific break times, such as lunch or after-work hours, and relies primarily on subjective reporting. However, this approach may overlook the potential for maintaining performance during work periods preceding or following these conventional breaks. To address this limitation, our study investigates whether strategic interventions can enhance productivity without compromising work efficiency. By implementing controlled recovery strategies, our study aims to optimize work performance and delay its degradation over time.

The current study acquaints a promising recovery strategy, known as micro-refresh, which utilizes short bursts of stimuli during work sessions to boost performance and prevent decline [6, 19]. This study introduces a novel intervention known as systematic visual stimuli micro-refresh, designed to enhance cognitive performance or mitigate cognitive decline during extended tasks. While previous research has focused on the benefits of conventional recovery activities like taking breaks, our study explores the impact of targeted visual stimuli strategically applied during work periods. Unlike conventional micro-breaks, which could potentially impede efficiency, our approach aims to provide a subtle cognitive boost without interrupting the workflow. By examining the impact of micro-refresh in a quantitatively measurable manner, this study contributes to a broader understanding of methods for optimizing cognitive function and reducing fatigue during work.

4.1.1 Micro-refresh

Micro-refresh is a novel intervention designed to enhance cognitive performance during work. Unlike traditional micro-breaks, which are typically initiated voluntarily by individuals and involve activities such as stretching or taking a coffee break [11, 20, 22] or brief periods of rest without external stimuli [161], micro-refresh involves brief, involuntary stimuli applied within a few seconds that triggers cognitive restoration or delays its degradation over time. These stimuli, such as changes in airflow [9, 135], lighting [7], or sound [136], aim to revitalize cognitive function and improve performance. Figure 4.1 offers an illustration of the micro-refresh concept.

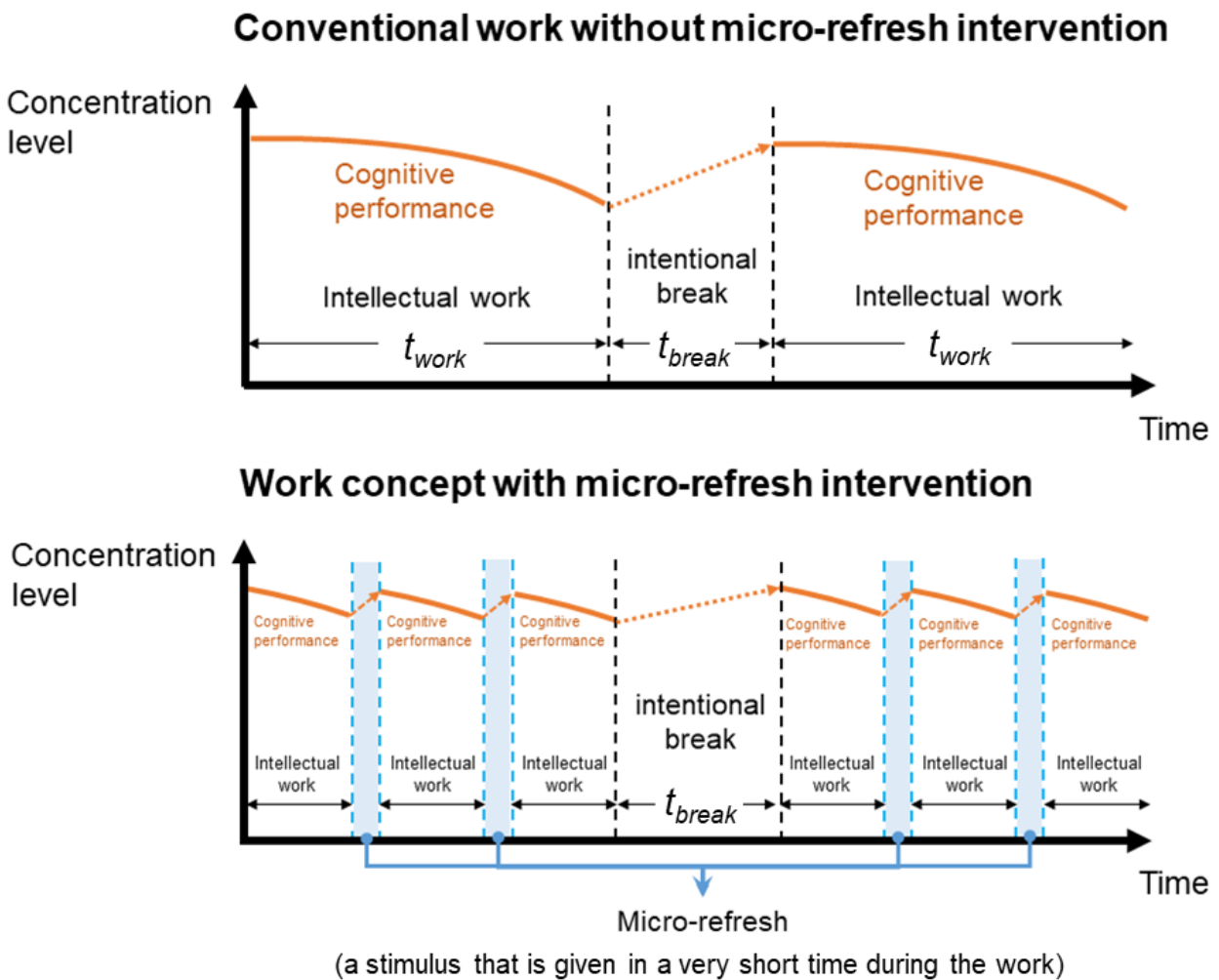


Figure 4.1: Illustration of the micro-refresh concept.

Previous research has shown that micro-refresh, implemented with various stimuli, has potential positive effects during work. A previous study investigating the effect of grey screen micro-refresh showed that most participants benefited after conducting the task under micro-refresh influence compared to non micro-refresh [19]. A previous study found positive effects of auditory micro-refresh on concentration and subjective workload [136]. Additionally, a short-term airflow intervention was classified as a micro-refresher and obtained varying results regarding concentration and subjective response [135]. Furthermore, developing a micro-refresh approach with visual stimuli is essential due to the vital role of visual attributes in various occupational settings [148, 149].

4.2 Investigation of Visual Stimuli Micro-refresh Evaluation on Cognitive Work Performance

This study aimed to investigate the impact of systematic visual stimuli micro-refresh on cognitive performance and well-being. By examining variables such as answering time, CTR, perceived workload, subjective symptoms, and psychological coping mechanisms, this study sought to gain a comprehensive understanding of these effects.

4.2.1 Visual stimuli and physical and psychological effects

Visual stimuli are important for creating physical and psychological changes. Visual stimuli can promote relaxation by enhancing engagement, instinct, derivation, and ambient qualities [150]. Additionally, some visual scenes or places could deliver certain psychological positive effects (e.g., recharging, immersing, calming, awe-inspiring, uplifting, mellowing, mind-clearing, reassuring) which thus complacent a feeling of relaxation [150]. Previous studies mentioned the application of integration visual nature properties into constructed environments to create positive effects on human health and well-being [109, 111, 116]. Previous research has highlighted the potential for outdoor views

to influence stress and recovery in office environments, suggesting that visual connections to the outdoor environment can contribute to both psychological and physiological well-being [137]. The stress and anxiety levels of participants who were exposed to visual stimuli in indoor environments were lower compared to the condition without visual stimuli exposure [113]. The condition without visual biophilic elements and traffic noise resulted in the worst performance compared to the condition with visual biophilic elements and natural sound [110]. Additionally, negative moods declined through exposure to visualization of natural elements similar to exposure to real nature [117].

4.2.2 Visual stimuli forms and varieties

Visual stimuli can take various forms, such as pictures, real objects, colors, or videos. Previous research has compared the effects of different visual stimuli, finding that real plants generally have a more positive impact than pictures or artificial plants [151]. 3D images have been shown to be more relaxing than 2D images [152]. However, a study investigating the effects of brief, pleasant videos found no significant differences in attention, working memory, or anxiety state, although anxiety traits varied by gender [153]. Nature-based visual stimuli, like forest imagery, have been found to be more effective than city images or grey screens in promoting relaxation and reducing stress [154]. This suggests the importance of considering visual stimuli in workplace environments to enhance well-being and recovery [155–158]. While previous research has explored the potential benefits of visual screensavers, their impact on cognitive performance remains inconclusive. Studies have shown both positive and limited effects. For example, visually-creative screensavers like fractals have been suggested to reduce stress [159], while other studies have found limited effects on cognitive performance measures [160].

4.2.3 Visual stimuli and its effect measurement

Visual stimuli are essential for daily work activities and significantly influence individual performance and perception. Utilizing a range of dependent variables becomes important to comprehensively measure the impact of visual stimuli on performance and recovery.

Answering time assessed cognitive processing efficiency and potential fatigue [136]. Concentration time ratio (CTR) measured sustained attention and focus by calculating the proportions of time participants spent actively concentrating on the task to the total task duration [5–7, 19]. The NASA-TLX questionnaire assessed subjective mental workload that could comprehensively understand participants' cognitive load [56, 58]. The subjective symptoms questionnaire captures participants' self-reported symptoms associated with stress and fatigue, including physical discomfort, emotional distress, and cognitive difficulties [55]. Furthermore, the detachment, recovery, and relaxation questionnaire utilization as a measurement could help to assess participants' ability to mentally detach from work, recover from stress, and experience relaxation. It provides insights into the psychological processes of coping with workload [83].

This study aimed to investigate the impact of systematic visual stimuli micro-refresh on cognitive performance and well-being. This study sought a comprehensive understanding of these effects by examining variables such as answering time, CTR, perceived workload, subjective symptoms, and psychological coping mechanisms.

A key differentiating factor in this study was the controlled manipulation of visual stimuli, particularly the duration and interval of micro-refresh stimuli. Previous research has primarily focused on absolute stimuli delivered during or after work [162–165]. Furthermore, while previous research on workplace interventions has primarily focused on absolute stimuli delivered during or after work, this study introduces a novel approach by systematically manipulating the duration and interval of visual stimuli. This controlled manipulation allows for a more nuanced investigation of the effects of micro-refresh visual stimuli on cognitive performance, productivity, and perceived recovery. By integrating systematic visual stimuli directly into the work, our research addresses a critical gap

in the literature and contributes to a growing body of evidence supporting the benefits of micro-refresh intervention that have not been extensively investigated.

4.3 Materials and Methods

A controlled experiment was conducted taking into account the experimental design, methods, and participants involved will be explained in the following sections.

4.3.1 Experimental Procedure

At the beginning, the participants received a brief explanation of the procedures to participate in the experiment such as an explanation of the consent form and the agreements, the estimated experiment duration, the participant's right to stop or not continue the experiment, and compensation given to participants after finishing the experiment. Participants were not informed about the research objectives or variables to avoid bias. All participants agreed with the consent form given before the experiment being started.

Each time the participants perform the given task, that period of performing the task will be called a SET. There are 4 sets in this experiment. A dummy starter set (i.e., SET 1) for 3 minutes was implemented in the beginning. This dummy starter set was performed to provide a short simulation of the experiment task that would be carried out (e.g., getting used to performing the tasks displayed on the display tablet). Secondly, a longer task set for forty-five minutes followed. In the second set, a visual stimulus was given. The visual stimuli were given for 30 seconds after 4.5 minutes of performing the task. During the 45-minute task duration, participants were exposed to visual stimuli eight times. The visual stimulus was displayed as a background overlay during the experiment task. Participants could choose to pause or continue the task during visual stimuli. Figure 4.2 illustrates the screen display during the experiment task when the visual stimuli appear and the screen display without the visual stimuli.

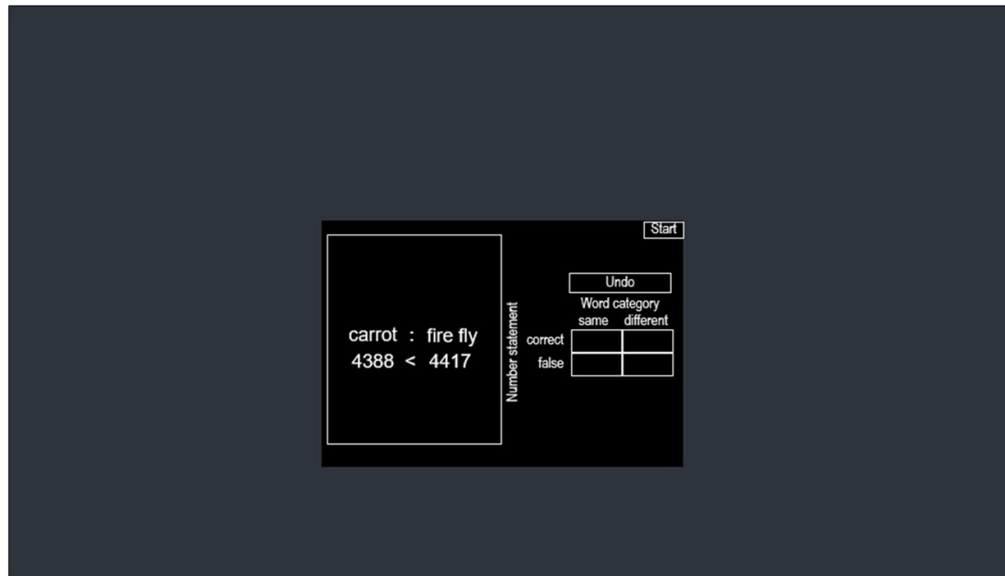
SET 1 and SET 2 were designed to familiarize participants with the experiment, especially the visual stimuli in SET 2. Data from SET 1 and SET 2 were excluded from the analysis. After finishing SET 2, a break was given for 10 minutes. Subsequently, an idle game session for 10 minutes was given. The purpose of this idle games session is to minimize boredom during the experiment sequence. Then, continued with another break for 10 minutes. The allotted break duration of 30 minutes was deemed sufficient to mitigate fatigue and ensure a refreshed state before commencing the next set.

SET 3 for forty-five minutes was started after the break finished, then followed with another 10-minute break, idle games, and a 10-minute break again. Similar to the post-SET 2 break, the 30-minute rest period was deemed sufficient to alleviate fatigue and prepare participants for the following task. Forty-five minutes of performing the task in SET 4 was followed after the prior break. Then, a 10-minute break is followed before the end survey for 20 minutes. A crossover design is adopted for SET 3 and SET 4 where the visual stimuli were induced. The induction of visual stimuli is employed in a counterbalanced design. Subsequently, only the data in SET 3 and SET 4 will be used for the analysis procedures with the assumption that the ordering effect is being minimized by the counter-balanced design of visual stimuli intervention employed within SET 3 and SET 4.

Before and after SET 2, SET 3, SET 4, and the idle game session, subjective ratings of progress questionnaire and subjective symptoms questionnaire were given. Additionally, the NASA task load index (NASA-TLX) questionnaire and detachment, recovery, and relaxation questionnaire were given at the end of SET 2, SET 3, and SET 4. On average, the experiment procedure lasts for five hours. The experiment was designed by following several procedures as shown in Figure 4.3.

4.3.2 Visual Stimulus in the Experiment

In this study, a scene of nature as the visual stimulus was chosen. The decision to adopt natural visualization is based on several considerations which believed to deliver positive



(A)



(B)

Figure 4.2: Illustration of the screen during experiment task: (A) the screen display without the visual stimulus, (B) the screen display when the visual stimulus appears.

benefits and enhance recovery during the work [155–158]. The visual stimuli utilized in this study are computer-generated (CG) animated imported from digital packages consisting of dynamic content featuring a cinematic view of swaying leaves in the forest with a flowing river in a daylight scene [138]. In particular, the scene depicted a non-localized

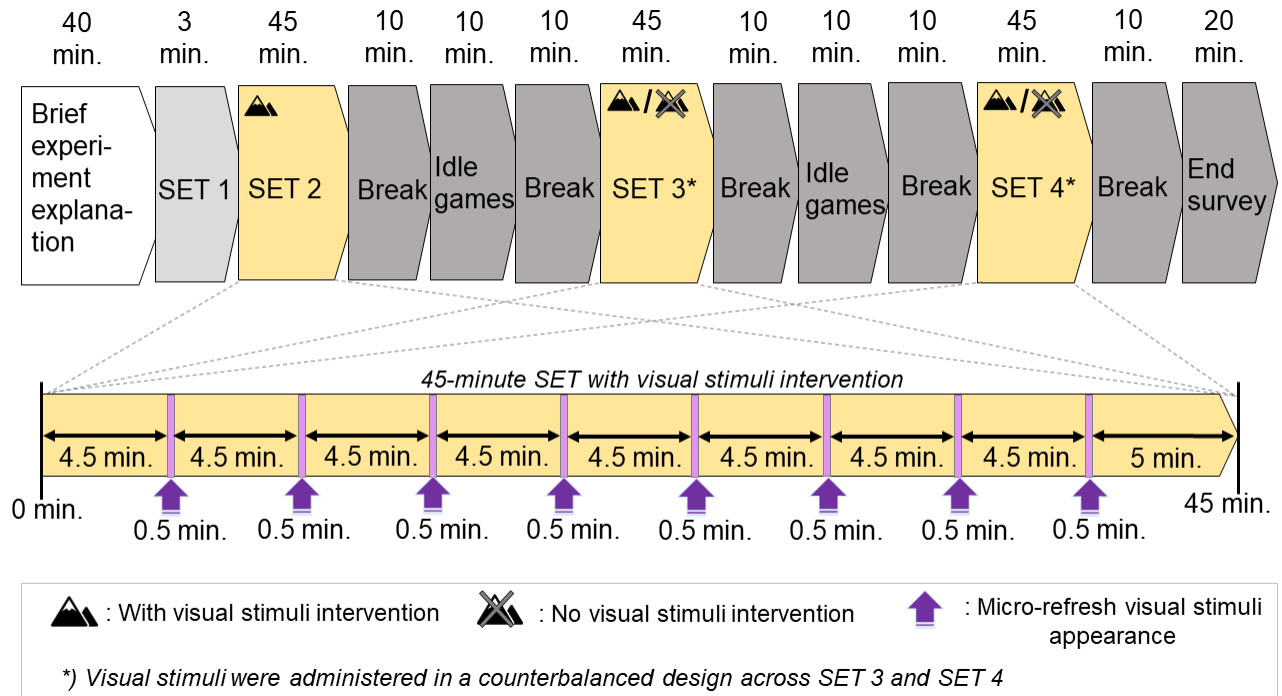


Figure 4.3: Illustration of the experiment design

natural environment, although it might have similarities to natural scenes found in Japan. Figure 4.4 illustrates the visual stimuli adopted in the experiment.

4.3.3 Participants

Thirty-eight participants (aged 18–32, $M = 22.3$, $SD = 2.8$; 23 male, 15 female) were recruited. The recruitment of this number of participants has met the *a priori* assumption of the number needed to obtain a *G*Power* of 0.8, an assumed alpha error probability of 0.05, and an effect size of 0.25 [139].

All the participants had normal or corrected-to-normal vision and were free of intellectual disabilities. All participants are Japanese students of Kyoto University recruited through the Kyoto University CO-OP bulletin board information and received a 6,000 yen gift card as compensation after finishing the experiment. All the participants agreed with the content of their requirements and rights stated in the consent form for conducting the



Figure 4.4: Illustration of the forest with a flowing river scene as the visual stimuli adopted.

experiment issued by the Graduate School of Energy Science Ethics Committee of Kyoto University.

4.3.4 Experiment Task

To measure the performance of the cognitive work, a comparison task was adopted [52]. Cognitive comparison tasks offer consistent difficulty and limited strategic flexibility, making them suitable for measuring intellectual concentration. The original task questions were presented in Japanese. For this manuscript, the questions and relevant terms were translated into English by native Japanese speakers with advanced English proficiency. In the task, the participants were expected to answer the task of comparing two numbers and make a judgment whether the mathematical statements linking the two numbers are correct or false, then make a judgment of comparison between two words whether is belong to the same group of category or not. For example, given the numbers “4388” and “4417” linked by “<”, the correct answer is ‘true’. Additionally, given two

words being compared “carrot” and “firefly”, then the expected correct answer is “these two words did not fall into the same category”, while “carrot” belongs to the “vegetable” category and “firefly” belongs to the “animal” category. Combining the answering comparison of two numbers and two words, the participants should touch the answering box crossing the area of “correct comparison number” and “different words category”. Figure 4.5 shows the sample of the comparison task displayed on the screen and the expected correct answer touch area.

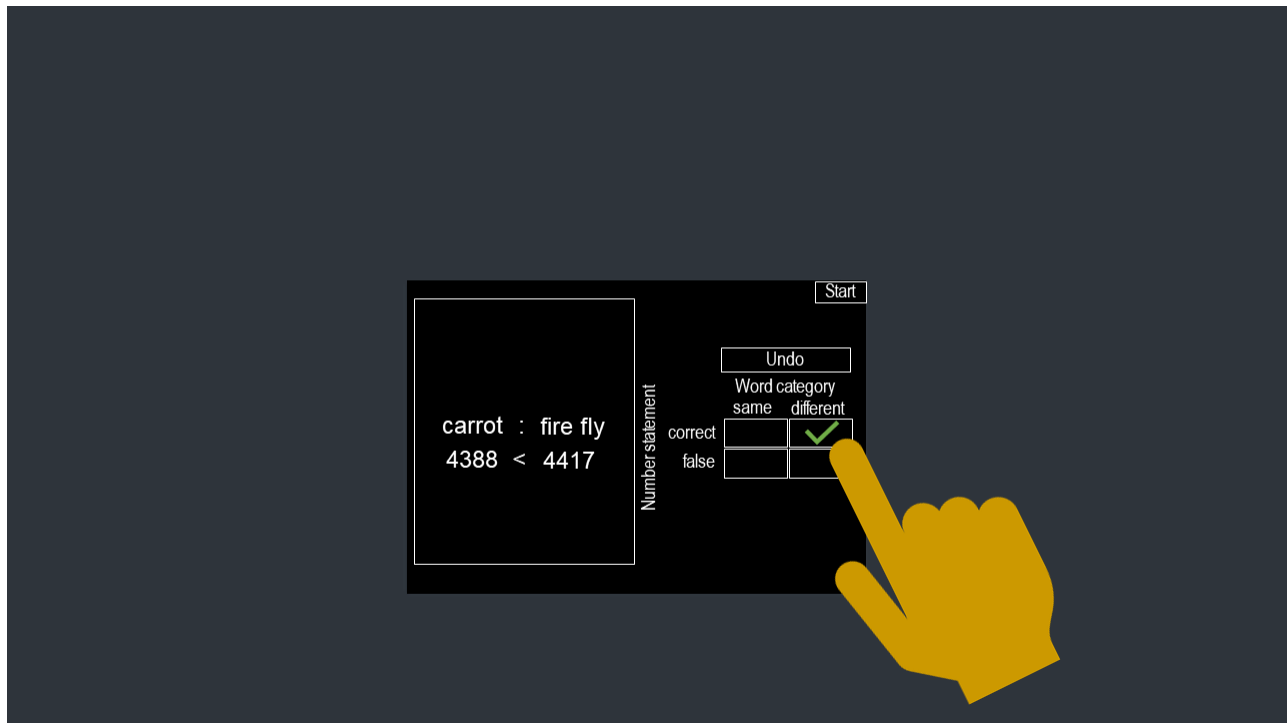


Figure 4.5: The sample illustration of the comparison task is displayed on the screen.

4.3.5 Experiment Environment and Equipment

The experiment was held in an experiment room at Kyoto University. A 43-inch LG display (43UD79-B) [166] was used for the experiment and placed on the work desk. The display resolution was 3840×2160 with a 16 : 9 aspect ratio. A PC with the following specifications was used:

- CPU: Intel Core i7-7700 [167]

- GPU: NVIDIA GeForce GTX 1060 [168]
- RAM: 16 GB
- Operating system: Windows 10 Pro 64bit [169]

A Logitech silent wireless mouse (M220CG) [170] was used to answer the question during the task and placed on the work desk. The room temperature was adjusted to $23 \pm 2^{\circ}\text{C}$ and the humidity level to 50%–60%. Participants sat in a comfortable working seat provided with a backrest and a work desk in front of them. The visual angle from the participant's head to the edge of the computer display was approximately 70° . The peripheral visual field, extending laterally from the central line of sight, measured approximately 60° in radius to the left and right. The work desk layout for each participant is shown in Figure 4.6. Additionally, Figure 4.7 shows the scene of the experiment

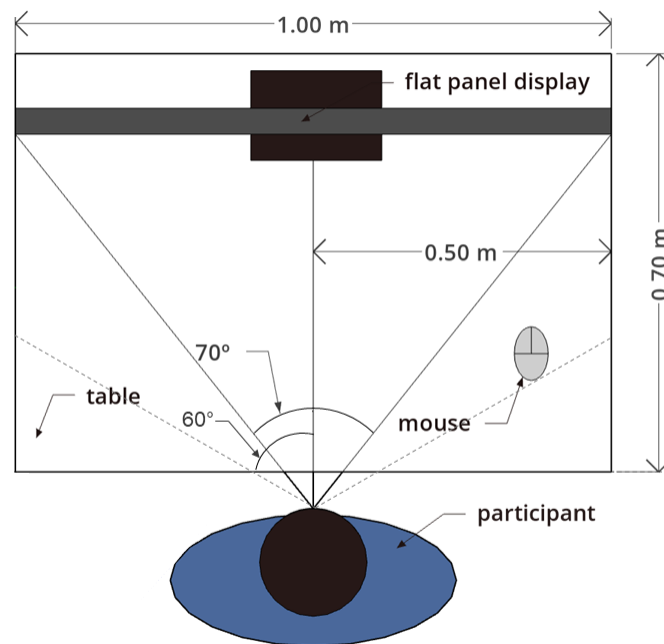


Figure 4.6: The work desk layout for each participant.



Figure 4.7: A scene of the experiment.

4.3.6 Outcome Measurement

Answering Time

One of the performance measurements was obtained through the recorded time required by participants to answer the tasks (i.e., answering time). During 45 minutes task duration in SET 3 and SET 4 where the data was then used in the analysis procedure, the answering time of each question was recorded automatically in the experiment program. One cycle of record answering time for each question was calculated from the first question that appeared on the screen until the participants clicked the button in a specifically designated answer area.

Concentration Time Ratio (CTR)

This study used the concentration time ratio (CTR) to measure concentration levels [5–7]. CTR is calculated by comparing the time spent concentrating to the total task time. A higher CTR indicates a higher concentration level. The superiority of CTR as a concentration performance indicator are 1) the learning effect does not have much affect on CTR because CTR is measured based on an index of the comparison of actual concentration time to total working time; 2) intellectual productivity (i.e., the outcome of knowledge processing over time) could indirectly be depicted by CTR and not just the speed response comes from muscle movement [7].

NASA Task Load Index (NASA-TLX)

The NASA-TLX was used to measure workload in this study [56, 58]. NASA-TLX is a comprehensive, validated, and easy-to-use workload measure. NASA-TLX was used to compare workload between the control and intervention groups. NASA-TLX consists of six subscales which are effort (EF), frustration level (FL), mental demand (MD), physical demand (PD), overall performance (OP), and temporal demand (TD). In this study, NASA-TLX was given at the end of each forty-five-minute set. The data used in the analysis procedure were extracted from the participants' responses after they finished SET 3 and SET 4 where the visual stimuli were employed in a counterbalance design.

Subjective Symptoms

A questionnaire measuring fatigue levels promoted by the Research Group of Industrial Fatigue Japan Society for Occupational Health was utilized in this study [55]. The questionnaire includes five subscales: drowsiness, instability, uneasiness, dullness, and eye-strain. The subjective symptoms questionnaire consists of twenty-five questions with five-point bipolar Likert style answering options starting with point 1 as “strongly disagree” to point 5 as “strongly agree”. This allows the measurement of both positive and

negative attitudes. The purpose of adopting this questionnaire is to catch the individual symptoms that happened before and after conducting the experiment tasks. Subjective symptoms were given before and after SET 2, SET 3, SET 4, and idle games sessions.

Detachment, Recovery, and Relaxation Questionnaire

Detachment, recovery, and relaxation questionnaires were administered as an additional measure to assess certain psychological factors. Table 4.1 presents the detachment, recovery, and relaxation questionnaire questions, which were originally in Japanese and translated into English for this paper. The translation was conducted by native Japanese speakers with advanced English proficiency and cross-checking assisted using translation software tools. To assess the level of detachment, recovery, and relaxation, a five-point unipolar Likert scale was employed. Participants rated their responses on a scale ranging from 1 (“not at all”) to 5 (“very much”). This unipolar scale slowed for the measurement of positive levels of the construct, capturing the extent to which participants exhibit or experience the specified behavior or characteristic. Recovery experiences can be influenced by psychological factors such as detachment, relaxation, mastery experiences, and leisure control [83]. However, due to the experimental design, mastery experiences and leisure control were not included in this study, as the task was not a typical mastery activity (e.g., playing instruments) and participants had limited control over their leisure activities.

Table 4.1. The list of questions of detachment, recovery, and relaxation questionnaire.

Questions	
1	Have you ever been distracted while performing the task because of the visual stimuli background?
2	Have you ever felt refreshed when performing the task because of the visual stimuli background?
3	Have you ever experienced a moment when the visual stimuli background appears and you are performing the task then you feel relaxed while doing it?

Ending Survey

At the end of the experiment, an ending survey was administered. This ending survey aimed to capture the participants' overall impressions and feelings after the end of the experiment. The survey questions are listed in the appendix. The answer options for the first, third, fourth, seventh, and eighth questions are formatted in an open-ended answer format. In the first question, the answers will be categorized as positive, negative, or neutral. In the third question, the answer responses will be categorized according to the variation of answers obtained ranging from a time interval of 5 minutes, and responses that are not related to the length of the interval given. In the fourth question, the category responses will be grouped according to the visualization character felt by the participants, whether it is a positive response or a negative response. Meanwhile, for the second question, three answer options are offered, while in the sixth question, five comfort levels are offered starting from the most uncomfortable level to the most comfortable level. Furthermore, in the discussion of the results, the answer categories from the ending survey will be displayed based on the answer categories that have been grouped in the previous explanation. Table 4.2 shows the list of questions of the ending survey.

4.4 Data Analysis

The analysis focused on answering time, CTR, and subjective ratings from SET 3 and SET 4. To facilitate a more comprehensive and detailed analysis of the answering time performance in each set, the 45-minute time horizon in SET 3 and SET 4 then divided into nine smaller time blocks represents stimuli induction time. The nine smaller time blocks were then named stages (i.e., stage 0–stage 8) where stage 0 started from 0–270 seconds, stage 1 from 271–570 seconds, stage 2 from 571–870 seconds, stage 3 from 871–1170 seconds, stage 4 from 1171–1470 seconds, stage 5 from 1471–1770 seconds, stage 6 from 1771–2070 seconds, stage 7 from 2071–2370 seconds, stage 8 from 2371–2700 seconds.

Table 4.2 The list of questions of the ending survey.

	Questions	Answering Format
Q1	Has the background change affected your work? If yes, what is the impact?	Open-ended
Q2	In the set with a visual change background for 30 seconds, how do you feel about the duration time of the appearance of the visual background?	Optional choice of the length of the visual background should be: 1) Longer 2) It's enough 3) Shorter
Q3	In the set with a visual change background, how do you feel about the interval time of the appearance of one visual background to the next visual background change?	Open-ended
Q4	How do you feel about the landscape image adopted in the visualization?	Open-ended
Q5	Do you have a feeling to stop and take a break every time the visual change background appears?	Optional choice: 1) I felt like taking a break 2) I didn't feel like taking a break
Q6	How comfortable and uncomfortable do you feel every time the visual change background appears while conducting the experimental task?	Likert scale from 0 (very uncomfortable) to 5 (very comfortable)
Q7	During the experiment, do you feel that you are influenced by other participants' behavior? If you feel that there was nothing special, you can skip this question.	Open-ended
Q8	If you have any other thoughts about this experiment as a whole, please write them down. No need to fill in anything unless there is something special.	Open-ended

The analysis used parametric and non-parametric tests. Given the non-normal distribution of the answering time data, as confirmed by the *Anderson-Darling* test, the *Kruskal-*

Wallis test was employed for analysis. Despite the homogeneity of variance, as verified by *Levene's* test, the *Kruskal-Wallis* test was deemed appropriate due to the non-normal data distribution. Considering the non-normal distribution of CTR data, as confirmed by a normality test, the *Mann-Whitney U* test was employed for statistical analysis. This decision was made despite the homogeneity of variance, as assessed by *Levene's* test. The assumptions of normality and homogeneity of variance were met for the NASA-TLX data, thus the *student's t-test* was conducted. Subjective symptoms questionnaire data were preprocessed using the *min-max* method [171] before applying the *Kruskal-Wallis* test, which considered the non-normal distribution despite being homogenous data. The detachment, recovery, and relaxation questionnaire data were analyzed using the *Mann-Whitney U* test after the *Anderson-Darling* test revealed non-normal distribution data, and *Levene's* test showed unequal variances.

The following criteria were used to exclude data from participants with inappropriate experimental results such as 1.) Participants were absent from at least one experimental session, 2.) Participants with CTR scores below 40% or fewer than 300 answers were excluded due to lack of motivation [19], 3.) The participants outside criteria number 1 or 2 that have the CTR score difference between SET 3 and SET 4 included in the 5% lower threshold or 5% upper threshold distribution were excluded to minimize the probability of Type-I errors and bias [89].

4.5 Results

Data from 26 participants (aged 18–32, $M = 22.3$, $SD = 3.1$; 15 male, 11 female) were analyzed; 12 participants were excluded for various reasons as mentioned in the Data Analysis section. Two participants were excluded due to absence from at least one experiment session. Six participants had a CTR score below 40% or answered fewer than 300 questions (indicating low motivation) [19]. Four participants had a CTR score difference between SET 3 and SET 4 exceeding the 5% threshold (indicating potential bias) [89].

From the remaining 26 participants, 38,472 answering time data were collected under both control and intervention conditions with a *posteriori* G^* Power level of 0.7, which is an assumption sufficient for the current investigation given the time and resource constraints associated with data collection and experimentation.

4.5.1 Answering Time

The *Anderson-Darling* test indicated a non-normal distribution of answering time data ($p < 0.05$). The *Levene's* test confirmed the homogeneity of variance ($p = 0.088$). The *Kruskal-Wallis* test revealed significant differences between groups ($p < 0.001$). *Dunn's post hoc* test identified significant differences between the No Visual Stimuli Stage 0 and other group (i.e., No Visual Stimuli Stage 3–Stage 8, With Visual Stimuli Stage 0–Stage 7) and No Visual Stimuli Stage 1 to other group (i.e., No Visual Stimuli Stage 7, With Visual Stimuli Stage 2, 4, 6, 7) ($p < 0.05$, *Cliff's delta* = 0.025).

There is a notable shift in the directionality of answering time, particularly following Stage 4. In the condition with visual stimuli, there was a noticeable acceleration of the response process. Conversely, in the absence of visual stimuli intervention, a tendency towards slower answering time was observed. Regarding accuracy, the error rate did not exhibit significant differences between conditions with and without visual stimuli intervention ($p = 0.791$, *Cliff's delta* = 0.013). This finding was based on the *Mann-Whitney U* test, which was employed due to the non-normal distribution of the data ($p < 0.005$, *Anderson-Darling* test), despite the homogeneity of variance ($p = 0.157$, *Levene's* test). Additionally, Figure 4.8 illustrates the average answering time for each stage under both condition.

4.5.2 Concentration Time Ratio (CTR)

The *Anderson-Darling* test revealed a non-normal distribution of CTR data in the no visual intervention group ($p = 0.018$). The *Levene's* test confirmed the homogeneity of variance

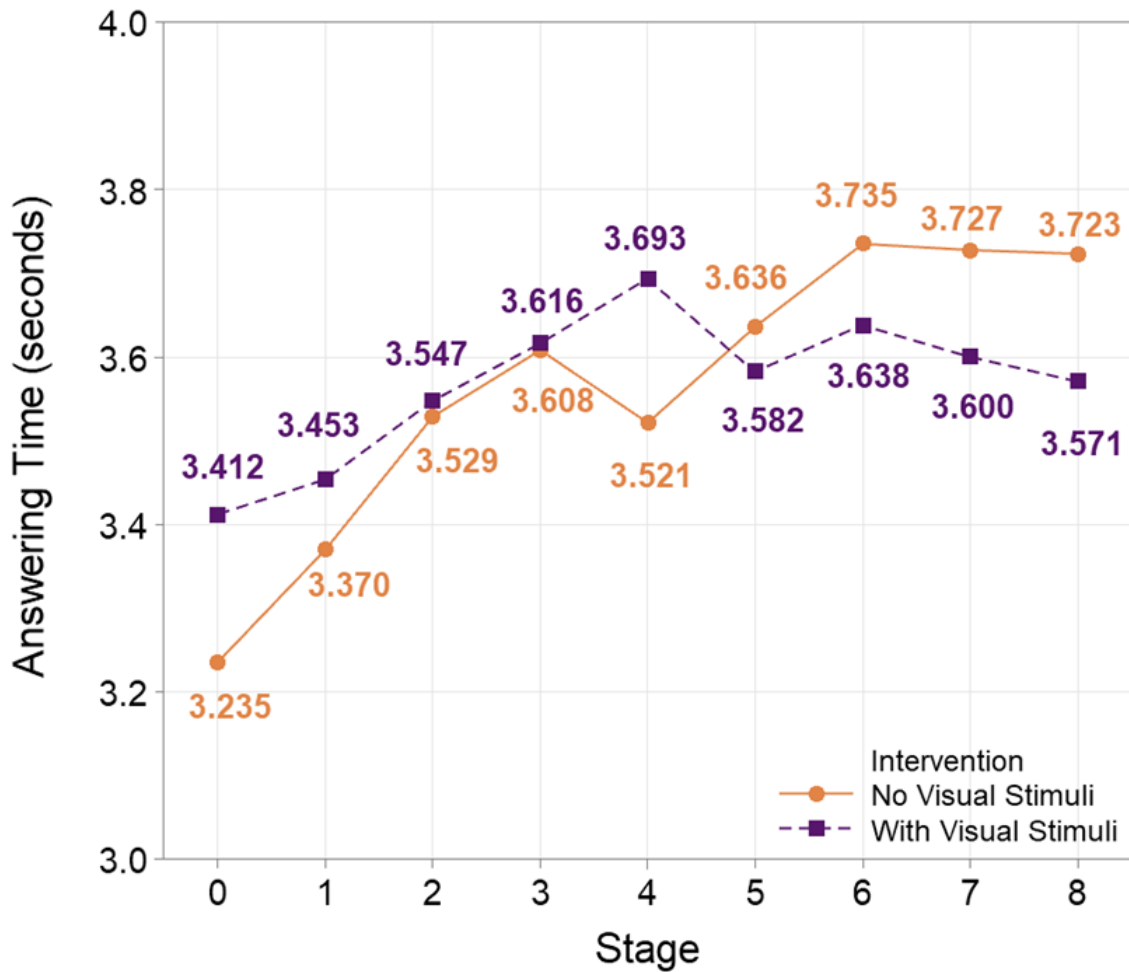


Figure 4.8: The answering time between conditions with no visual stimuli and with visual stimuli.

($p = 0.843$). The *Mann-Whitney U* test found no significant differences in CTR between the no visual stimuli group and the visual stimuli group ($p = 0.66$, *Cliff's delta* = 0.07). Figure 4.9 shows the CTR score between condition with and without the visual stimuli.

4.5.3 NASA Task Load Index (NASA-TLX)

The NASA-TLX data were normally distributed for both groups with and without visual stimuli ($p = 0.852$ and $p = 0.075$) and had equal variances (*Levene's test*, $p = 0.625$). The average NASA-TLX score was 53.76 ± 15.09 for the control group and 52.87 ± 14.77 for

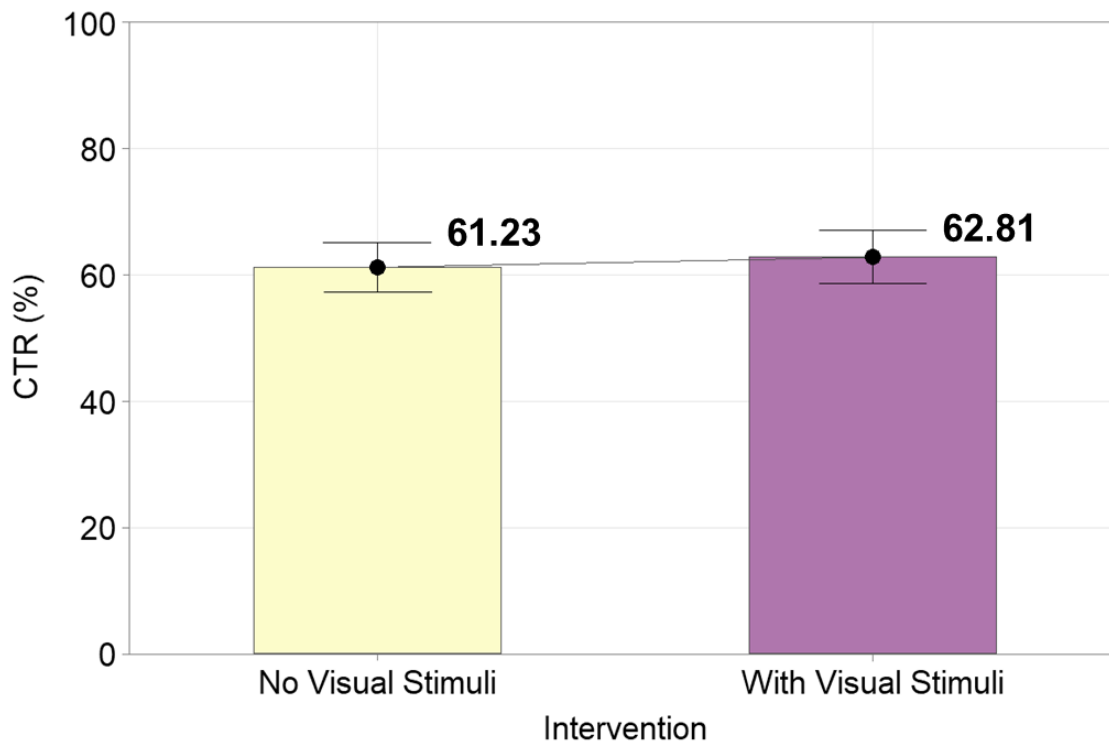


Figure 4.9: The concentration time ratio (CTR) between conditions with no visual stimuli and with visual stimuli.

the visual stimuli group. A *t-test* revealed no significant difference between groups ($p = 0.832$, *Cohen's d* = 0.06, *Cronbach's alpha* = 0.82). Figure 4.10 shows the NASA-TLX score between conditions with and without the visual stimuli.

4.5.4 Subjective Symptoms

The subjective symptoms questionnaire data were non-normally distributed (*Anderson-Darling* test, $p < 0.005$) but had homogeneous variances (sphericity test, $p > 0.05$). *Cronbach's alpha* was 0.63. The *Kruskal-Wallis* test revealed a no significant differences in concentration, fatigue, haziness, or sleepiness ($p > 0.05$). However, a significant difference was found in sluggishness ($p = 0.038$). Figure 4.11 shows the boxplot of subjective symptoms data for each subscale, comparing intervention and control groups, as well as pre and post-experiment responses.

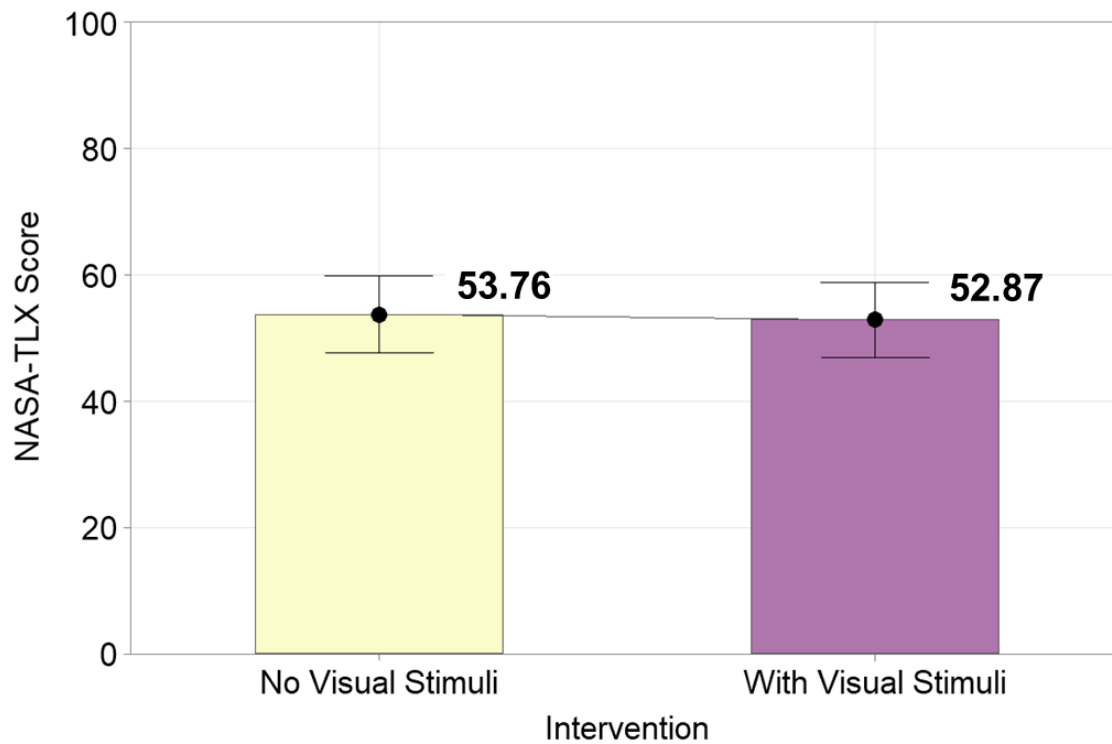


Figure 4.10: The NASA-TLX score in a condition with and no visual stimuli.

4.5.5 Detachment, Recovery, and Relaxation

The detachment, recovery, and relaxation questionnaire data were non-normally distributed (*Anderson-Darling* test, $p < 0.005$) and had unequal variances (*Levene's* test, $p = 0.001$). *Cronbach's alpha* was 0.91. The *Mann-Whitney U* test revealed significant differences between groups for all subscales ($p < 0.001$, *Cliff's delta* = 0.97 for detachment, 0.81 for recovery, and 0.93 for relaxation). Figures 4.12, 4.13, and 4.14 illustrate the detachment, recovery, and relaxation scores, respectively, comparing conditions with and no visual stimuli.

4.5.6 Ending Survey

Due to the open-ended format, participants could provide multiple responses to questions 1, 3, and 4. Therefore, the total number of responses exceeded 26. Table 4.4 summa-

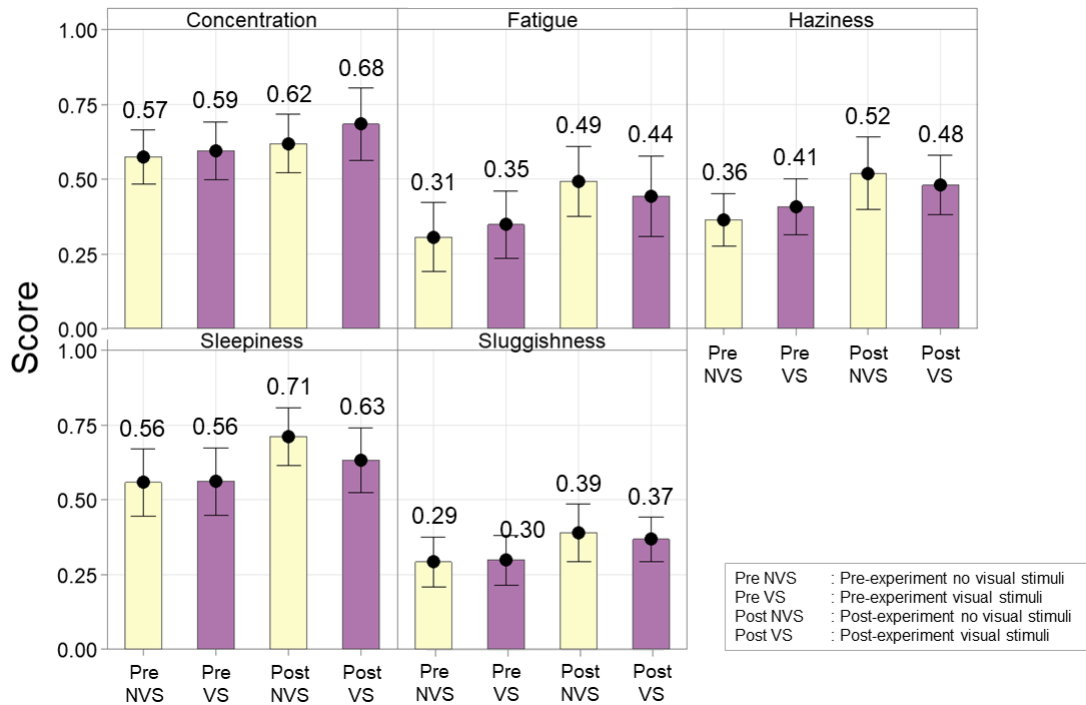


Figure 4.11: Boxplot of subjective symptoms questionnaire

rizes these open-ended responses. Figure 4.13 shows the distribution of responses for the closed-ended questions 2, 5, and 6.

Table 4.4 Open-ended response of visual background change (Q1).

Response category	Number of response
The answer corresponds to the positive category:	
"I was able to concentrate"	4
"I was able to refresh"	5
"I was able to relax"	4
"I felt a change to a good mood"	4
The total answer corresponds to the positive category	17
The answer corresponds to the negative category:	
"My concentration is decreased"	9
"My speed response is decreased"	4
"I was distracted"	8
The total answer corresponds to the negative category	21
Response neither positive nor negative	1

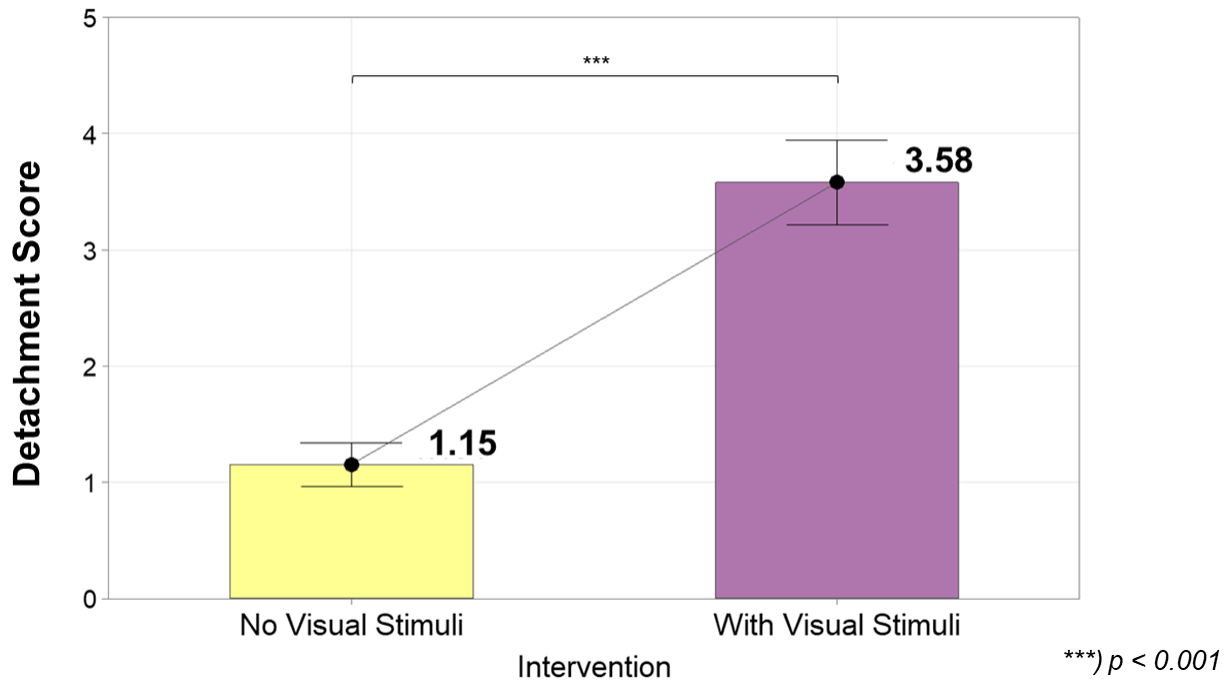


Figure 4.12: The detachment score between conditions in no visual stimuli and with visual stimuli.

Table 4.5 Open-ended response of the visual stimuli interval time (Q3).

Response category	Number of response
The interval felt longer than 5 minutes	7
The interval felt shorter than 5 minutes	1
I thought the interval was about 5 minutes	2
The interval should be longer than 5 minutes	1
The interval should be shorter than 5 minutes	2
The interval was just right	10
Other responses which not correlate to the interval length	5

4.6 Discussion

The result of this study provides valuable insights into the effects of visual stimuli on several performance measurements and subjective feelings during a cognitive task. Answering time results revealed significant differences between groups, indicating that visual stimuli impacted answering time. Specifically, visual stimuli improved answering

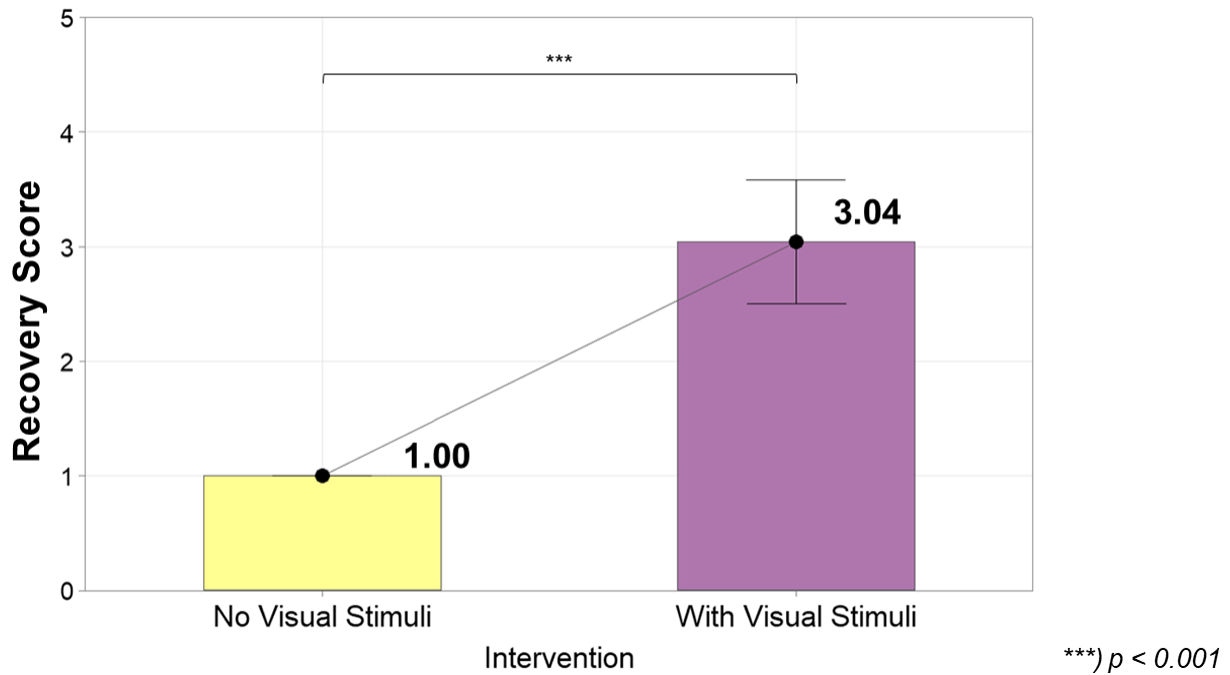


Figure 4.13: The recovery score between conditions in no visual stimuli and with visual stimuli.

Table 4.6 Open-ended response of the visualization image adopted (Q4).

Response category	Number of response
"I felt it was a relaxing landscape"	8
"It was beautiful"	6
"It was suitable for a mood change"	2
"It was calm"	4
"I paid attention to the movement in the landscape visualization"	8
"It was not unpleasant"	1

time during a 45-minute cognitive task when introduced in the latter half of the duration (Stages 5–8) but may not enhance performance at the beginning (Stages 0–4). The observed change in the directionality of answering times, particularly after Stage 4, can be attributed to the interplay of recovery processes and fatigue accumulation. In conditions with visual stimuli, the recovery process appears to be more effective, mitigating the accumulation of fatigue. Conversely, in the absence of visual stimuli, the recovery process

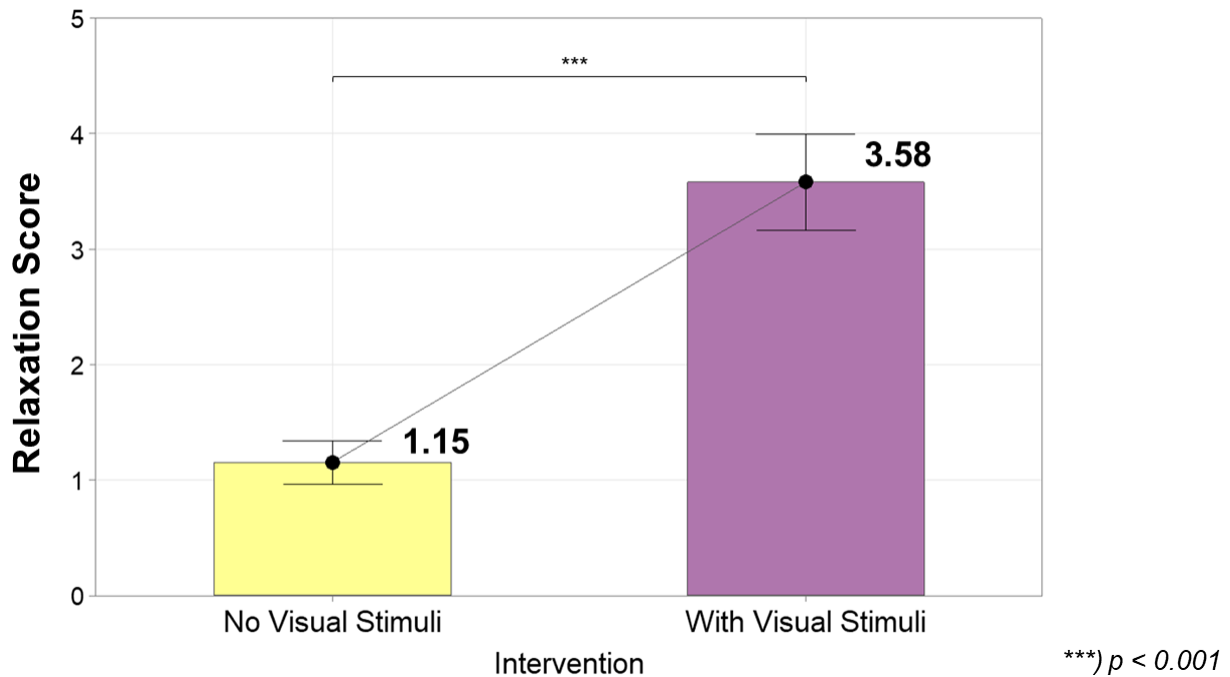


Figure 4.14: The relaxation score between conditions in no visual stimuli and with visual stimuli.

may be less efficient, leading to increased fatigue and potentially hindering performance. The post-hoc comparisons highlight specific time points where visual stimuli have influenced performance. These findings suggest that the timing of visual stimuli introduction may play a role in task performance. However, the accuracy of the work was no different between conditions, indicating that productivity remained improved with visual stimuli but not necessarily improved accuracy. Thus, the result of the answering time supports hypothesis 1 however it was not considering the accuracy.

The *Mann-Whitney U* test shows $p = 0.66$ for comparing CTR with and without visual stimuli. This indicates that visual stimuli did not significantly impact CTR in this study. Additionally, despite the positive findings for answering time measurement, the CTR data did not support hypothesis 1. This discrepancy may be attributed to the differing methodologies utilized for calculating these two metrics. While CTR considered the time spent concentrating on the overall task completion time within 45 minutes, the

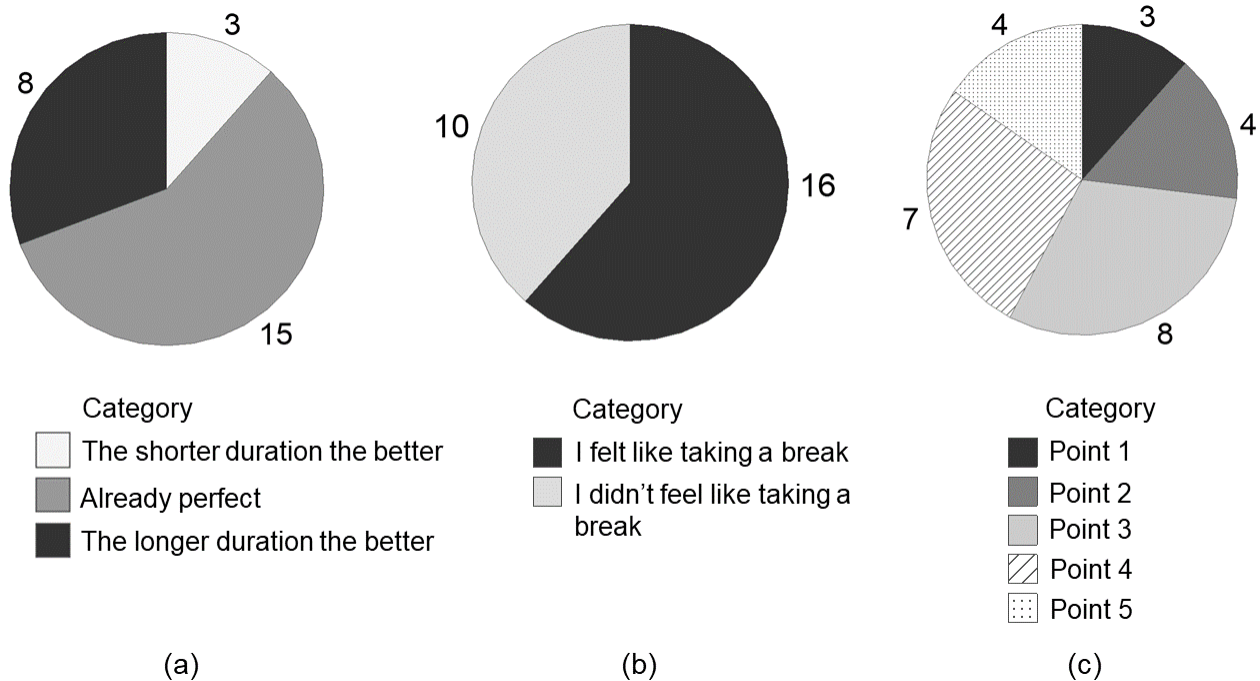


Figure 4.15: (a) Distribution response of visual stimuli duration (Q2), (b) Distribution response of initiation to taking a break during the visual stimuli appearance (Q5), (c) Distribution response of comfortability during the visual stimuli appearance (Q6).

answering time analysis provided a more chapped assessment, considering performance at each stage (Stage 0–Stage 8) of the stimuli induction time.

The results from the NASA-TLX analysis indicate that the perceived workload remained relatively consistent across conditions with and without visual stimuli. This suggests that while visual stimuli may have influenced other aspects of task performance, they did not significantly impact the participants' subjective experience of workload.

The subjective symptoms questionnaire revealed no significant differences between conditions with and without visual stimuli for most subscales, except for sluggishness. While participants reported similar levels of concentration, fatigue, haziness, and sleepiness in both conditions, the intervention group exhibited significantly different levels of sluggishness.

The findings of the detachment, recovery, and relaxation questionnaire suggest that visual stimuli significantly positively impacted all three psychological factors assessed.

Participants in the intervention group reported feeling more detached, recovered, and relaxed than the control group. The results highlight the potential benefits of incorporating visual stimuli into work environments. Visual stimuli improve well-being and reduce stress by promoting detachment, recovery, and relaxation.

The ending survey revealed a range of responses to visual stimuli, including both positive and negative feedback. Negative responses may be attributed to the potential distraction of visual stimuli on selective attention [172]. Most participants found the interval timing appropriate. The nature-based visual stimuli in this study, featuring a forest scene with a waterfall and river, evoked a relaxing and calming atmosphere, likely contributing to a sense of recovery. Previous research suggests that various visual presentations can positively impact well-being through thinking, sensing, and doing [173]. Creating a calming environment, such as using visual and multisensory stimuli, can improve the well-being of individuals, as demonstrated in studies on intensive care unit patients [174].

Limitations

Several limitations should be acknowledged in this study. The laboratory setting, while providing a controlled environment, may not fully replicate real-world scenarios, potentially limiting the generalizability of findings. The use of a single natural scene (a forest with a flowing river) may not cater to individual preferences, as relaxation can be influenced by various sensory, cognitive, and behavioral factors [173,174].

Additionally, the potential for visual stimuli habituation, where participants become accustomed to the stimuli over time, needs further investigation. It remains unclear whether the observed effects of visual stimuli would be sustained over extended periods, such as months or years of use in real-world settings. Thus, further studies investigating long-term effects can provide a more comprehensive understanding of the efficacy and long-term effects of micro-refresh visual stimuli interventions.

This study did not explore potential gender differences in the effects of systematic visual stimuli micro-refresh on cognitive performance. Previous research suggests that

gender may play role in how individuals respond to nature-based visual interventions [100, 175, 176]. Future research might explore whether systematic visual stimuli micro-refresh interventions have differential effects on cognitive performance and well-being depending on participants' gender. This would provide a more comprehensive understanding of the potential benefits of this intervention for a wider population.

Furthermore, the reliance on a single sensory modality (visual stimuli) may not have fully created an immersive environment for optimal recovery. Future research could explore the benefits of combining visual stimuli with other sensory modalities, such as auditory or olfactory cues.

Finally, the use of subjective questionnaires introduces the potential for bias and measurement error. Factors like participants' expectations, stimulus, and familiarity can influence questionnaire responses [140]. To address these limitations, future studies should consider larger and more diverse samples, as well as objective measures, to enhance the validity and reliability of the findings.

Implication

The concept of systematic micro-refresh visual stimuli in work settings is based on the idea that incorporating brief, visually engaging breaks can enhance employee productivity and well-being without compromising overall work efficiency. These systematic micro-refresh visual stimuli can be implemented through various means, such as displaying nature scenes or calming animations on digital screens or scheduling short structured breaks throughout the workday. By strategically incorporating these visual stimuli, organizations can create a more engaging and supportive work environment.

4.7 Conclusion

In conclusion, our findings demonstrate that the strategic implementation of systematic micro-refresh visual stimuli can significantly enhance both cognitive performance and

perceived recovery. These results imply that integrating systematic micro-refresh visual stimuli into office work environments has the potential to offer substantial benefits for employee well-being and productivity. While this study provides valuable insights, it is important to acknowledge its limitations. Future research exploring variations in visual stimuli, such as the type of scene, duration, and interval, can further elucidate the optimal parameters for maximizing the effectiveness of micro-refresh interventions.

Chapter 5

Conclusion

5.1 Concluding Remarks

This dissertation has made significant contributions to the understanding of micro-break and micro-refresh interventions, also their impact on cognitive performance and well-being. By systematically investigating the effects of micro-break and micro-refresh auditory and visual stimuli, this research has demonstrated the potential of these interventions to enhance workplace productivity and employee satisfaction.

This study showed that a systematic micro-break and micro-refresh have the potential benefit of stabilizing worker performance and hindering performance degradation over time. The highlights results from the series investigation reveal that:

Chapter 2: Effect of Systematic Micro-Break on Intellectual Work

This study demonstrated that systematic micro-breaks (MB) significantly improved cognitive performance, particularly during the later stages of a prolonged task. MB interventions helped to mitigate performance degradation over time, as evidenced by the more stable performance patterns in the MB condition. The study highlighted the importance of timing MB interventions.

Chapter 3: Effect of Systematic Micro-refresh Audio Stimuli on Intellectual Work

The study found that the systematic introduction of brief auditory stimuli can enhance cognitive performance, especially during prolonged tasks. The intervention positively affected participants' subjective feelings of recovery and reduced perceived workload. The timing of micro-refresh stimuli is crucial.

Chapter 4: Effect of Systematic Micro-refresh Visual Stimuli on Intellectual Work

The study found that systematic micro-refresh visual stimuli can improve cognitive performance, particularly during extended tasks. Participants reported increased feelings of detachment, recovery, and relaxation after exposure to visual stimuli. The timing of visual stimuli interventions may play a crucial role in maximizing their benefits.

Figure 5.1 summarizes the significant findings from the objective and subjective assessments presented in Chapters 2, 3, and 4. Subsequently, Figure 5.2 highlights the key results of Chapters 2, 3, and 4.

5.2 Limitations

While this study provides valuable insights into the effects of systematic micro-break and systematic micro-refresh on intellectual work, it is important to acknowledge several limitations. Firstly, while the controlled laboratory setting allowed for precise manipulation of variables, it may limit the generalizability of findings to real-world work environments. Additionally, the potential for habituation to the auditory or visual stimuli over time warrants further investigation. While the focus on a single sensory modality provided valuable insights, exploring the combined effects of multiple sensory modalities could offer enhanced benefits. Subjective questionnaires, while useful, are susceptible to bias and measurement error. Future research should consider incorporating objective physiological measures to complement subjective reports. Lastly, the study did not examine

Chapter	Objective Assessments	Subjective Assessments
Chapter 2: Effect of Systematic Micro-breaks	Answering time significantly differed between conditions with and non micro-breaks, especially during the later stages of the task.	NASA-TLX shows a significant difference between conditions with micro-break and no micro-break. A lower score for micro-break condition → lower perceived workload.
Chapter 3: Effect of Systematic Micro-refresh Auditory Stimuli	[Study 2] Answering time differed significantly between conditions with and no auditory stimuli, particularly after stage 6.	[Study 1] - The recovery questionnaire revealed a significant difference between conditions, with higher scores reported for the auditory stimuli conditions. [Study 2] - Significant differences were found in the detachment, recovery, and relaxation questionnaires, with higher scores reported in the auditory stimuli condition.
Chapter 4: Effect of Systematic Micro-refresh Visual Stimuli	The analysis of answering times revealed a significant difference between the two conditions, especially after stage 4. The condition with visual stimuli showed a more stable performance trajectory, while the no-visual-stimuli condition exhibited a decline over time.	- The subjective symptoms questionnaire revealed a significant difference in sluggishness between the visual stimuli and non-visual stimuli conditions. - Significant differences were found in the detachment, recovery, and relaxation questionnaires, with higher scores reported for the visual stimuli condition.

Figure 5.1: Summary of the significant findings from the objective and subjective assessments in Chapters 2, 3, and 4.

potential gender differences in response to micro-refresh interventions, which could be a fruitful avenue for future research.

5.3 Implications

The findings of this study have significant implications for workplace design and management. By incorporating systematic micro-refresh strategies, organizations can create more supportive and productive work environments. Implementing techniques such as displaying nature scenes on digital screens, scheduling short, structured breaks, or integrating auditory stimuli of natural sounds can enhance employee well-being and cognitive performance. These strategies can help reduce stress, fatigue, and cognitive decline, ultimately leading to increased productivity and job satisfaction.

Chapter	Key Findings	Highlights
Chapter 2: Effect of Systematic Micro-breaks	Significant improvement in cognitive performance, especially during later stages of tasks. Micro-break reduced performance degradation over time and reduced perceived workload.	Highlights the importance of strategic timing and duration of micro-breaks to optimize cognitive performance.
Chapter 3: Effect of Systematic Micro-refresh Auditory Stimuli	Enhanced cognitive performance, particularly during prolonged tasks. Positive impact on subjective well-being, such as increasing feelings of recovery, also detachment and relaxation during extended task.	Suggests that auditory stimuli can be a valuable tool for improving workplace productivity and employee well-being.
Chapter 4: Effect of Systematic Micro-refresh Visual Stimuli	Improved cognitive performance, reduced performance degradation, increased feelings of detachment, recovery, and relaxation, and decreased feelings of sluggishness.	Emphasizes the potential of visual stimuli to promote cognitive performance and create more restorative work environments.

Figure 5.2: Summary of the highlights of the key results of Chapters 2, 3, and 4.

5.4 Prospect for Future Research

The investigation of various types of stimuli as a micro-refresh becomes a promising potential for future research. In this study, the investigation is being focused and limited to the visual and auditory aspects. Thus, incorporating other human senses outside the visual and auditory could enrich the investigation correlates to the micro-refresh study. Several promising senses to be investigated such as somatosensation (i.e., touch stimuli) and olfaction (i.e., smell). For example, somatosensation could be applied in the work devices by providing sensations related to pressures or texture to the skin. The application of the somatosensation concept was not a new thing, for example, the acupressure application [177–179] in devices and traditional medicine to release fatigue and the utilization of modern mechanical keyboards that provides tactile feedback [180–182]. Additionally, the olfaction sense will enable individuals to detect and identify odors. Olfaction might correlate with and influence cognition to some extent [183–185], in which some specific scents or aromas with perceived pleasantly have the potency to improve mood and relax feelings which might indirectly boost cognitive performance [186–188].

Multisensory integration also has the potential for further research. Several cognitive tasks entangle multiple senses that carry information being integrated together. The multisensory approach carried potential benefits to improve focus, memory, and cognitive performance [189–191]. Future research exploring the combination of several sensory stimuli to enhance cognitive performance is promising in current multi-tasking job demands.

Bibliography

- [1] International Energy Agency (IEA). (2024). Buildings. <https://www.iea.org/energy-system/buildings>.
- [2] Liang, W., Han, L., Zhan, S., Chong, A., & Hong, T. (2024). Energy flexibility quantification of a tropical net-zero office building using physically consistent neural network-based model predictive control. *Advances in Applied Energy*, 14. <https://doi.org/10.1016/j.adapen.2024.100167>.
- [3] Webster, B., Toffoli, L., Campbell, M., Badger, L., Donovan, A., Lane, D., McGrath, K., Satre-Meloy, A., Wilson, E., Reyna, J., Metzger, C., & Pilet, T. (2024). Accelerating residential building decarbonization: Market guidance to scale zero-carbon-aligned buildings. *Advanced Building Construction*.
- [4] Harris, R. (2024). Productive and healthy workplaces: A literature review. www.ramidus.co.uk.
- [5] Miyagi, K., Oishi, K., Uchiyama, K., Ishii, H., & Shimoda, H. (2013). Proposal of Intellectual Productivity Model Based on Work State Transition. *International Conference on Engineering Psychology and Cognitive Ergonomics*, 335-343. Berlin: Springer. https://doi.org/10.1007/978-3-642-39360-0_37.
- [6] Shimoda, H., Oishi, K., Miyagi, K., Uchiyama, K., Ishii, H., Obayashi, F., & Iwakawa, M. (2013). An Intellectual Productivity Evaluation Tool Based on Work Concen-

- tration. *International Conference on Engineering Psychology and Cognitive Ergonomics*, 364–372. https://doi.org/10.1007/978-3-642-39360-0_40.
- [7] Ishii, H., Kanagawa, H., Shimamura, Y., Uchiyama, K., Miyagi, K., Obayashi, F., & Shimoda, H. (2018). Intellectual productivity under task ambient lighting. *Lighting Research Technology*, 50(2), 237-252. <https://doi.org/10.1177/1477153516656034>.
- [8] Bills, A. G. (1931). Blocking: A New Principle of Mental Fatigue. *The American Journal of Psychology*, 230-245. <https://doi.org/10.2307/1414771>.
- [9] Obayashi, F., Miyagi, K., Ito, K., Taniguchi, K., Ishii, H., & Shimoda, H. (2019). Objective and quantitative evaluation of intellectual productivity under control of room airflow. *Building and Environment*, 149, 48–57. <https://doi.org/10.1016/j.buildenv.2018.12.005>.
- [10] Meijman, T. F., & Mulder, G. (1998). Psychological aspects of workload. In P. J. D. Drenth H. Thierry (Eds.), *Handbook of work and organizational psychology*, Vol. 2, pp. 5-33. Hove, UK: Psychology Press.
- [11] Sianoja, M., Syrek, C. J., de Bloom, J., Korpela, K., & Kinnunen, U. (2018). Enhancing daily well-being at work through lunchtime park walks and relaxation exercises: Recovery experiences as mediators. *Journal of occupational health psychology*, 23(3), pp. 428–442. <https://doi.org/10.1037/ocp0000083>.
- [12] Kaplan, S. (1995). The restorative benefits of nature: Toward an integrative framework. *Journal of Environmental Psychology*, vol. 15, pp. 169–182.
- [13] Schumann, F., Steinborn, M. B., Kürten, J., Cao, L., Händel, B. F., & Huestegge, L. (2022). Restoration of attention by rest in a multitasking world: Theory, methodology, and empirical evidence. *Frontiers in Psychology*, vol.13. <https://doi.org/10.3389/fpsyg.2022.867978>.

- [14] Ulrich, R. S. (1986). Human responses to vegetation and landscapes. *Landscape and Urban Planning*, vol. 13, pp. 29–44. [https://doi.org/10.1016/0169-2046\(86\)90005-8](https://doi.org/10.1016/0169-2046(86)90005-8).
- [15] Thompson, C. W., & de Oliveira, E. M. S. (2016). Urban green spaces and health: A review of evidence. Evidence on health benefits of urban green spaces. In A. Egorov, P. Mudu, M. Braubach, M. Martuzzi (Eds.) *World Health Organisation Regional Office for Europe, Copenhagen*, pp. 3–20.
- [16] Hobfoll, S. E. (1989). Conservation of resources: A new attempt at conceptualizing stress. *American Psychologist*, 44(3), 513–524. <https://doi.org/10.1037/0003-066X.44.3.513>
- [17] Lazarus, R. S., & Folkman, S. (1984). *Stress, appraisal and coping*. New York: Springer.
- [18] Lazarus, R. S., & Folkman, S. (1987). Transactional theory and research on emotions and coping. *European Journal of Personality*, 1(3), 141–169. <https://doi.org/10.1002/per.2410010304>.
- [19] Kitayama, K., Dianita, O., Ueda, K., Ishii, H., Shimoda, H., & Obayashi, F. (2022). Micro-refresh to Restore Intellectual Concentration Decline During Office Work: An Attempt at Quantitative Effect Evaluation. *Proceedings on the 6th International Conference on Intelligent Human Systems Integration*, 56, Italy, February 22–24, pp. 169–182. <https://doi.org/10.54941/ahfe1002268>.
- [20] Bosch, C., & Sonnentag, S. (2019). Should I take a break? A daily reconstruction study on predicting micro-breaks at work. *International Journal of Stress Management*, vol. 26(4), pp. 378–388. <https://doi.org/10.1037/str0000117>.
- [21] Sianoja, M., Syrek, C. J., de Bloom, J., Korpela, K., & Kinnunen, U. (2018). Enhancing daily well-being at work through lunchtime park walks and relaxation exercises:

- Recovery experiences as mediators. *Journal of occupational health psychology*, vol. 23(3), pp. 428–442. <https://doi.org/10.1037/ocp0000083>.
- [22] Zacher, H., Brailsford, H. A., & Parker, S. L. (2014). Micro-breaks matter: A diary study on the effects of energy management strategies on occupational well-being. *Journal of Vocational Behavior*, vol. 85(3), pp. 287–297. <https://doi.org/10.1016/j.jvb.2014.08.005>.
- [23] Zapf, D. (2002). Emotion work and psychological well-being: A review of the literature and some conceptual considerations. *Human Resource Management Review*, vol. 12(2), pp. 237–268. [https://doi.org/10.1016/S1053-4822\(02\)00048-7](https://doi.org/10.1016/S1053-4822(02)00048-7).
- [24] Zapf, D., Seifert, C., Schmutte, B., Mertini, H., & Holz, M. (2001). Emotion work and job stressors and their effects on burnout. *Psychology health*, vol. 16(5), pp. 527–545. <https://doi.org/10.1080/08870440108405525>.
- [25] Wickens, C. (2021). Attention: Theory, Principles, Models and Applications. *International Journal of Human-Computer Interaction*, vol. 37(5), pp. 403–417. <https://doi.org/10.1080/10447318.2021.1874741>.
- [26] Wickens, C. D., Gutzwiller, R. S., & Santamaria, A. (2015). Discrete task switching in overload: A meta-analysis and a model. *International Journal of Human-Computer Studies*, vol. 79, pp. 79–84. <https://doi.org/10.1016/j.ijhcs.2015.01.002>.
- [27] Wickens, C. D. (2002). Multiple resources and performance prediction. *Theoretical Issues in Ergonomics Science*, vol. 3(2), pp. 159–177. <https://doi.org/10.1080/14639220210123806>.
- [28] Sonnentag, S., & Fritz, C. (2014). Recovery from job stress: The stressor-detachment model as an integrative framework. *Journal of Organizational Behavior*, vol. 36(S1), pp. S72–S103. <https://doi.org/10.1002/job.1924>.

- [29] Karabinski, T., Haun, V. C., Nübold, A., Wendsche, J., & Wegge, J. (2021). Interventions for improving psychological detachment from work: A meta-analysis. *Journal of occupational health psychology*, vol. 26(3), pp. 224–242. <https://doi.org/10.1037/ocp0000280>.
- [30] Wendsche, J., & Lohmann-Haislah, A. (2017). A meta-analysis on antecedents and outcomes of detachment from work. *Frontiers in Psychology*, 7, Article 2072. <https://doi.org/10.3389/fpsyg.2016.02072>.
- [31] Kianto, A., Shujahat, M., Hussain, S., Nawaz, F., & Ali, M. (2019). The impact knowledge management on knowledge worker productivity. *Baltic Journal of Management*, 14(2), 178–197. <https://doi.org/10.1108/BJM-12-2017-0404>.
- [32] Simonenko, S. I. (2018). Contribution of intellectual abilities to a manager's success: correlation between the results of cognitive ability tests and an assessment center. *Journal of Psychology and Clinical Psychiatry*, 9(6), 671–676. <https://doi.org/10.15406/jpcpy.2018.09.00614>.
- [33] Sonnentag, S., Venz, L., & Casper, A. (2017). Advances in recovery research: What have we learned? What should be done next?. *Journal of Occupational Health Psychology*, 22(3), 365–380. <https://doi.org/10.1037/ocp0000079>
- [34] Sonnentag, S. (2018). The recovery paradox: Portraying the complex interplay between job stressors, lack of recovery, and poor well-being. *Research in Organizational Behavior*, 38, 169–185. <https://doi.org/10.1016/j.riob.2018.11.002>
- [35] Japan External Trade Organization (JETRO). (2023). Section 4. Human resource management 4.5 Legislation on working hours, breaks and days off, JETRO websites, retrieved on 7 May 2023, https://www.jetro.go.jp/en/invest/setting_up/section4/page5/.

- [36] OSHA Education Center. (2023). What are the employee lunch break labor laws? OSHA Education Center websites, retrieved on 7 May 2023, <https://www.oshaeducationcenter.com/articles/employee-lunch-breaks/>.
- [37] UK Government. (2023). Rest breaks at work, UK Government websites, retrieved on 7 May 2023, <https://www.gov.uk/rest-breaks-work>.
- [38] Trougakos, J. P., & Hideg, I. (2009). Momentary work recovery: The role of within-day work breaks. Current perspectives on job-stress recovery, 37–84. JAI Press/Emerald Group Publishing. [https://doi.org/10.1108/S1479-3555\(2009\)0000007005](https://doi.org/10.1108/S1479-3555(2009)0000007005).
- [39] Kim, S., Park, Y., & Headrick, L. (2018). Daily micro-breaks and job performance: General work engagement as a cross-level moderator. *Journal of Applied Psychology*, 103(7), 772–786. <https://doi.org/10.1037/apl0000308>.
- [40] Ibes, D., Hiram, I., & Schuyler, C. (2018). Greenspace ecotherapy interventions: The stress-reduction potential of green micro-breaks integrating nature connection and mind-body skills. *Ecopsychology*, 10(3), 137-150. <https://doi.org/10.1089/eco.2018.0024>.
- [41] Lee, K. E., Williams, K. J. H., Sargent, L. D., Williams, N. S. G., & Johnson, K. A. (2015). 40-second green roof views sustain attention: The role of micro-breaks in attention restoration. *Journal of Environmental Psychology*, 42, 182-189. <https://doi.org/10.1016/j.jenvp.2015.04.003>.
- [42] Fritz, C., Lam, C. F., & Spreitzer, G. M. (2011). It's the little things that matter: An examination of knowledge workers' energy management. *The Academy of Management Perspectives*, 25(3), 28–39. <https://doi.org/10.5465/AMP.2011.63886528>.
- [43] Mijović, P., Ković, V., Mačuzić, I., Todorović, P., Jeremić, B., Milovanović, M., & Gligorić, I. (2015). Do micro-breaks increase the attention level of an assembly

- worker? An ERP study. *Procedia Manufacturing*, 3, 5074-5080. <https://doi.org/10.1016/j.promfg.2015.07.521>.
- [44] Biwer, F., Wiradhany, W., Oude Egbrink, M. G. A., & de Bruin, A. B. H. (2023). Understanding effort regulation: Comparing 'Pomodoro' breaks and self-regulated breaks. *British Journal of Educational Psychology*, 1-15. <https://doi.org/10.1111/bjep.12593>.
- [45] Conlin, A., Hu, X., & Barber, L. K. (2021). Comparing relaxation versus mastery microbreak activity: A within-task recovery perspective. *Applied Psychology*, 124(1), 248-265. <https://doi.org/10.1177/0033294119900347>.
- [46] Lee, J. Y., Donkers, J., Jarodzka, H., Sellenraad, G., & van Merriënboer, J. J. G. (2020). Different effects of pausing on cognitive load in a medical simulation game. *Computers in Human Behavior*, 110, <https://doi.org/10.1016/j.chb.2020.106385>.
- [47] Cropley, M., Weidenstedt, L., Leick, B., & Sütterlin, S. (2023). Working from home during lockdown: the association between rest breaks and well-being. *Ergonomics*, 66(4), 443-453. <https://doi.org/10.1080/00140139.2022.2095038>.
- [48] Hunter, E. M., & Wu, C. (2016). Give me a better break: Choosing workday break activities to maximize resource recovery. *Journal of Applied Psychology*, 1(2), 302-311. <http://dx.doi.org/10.1037/apl0000045302>.
- [49] Ayres, P., Lee, J. Y., Paas, F., & van Merriënboer, J. J. G. (2021). The validity of physiological measures to identify differences in intrinsic cognitive load. *Frontiers in Psychology*, 12. <https://doi.org/10.3389/fpsyg.2021.702538>.
- [50] Ichien, N., Alfred, K. L., Baia, S., Kraemer, D. J. M., Holyoak, K. J., Bunge, S. A., & Lu, H. (2023). Relational and lexical similarity in analogical reasoning and recognition memory: Behavioral evidence and computational evaluation. *Cognitive Psychology*, 141. <https://doi.org/10.1016/j.cogpsych.2023.101550>.

- [51] Farell, B. (2022). Hypothesis testing, attention, and 'same'-'different' judgments, *Cognitive Psychology*, 132. <https://doi.org/10.1016/j.cogpsych.2021.101443>.
- [52] Ueda, K., Tsuji, Y., Shimoda, H., Ishii, H., Obayashi, F., & Taniguchi, K. (2016). Development of "Comparison Task" to Measure Intellectual Concentration Affected by Room Environment. *Proceedings of the 2016 International Conference on Communication and Information Systems*, 58-64. <https://doi.org/10.1145/3023924.3023939>.
- [53] JavaScript. (2016). <https://www.javascript.com/>.
- [54] Apple Computer Inc. (2011). Apple iPad 2 A1395 <https://www.apple.com/>.
- [55] Sasaki, T., & Matsumoto, S. (2005). Actual conditions of work, fatigue and sleep in non-employed, home-based female information technology workers with preschool children. *Industrial Health*, 43, 142 – 150. <https://doi.org/10.2486/indhealth.43.142>.
- [56] Hart, S. G. (2006). Nasa-Task Load Index (NASA-TLX); 20 Years Later. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 50(9), pp. 904-908. <https://doi.org/10.1177/154193120605000909>.
- [57] Virtanen, K., Mansikka, H., Kontio, H., & Harris, D. (2021). Weight watchers: NASA-TLX weights revisited. *Theoretical Issues in Ergonomics Science*, 23(6), 725-748. <https://doi.org/10.1080/1463922X.2021.2000667>.
- [58] Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. In Gawron, V. J. *Human Performance Measures Handbook*. New Jersey: Lawrence Erlbaum Associates.
- [59] Gawron, V. J. (2000). *Human Performance Measures Handbook*. New Jersey: Lawrence Erlbaum Associates.

- [60] Minitab. (2023). Minitab. Retrieved from Minitab: <https://www.minitab.com/>.
- [61] Dragoni, L., Oh, I.-S., Vankatwyk, P., & Tesluk, P. E. (2011). Developing executive leaders: The relative contribution of cognitive ability, personality, and the accumulation of work experience in predicting strategic thinking competency. *Personnel Psychology*, 64(4), 829–864. <https://doi.org/10.1111/j.1744-6570.2011.01229.x>.
- [62] Morgeson, F. P., Delaney-Klinger, K., & Hemingway, M. A. (2005). The importance of job autonomy, cognitive ability, and job-related skill for predicting role breadth and job performance. *Journal of Applied Psychology*, 90(2), 399–406. <https://doi.org/10.1037/0021-9010.90.2.399>.
- [63] Meijman, T. F. (1989). Belasting en herstel: een begrippenkader voor arbeidspsychologisch onderzoek van werkbelasting [Effort and recuperation: a conceptual framework for psychological research of workload]. In T. F. Meijman (Ed.), *Mentale belasting en werkstress: een arbeidspsychologische benadering* [Mental workload and job stress: a work psychological approach], 5–20.
- [64] van Veldhoven, M. J. P. M. (2008). Need for recovery after work: An overview of construct, measurement and research. in J. Houdmont & S. Leka (eds), *Occupational health psychology: European perspectives on research, education and practice*. 3, Nottingham University Press, Nottingham, 1-25.
- [65] Ulrich, R. S., Simons, R. F., Losito, B. D., Fiorito, E., Miles, M. A., & Zelson, M. (1991). Stress recovery during exposure to natural and urban environments. *Journal of Environmental Psychology*, 11(3), 201–230. [https://doi.org/10.1016/S0272-4944\(05\)80184-7](https://doi.org/10.1016/S0272-4944(05)80184-7).
- [66] Makov, S., Pinto, D., Yahav, P. H-s., Miller, L. M., & Golumbic, E. Z. (2023). “Unattended, distracting or irrelevant”: Theoretical implications of terminological choices

- in auditory selective attention research. *Cognition*, 231, 1–9. <https://doi.org/10.1016/j.cognition.2022.105313>.
- [67] Liu, C., Zang, Q., Li, J., Pan, X., Dai, H., & Gao, W. (2023). The effect of the acoustic environment of learning spaces on students' learning efficiency: A review. *Journal of Building Engineering*, 79, 1–15. <https://doi.org/10.1016/j.jobbe.2023.107911>.
- [68] Visentin, C., Pellegatti, M., Garraffa, M., Domenico, A. D., & Prodi, N. (2023). Individual characteristics moderate listening effort in noisy classrooms. *Scientific Reports*, 13. <https://doi.org/10.1038/s41598-023-40660-1>.
- [69] Pellegatti, M., Torresin, S., Visentin, C., Babich, F., & Prodi, N. (2023). Indoor soundscape, speech perception, and cognition in classrooms: A systematic review on the effects of ventilation-related sounds on students. *Building and Environment*, 236, 1–17. <https://doi.org/10.1016/j.buildenv.2023.110194>.
- [70] Annerstedt, M., Jönsson, P., Wallergård, M., Johansson, G., Karlson, B., Grahn, P., Hansen, A. M., & Währborg, P. (2013). Inducing physiological stress recovery with sounds of nature in a virtual reality forest - Result from a pilot study. *Physiology & Behavior*, 118, 240–250. <https://doi.org/10.1016/j.physbeh.2013.05.023>.
- [71] Song, I., Baek, K., Kim, C., & Song, C. (2023). Effects of nature sounds on the attention and physiological and psychological relaxation. *Urban Forestry & Urban Greening*, 86, 1–8. <https://doi.org/10.1016/j.ufug.2023.127987>.
- [72] Ge, Y., Xie, H., Su, M., & Gu, T. (2023). Effects of the acoustic characteristics of natural sounds on perceived tranquility emotional valence and arousal in patients with anxiety disorders. *Applied Acoustic*, 213, 1–13. <https://doi.org/10.1016/j.apacoust.2023.109664>.

- [73] Liu, G., Zou, J., Qiao, M., Zhu, H., Yang, Y., Guan, H., & Hu, S. (2023). Stress recovery at home: Effects of the indoor visual and auditory stimuli in buildings, *Building and Environment*, 244, 1–10. <https://doi.org/10.1016/j.buildenv.2023.110752>.
- [74] Ghezeljeh, T. N., Nasari, M., Haghani, H., & Rezaei Loieh, H. (2017). The effect of nature sounds on physiological indicators among patients in the cardiac care unit. *Complementary Therapies in Clinical Practice*, 29, 147–152. <https://doi.org/10.1016/j.ctcp.2017.09.010>.
- [75] Krzywicka, P., & Byrka, K. (2017). Restorative Qualities of and Preference for Natural and Urban Soundscapes. *Frontiers in Psychology*, 8, 1705. <https://doi.org/10.3389/fpsyg.2017.01705>.
- [76] PreSonus. (2022). PreSonus Audio Electronics, Inc. <https://www.presonus.com/>.
- [77] The National Institute for Occupational Safety and Health (NIOSH). (2023). Understand noise exposure. <https://www.cdc.gov/niosh/topics/noise/>.
- [78] Dali Zensor 1 (2012). Danish Audiophile Loudspeaker Industries. <https://www.dali-speakers.com/>.
- [79] Victor AX-S313. JVC Kenwood. <https://www3.jvckenwood.com/>.
- [80] AG06MK2. Yamaha. <https://jp.yamaha.com/>.
- [81] A2602 Apple iPad. (2021). Apple Computer Inc. <https://www.apple.com/>.
- [82] Dror, I. E. (2020). The error in "error rate": Why error rates are so needed, yet so elusive. *Journal of Forensic Sciences*, vol. 65(4). pp. 1034–1039. <https://doi.org/10.1111/1556-4029.14435>.

- [83] Sonnentag, S., & Fritz, C. (2007). The Recovery Experience Questionnaire: Development and validation of a measure for assessing recuperation and unwinding from work. *Journal of Occupational Health Psychology*, 12(3), 204–221. <https://doi.org/10.1037/1076-8998.12.3.204>.
- [84] Derryberry, D., & Reed, M. A. (2002). Anxiety-related attentional biases and their regulation by attentional control. *Journal of Abnormal Psychology*, 111(2), 225–236. <https://doi.org/10.1037//0021-843x.111.2.225>.
- [85] Abasi, I., Mohammadkhani, P., Purshahbaz, A., & Dolatshahi, B. (2017). The psychometric properties of attentional control scale and its relationship with symptoms of anxiety and depression: A study on Iranian population. *Iranian Journal of Psychiatry*, 12(2), 109–117.
- [86] Fajkowska, M., & Derryberry, D. (2010). Psychometric properties of Attentional Control Scale: The preliminary study on a Polish sample. *Polish Psychological Bulletin*, 41(1), 1–7. <https://doi.org/10.2478/s10059-010-0001-7>.
- [87] Melendez, R., Bechor, M., Rey, Y., Pettit, J. W., & Silverman, W. K. (2017). Attentional control scale for children: Factor structure and concurrent validity among children and adolescents referred for anxiety disorders. *Journal of Clinical Psychology*, 73(4). 489499. <https://doi.org/10.1002/jclp.22346>.
- [88] Ólafsson, R. P., Smári, J., Gumundsdóttir, F., Olafsdóttir, G., Harardóttir, H. L., & Einarsson, S. M. (2011). Self reported attentional control with the Attentional Control Scale: Factor structure and relationship with symptoms of anxiety and depression. *Journal of Anxiety Disorders*, 25(6), 777–782. <https://doi.org/10.1016/j.janxdis.2011.03.013>.
- [89] Berger, A., & Kiefer, M. (2021). Comparison of different response time outlier exclusion methods: A simulation study. *Frontiers in Psychology*, 12. <https://doi.org/10.3389/fpsyg.2021.675558>.

- [90] Luo, J., Wang, M., & Chen, L. (2021). The Effects of Using a Nature-Sound Mobile Application on Psychological Well-Being and Cognitive Performance Among University Students. *Frontiers in Psychology*, 12, 699908. <https://doi.org/10.3389/fpsyg.2021.699908>.
- [91] Qiu, M., Sha, J., & Utomo, S. (2021). Listening to forests: Comparing the perceived restorative characteristics of natural soundscapes before and after the COVID-19 pandemic. *Sustainability*, 13(1): 293. <https://doi.org/10.3390/su13010293>.
- [92] Head, J., Tenan, M. S., Tweedell, A. J., Wilson, K. M., & Helton, W. S. (2020). Response Complexity Reduces Errors on a Response Inhibition Task. *Human Factors*, 62(5), 787–799. <https://doi.org/10.1177/0018720819852801>.
- [93] Hedblom, M., Gunnarsson, B., Schaefer, M., Knez, I., Thorsson, P., & Lundström, J. N. (2019). Sounds of Nature in the City: No Evidence of Bird Song Improving Stress Recovery. *International Journal of Environmental Research and Public Health*, 16(8), 1390. <https://doi.org/10.3390/ijerph16081390>.
- [94] Nicolosi, V., Wilson, J., Yoshino, A., & Viren, P. (2020). The restorative potential of coastal walks and implications of sound. *Journal of Leisure Research*, 52(1), 41–61. <https://doi.org/10.1080/00222216.2020.1741329>.
- [95] Ratcliffe, E., Gatersleben, B., & Sowden, P. T. (2020). Predicting the perceived restorative potential of bird sounds through acoustics and aesthetics. *Environment and Behavior*, 52(4), 371–400. <https://doi.org/10.1177/0013916518806952>.
- [96] Hornung, S. (2019). Crafting task and cognitive job boundaries to enhance self-determination, impact, meaning and competence at work. *Behavioral Sciences*, 9(12):136. <https://doi.org/10.3390/bs9120136>.
- [97] Kotur, B. R., & Anbazhagan, S. (2014). Education and work-experience-influence on the performance. *IOSR Journal of Business and Management*, 16(5):III, 104–110.

- [98] Quiñones, M. A., Ford, J. K., & Teachout, M. S. (1995). The relationship between work experience and job performance: A conceptual and meta-analytic review. *Personnel Psychology*, 48(4), 887–910. <https://doi.org/10.1111/j.1744-6570.1995.tb01785.x>.
- [99] Cohrdes, C., Wrzus, C., Wald-Fuhrmann, M., & Riediger, M. (2020). “The sound of affect”: Age differences in perceiving valence and arousal in music and their relation to music characteristics and momentary mood. *Musicae Scientiae*, 24(1), 21-43. <https://doi.org/10.1177/1029864918765613>.
- [100] Sudimac, S., & Kühn, S. (2022). A one-hour walk in nature reduces amygdala activity in women, but not in men. *Frontiers in Psychology*, 13. <https://doi.org/10.3389/fpsyg.2022.931905>.
- [101] Korpela, K. M., Ylén, M., Tyrväinen, L., & Silvennoinen H. (2010). Favorite green, waterside and urban environments, restorative experiences and perceived health in Finland. *Health Promotion International*, 25(2), 200–209. <https://doi.org/10.1093/heapro/daq007>.
- [102] Deng, L., Luo, H., Ma, J., Huang, Z., Sun, L-X., Jiang, M-Y., Zhu, C-Y., & Li, X. (2020). Effects of integration between visual stimuli and auditory stimuli on restorative potential and aesthetic preference in urban green spaces. *Urban Forestry Urban Greening*, 53, 1–13. <https://doi.org/10.1016/j.ufug.2020.126702>.
- [103] Park, S. H., Lee, P. J., Jung, T., & Swenson, A. (2020). Effects of the aural and visual experience on psycho-physiological recovery in urban and rural environments. *Applied Acoustics*, 169, 1–14. <https://doi.org/10.1016/j.apacoust.2020.107486>.
- [104] Geurts, S. A. E., & Sonnentag, S. (2006). Recovery as an explanatory mechanism in the relation between acute stress reactions and chronic health impairment. *Scandina-*

- vian Journal of Work, Environment & Health, 32(6), 482–492. <https://doi.org/10.5271/sjweh.1053>.
- [105] Headrick, L., Newman, D. A., Park, Y. A., & Liang, Y. (2022). Recovery experiences for work and health outcomes: A meta-analysis and recovery-engagement-exhaustion model. *Journal of Business and Psychology*, 38, 821–864. <https://doi.org/10.1007/s10869-022-09821-3>.
- [106] Firoozabadi, A., Uitdewilligen, S., & Zijlstra, F. R. H. (2018). Should you switch off or stay engaged? The consequences of thinking about work on the trajectory of psychological well-being over time. *Journal of Occupational Health Psychology*, 23(2), 278–288. <https://doi.org/10.1037/ocp0000068>.
- [107] Weigelt, O., Gierer, P., & Syrek, C. J. (2019). My Mind is Working Overtime-Towards an Integrative Perspective of Psychological Detachment, Work-Related Rumination, and Work Reflection. *International journal of environmental research and public health*, 16(16), 2987. <https://doi.org/10.3390/ijerph16162987>.
- [108] Brosschot, J. F., Pieper, S., & Thayer, J. F. (2005). Expanding stress theory: Prolonged activation and perseverative cognition. *Psychoneuroendocrinology*, 30(10), 1043–1049. <https://doi.org/10.1016/j.psyneuen.2005.04.008>.
- [109] Aristizabal, S., Byun, K., Porter, P. Clements, N., Campanella, C., Li, L., Mullan, A., Ly, S., Senerat, A., Nenadic, I. Z., Browning, W. D., Loftness, V., & Bauer, B. (2021). Biophilic office design: Exploring the impact of a multisensory approach on human well-being. *Journal of Environmental Psychology*, 77, 1–15. <https://doi.org/10.1016/j.jenvp.2021.101682>.
- [110] Latini, A., Torresin, S., Oberman, T., Di Giuseppe, E., Aletta, F., Kang, J., & D’Orazio, M. (2024). Effects of biophilic design interventions on university students’ cognitive performance: An audio-visual experimental study in an immersive virtual of-

- office environment. *Building and Environment*, 250, 111196. <https://doi.org/10.1016/j.buildenv.2024.111196>.
- [111] Mollazadeh, M., & Zhu, Y. (2021). Application of virtual environments for biophilic design: A critical review. *Buildings*, 11(4), 148. <https://doi.org/10.3390/buildings11040148>.
- [112] Yin, J., Arfaei, N., MacNaughton, P., Catalano, P. J., Allen, J. G., & Spengler, J. D. (2019). Effects of biophilic interventions in office on stress reaction and cognitive function: A randomized crossover study in virtual reality. *Indoor Air*, 29(6), 1028–1039. <https://doi.org/10.1111/ina.12593>.
- [113] Yin, J., Yuan, J., Arfaei, N., Catalano, P. J., Allen, J. G., & Spengler, J. D. (2020). Effects of biophilic indoor environment on stress and anxiety recovery: A between-subjects experiment in virtual reality. *Environment International*, 136, 105427. <https://doi.org/10.1016/j.envint.2019.105427>.
- [114] Bogdanov, V. B., Marquis-Favre, C., Cottet, M., Beffara, B., Perrin, F., Dumortier, D., & Ellermeier, W. (2022). Nature and the city: Audiovisual interactions in pleasantness and psychophysiological reactions, *Applied Acoustics*, 193, 108762. <https://doi.org/10.1016/j.apacoust.2022.108762>.
- [115] Schertz, K. E., & Berman, M. G. (2019). Understanding nature and its cognitive benefits. *Current Directions in Psychological Science*, 28(5), 496–502. <https://doi.org/10.1177/09637214198541>.
- [116] Yin, J., Zhu, S., MacNaughton, P., Allen, J.G., & Spengler, J. D. (2018). Physiological and cognitive performance of exposure to biophilic indoor environment. *Building and Environment*, 132, 255–262. <https://doi.org/10.1016/j.buildenv.2018.01.006>.

- [117] Emamjomeh, A., Zhu, Y., & Beck, M. (2020). The potential of applying immersive virtual environment to biophilic building design: A pilot study. *Journal of Building Engineering*, 32, 101481. <https://doi.org/10.1016/j.jobe.2020.101481>.
- [118] White, M. P., Yeo, N. L., Vassiljev, P., Lundstedt, R., Wallergård, M., Albin, M., & Löhmus, M. (2018). A prescription for “nature” – the potential of using virtual nature in therapeutics. *Neuropsychiatric Disease and Treatment*, 14, 3001–3013. <https://doi.org/10.2147/NDT.S179038>.
- [119] Bell, S. L. (2019). Nurturing sociality with birdlife in the context of life with sight impairment: a role for nonhuman charisma. *Social & Cultural Geography*, 22(7), 917–935. <https://doi.org/10.1080/14649365.2019.1667018>.
- [120] Shaw, B., Coyle, A., Gatersleben, B., & Ungar, S. (2015). Exploring nature experiences of people with visual impairments / Vivir la naturaleza con una discapacidad visual. *PsyEcology*, 6(3), 287–327. <https://doi.org/10.1080/21711976.2015.1026086>.
- [121] International Organization for Standardization. (2014). Acoustics – Soundscape – Part 1: Definition and Conceptual Framework (ISO 12913-1: 2014). <https://www.iso.org/standard/52161.html>.
- [122] World Health Organization. (2009). Night noise guidelines for Europe. <https://iris.who.int/handle/10665/326486>.
- [123] Ratcliffe, E. (2021). Sound and soundscape in restorative natural environments: A narrative literature review. *Frontiers in Psychology*, 12, 1–8. <https://doi.org/10.3389/fpsyg.2021.570563>.
- [124] Grinfeder, E., Lorenzi, C., Hauptert, S., & Sueur, J. (2022). What do we mean by “soundscape”? A functional description. *Frontiers in Ecology and Evolution*, 10, 894232. <https://doi.org/10.3389/fevo.2022.894232>.

- [125] Hsieh, C.-H., Yang, J.-Y., Huang, C.-W., & Chin, W. C. B. (2023). The effect of water sound level in virtual reality: A study of restorative benefits in young adults through immersive natural environments. *Journal of Environmental Psychology*, 88. <https://doi.org/10.1016/j.jenvp.2023.102012>.
- [126] Hong, J. Y., Lam, B., Ong, Z.-T., Ooi, K., Gan, W.-S., Kang, J., Yeong, S., Lee, I., & Tan, S.-T. (2021). A mixed-reality approach to soundscape assessment of outdoor urban environments augmented with natural sounds. *Building and Environment*, 194, 1–14. <https://doi.org/10.1016/j.buildenv.2021.107688>.
- [127] Alvarsson, J. J., Wiens, S., & Nilsson, M. E. (2010). Stress recovery during exposure to nature sound and environmental noise. *International Journal of Environmental Research and Public Health*, 7, 1036–1046. <https://doi.org/10.3390/ijerph7031036>.
- [128] Grinfeder, E., Lorenzi, C., Hauptert, S., & Sueur, J. (2022). What do we mean by “soundscape”? A functional description. *Frontiers in Ecology and Evolution*, 10, 894232. <https://doi.org/10.3389/fevo.2022.894232>.
- [129] Sonnentag, S., & Fritz, C. (2007). The recovery experience questionnaire: Development and validation of a measure for assessing recuperation and unwinding from work. *Journal of Occupational Health Psychology*, 12(3), 204–221. <https://doi.org/10.1037/1076-8998.12.3.204>.
- [130] Alarcon, G. E. (2011). A meta-analysis of burnout with job demands, resources, and attitudes. *Journal of Vocational Behavior*, 79(2), 549–562. <https://doi.org/10.1016/j.jvb.2011.03.007>.
- [131] Meyer, S. C., & Hünefeld, L. (2018). Challenging cognitive demands at work, related working conditions, and employee well-being. *International Journal of Environmental Research and Public Health*, 15(12), 2911. <https://doi.org/10.3390/ijerph15122911>

- [132] Van den Broeck, A., Elst, T. V., Baillien, E., Sercu, M., Schouteden, M., De Witte, H., & Godderis, L. (2017). Job demands, job resources, burnout, work engagement, and their relationships: An analysis across sectors. *Journal of Occupational and Environmental Medicine*, 59(4), 369-376. <https://doi.org/10.1097/JOM.0000000000000964>.
- [133] Headrick, L., Newman, D. A., Park, Y. A., & Liang, Y. (2023). Recovery experiences for work and health outcomes: A meta-analysis and recovery-engagement-exhaustion model. *Journal of Business and Psychology*, 38, 821-864. <https://doi.org/10.1007/s10869-022-09821-3>
- [134] Van Hooff, M. L. M., Flaxman, P. E., Söderberg, M., Stride, C. B., & Geurts, S. A. E. (2018). Basic psychological need satisfaction, recovery state, and recovery timing. *Human Performance*, 31(2), 125–143. <https://doi.org/10.1080/08959285.2018.1466889>.
- [135] Abe, R., Higashimaki, T., Nomura, K., Dianita, O., Ueda, K., Ishii, H., Shimoda, H., & Obayashi, F. (2024). “An experimental study on the effect of short-term air-flow on concentration during intellectual work,” in *Applied Human Factors and Ergonomics (AHFE 2024): Proceedings of the 15 International Conference on Applied Human Factors and Ergonomics and the Affiliated Conference, AHFE 2024, Nice, France, July 24-27, 2024*, In Vesa Salminen (eds) Human Factors, Business Management and Society. USA: AHFE Open Access, 170-177, 135. <http://doi.org/10.54941/ahfe1004943>.
- [136] Dianita, O., Higashimaki, T., Abe, R., Ueda, K., Ishii, H., Shimoda, H., & Obayashi, F. (2024). “The investigation of systematic micro-refresh with auditory stimuli on intellectual work,” in *Applied Human Factors and Ergonomics (AHFE 2024): Proceedings of the 15th International Conference on Applied Human Factors and Ergonomics and the Affiliated Conference, AHFE 2024, Nice, France, July 24-27, 2024*,

In Vesa Salminen (eds) Human Factors, Business Management and Society. USA: AHFE Open Access, 163-169, 135. <http://doi.org/10.54941/ahfe1004942>.

- [137] Abd-Alhamid, F., Kent, M., Calautit, J., & Wu, Y. (2020). Evaluating the impact of viewing location on view perception using a virtual environment. *Building and Environment*, 180, 106932. <https://doi.org/10.1016/j.buildenv.2020.106932>.
- [138] NatureManufacture: Forest environment – Dynamic Nature, (2019). <https://assetstore.unity.com/packages/3d/vegetation/forest-environment-dynamic-nature-150668>.
- [139] Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, 39(2), 175–191. <https://doi.org/10.3758/bf03193146>.
- [140] Poulton, E. C. (1982). Poulton, Biases in quantitative judgements. *Applied Ergonomics*, 13(1), 31–42. [https://doi.org/10.1016/0003-6870\(82\)90129-6](https://doi.org/10.1016/0003-6870(82)90129-6).
- [141] Suarez, S., Eynard, B., & Granon, S. (2021). A Dissociation of Attention, Executive Function and Reaction to Difficulty: Development of the MindPulse Test, a Novel Digital Neuropsychological Test for Precise Quantification of Perceptual-Motor Decision-Making Processes. *Frontiers in neuroscience*, vol. 15, 650219. <https://doi.org/10.3389/fnins.2021.650219>.
- [142] Andersson, J., & Peters, B. (2020). The importance of reaction time, cognition, and meta-cognition abilities for drivers with visual deficits. *Cognition, Technology, & Work*, vol. 22, pp. 787–800. <https://doi.org/10.1007/s10111-019-00619-7>.

- [143] Hedge, C., Powell, G., Bompas, A., Vivian-Griffiths, S., & Sumner, P. (2018). Low and variable correlation between reaction time costs and accuracy costs explained by accumulation models: Meta-analysis and simulations. *Psychological Bulletin*, vol. 144(11), pp. 1200–1227. <https://doi.org/10.1037/bul0000164>.
- [144] Kumar, A. P., Omprakash, A., Kuppusamy, M., Maruthy, K. N., Sathiyasekaran, B. W. C., Vijayaraghavan, P. V., & Ramaswamy, P. (2020). How does cognitive function measured by the reaction time and critical flicker fusion frequency correlate with the academic performance of students? *BMC Medical Education*, vol. 20(507). <https://doi.org/10.1186/s12909-020-02416-7>.
- [145] Tubbs-Cooley, H. L., Mara, C. A., Carle, A. C., & Gurses, A. P. (2018). The NASA Task Load Index as a measure of overall workload among neonatal, pediatric and adult intensive care nurses. *Intensive and Critical Care Nursing*, vol. 46, pp. 64-69. <https://doi.org/10.1016/j.iccn.2018.01.004>.
- [146] Said, S., Gozdzik, M., Roche, T. R., Braun, J., Rössler, J., Kaserer, A., Spahn, D. R., Nöthiger, C. B., & Tscholl, D. W. (2020). Validation of the Raw National Aeronautics and Space Administration Task Load Index (NASA-TLX) Questionnaire to Assess Perceived Workload in Patient Monitoring Tasks: Pooled Analysis Study Using Mixed Models. *Journal of medical Internet research*, vol. 22(9), e19472. <https://doi.org/10.2196/19472>.
- [147] Braarud, P. Ø. (2021). Investigating the validity of subjective workload rating (NASA TLX) and subjective situation awareness rating (SART) for cognitively complex human–machine work. *International Journal of Industrial Ergonomics*, vol. 86. <https://doi.org/10.1016/j.ergon.2021.103233>.
- [148] Weng, M., Huber, S., Vilgan, E., Grundgeiger, T., & Sanderson, P. M. (2017). Interruptions, visual cues, and the microstructure of interaction: Four laboratory

- studies. *International Journal of Human-Computer Studies*, 103, 77–94. <https://doi.org/10.1016/j.ijhcs.2017.02.002>.
- [149] Hrymak, V., & de Vries, J. M. A. (2020). The development and trial of systematic visual search: a visual inspection method designed to improve current workplace risk assessment practice. *Policy and Practice in Health and Safety*, 18(1), 9–24. <https://doi.org/10.1080/14773996.2019.1708615>.
- [150] Kim, C. M., van Rompay, T. J. L., Louwers, G. L. M., Yoon, J., & Ludden, G. D. S. (2023). From a morning forest to a sunset beach: Understanding visual experiences and the roles of personal characteristics for designing relaxing digital nature. *International Journal of Human-Computer Interaction*, 1–18. <https://doi.org/10.1080/10447318.2023.2285626>.
- [151] Jeong, J. -E., & Park, S. -A. (2021). Physiological and psychological effects of visual stimulation with green plant types. *International Journal of Environmental Research and Public Health*, 18(24), 12932. <https://doi.org/10.3390/ijerph182412932>.
- [152] Igarashi, M., Yamamoto, T., Lee, J., Song, C., Ikei, H., & Miyazaki, Y. (2014). Effects of stimulation by three-dimensional natural images on prefrontal cortex and autonomic nerve activity: A comparison with stimulation using two-dimensional images. *Cognitive Processing*, 15(4), 551–556. <https://doi.org/10.1007/s10339-014-0627-z>.
- [153] Gago, D., & de Almeida, R. M. M. (2013). Effects of pleasant visual stimulation on attention, working memory, and anxiety in college students. *Psychology & Neuroscience*, 6(3), 351–355. <https://doi.org/10.3922/j.psns.2013.3.12>.
- [154] Song, C., Ikei, H., & Miyazaki, Y. (2018). Physiological effects of visual stimulation with forest imagery. *International Journal of Environmental Research and Public Health*, 15(2), 213. <https://doi.org/10.3390/ijerph15020213>.

- [155] Browning, M. H. E. M., Saeidi-Rizi, F., McAnirlin, O., Yoon, H., & Pei, Y. (2021). The role of methodological choices in the effects of experimental exposure to simulated natural landscapes on human health and cognitive performance: A systematic review. *Environment and Behavior*, 53(7), 687–805. <https://doi.org/10.1177/0013916520906481>.
- [156] Mostajeran, F., Krzikawski, J., Steinicke, F., & Kühn, S. (2021). Effects of exposure to immersive videos and photo slideshows of forest and urban environments. *Scientific Reports*, 11(1), 3994. <https://doi.org/10.1038/s41598-021-83277-y>.
- [157] Mostajeran, F., Fischer, M., Steinicke, F., & Kühn, S. (2023). Effects of exposure to immersive computer-generated virtual nature and control environments on affect and cognition. *Scientific Reports*, 13(1), 220. <https://doi.org/10.1038/s41598-022-26750-6>.
- [158] Reese, G., Kohler, E., & Menzel, C. (2021). Restore or get restored: The effect of control on stress reduction and restoration in virtual nature settings. *Sustainability*, 13(4), 1995. <https://doi.org/10.3390/su13041995>.
- [159] Taylor, R. P., & Sprott, J. C. (2008). Biophilic fractals and the visual journey of organic screen-savers. *Nonlinear Dynamics, Psychology, and Life Sciences*, 12(1), 117–129.
- [160] Alegria, K. (2017). Does technological nature make us smarter: testing the impact of nature on cognition. M. S. thesis, Department of Psychology, California State University, Northridge. Available: <http://hdl.handle.net/10211.3/192566>.
- [161] Dianita, O., Higashimaki, T., Abe, R., Ueda, K., Ishii, H., Shimoda, H., & Obayashi, F. (2024). The investigation of systematic micro-refresh with auditory stimuli on intellectual work. *Proceedings of the 15th International Conference on Applied Human Factors and Ergonomics and the Affiliated Conference*, 163-169, 135, France, July 24-27, 2024, AHFE Open Access. <http://doi.org/10.54941/ahfe1004942>.

- [162] Rodrigues, P. F. S., & Pandeirada, J. N. S. (2018). When visual stimulation of the surrounding environment affects children's cognitive performance, *Journal of Experimental Child Psychology*, 176, 140–149. <https://doi.org/10.1016/j.jecp.2018.07.014>.
- [163] Browning, M. H. E. M., Mimnaugh, K. J., van Riper, C. J., Laurent, H. K., & LaValle, S. M. (2020). Can simulated nature support mental health? Comparing short, single-doses of 360-degree nature videos in virtual reality with the outdoors. *Frontiers in Psychology*, 10. <https://doi.org/10.3389/fpsyg.2019.02667>.
- [164] Knaust, T., Felnhofer, A., Kothgassner, O. D., Höllmer, H., Gorzka, R. -J., & Schulz, H. (2021). Exposure to virtual nature: the impact of different immersion levels on skin conductance level heart rate and perceived relaxation. *Virtual Reality*, 26, 925–938. <https://doi.org/10.1007/s10055-021-00595-2>.
- [165] Luo, H., Wang, X., Fan, M., Deng, L., Jian, C., Wei, M., & Luo, J. (2018). The effect of visual stimuli on stability and complexity of postural control. *Frontiers in Neurology*, 9(48). <https://doi.org/10.3389/fneur.2018.00048>.
- [166] LG. (2024). LG Display Monitor43UD79-B
https://www.lg.com/hk_en/monitors/ultrawide/43ud79-b/.
- [167] Intel. (2017). Intel Core i7-7700 [processor]
<https://www.intel.com/content/www/us/en/products/sku/97128/intel-core-i77700-processor-8m-cache-up-to-4-20-ghz/specifications.html>.
- [168] NVIDIA. (2016). GeForce GTX 1060
<https://www.nvidia.com/content/apac/event/id/overwatch-campaign/geforce-gtx-1060.html>.
- [169] Microsoft. (2023). Windows 10 Pro 16bit [software] <https://www.microsoft.com/ja-jp/windows/business/windows-10-pro>.

- [170] Logitech. (2024). Logitech M220CG silent wireless mouse <https://www.logitech.com/>.
- [171] Patro, S. G. K., & Sahu, K. K. (2015). Normalization: A preprocessing stage. <https://doi.org/10.48550/arXiv.1503.06462>.
- [172] Chelazzi, L., Marini, F., Pascucci, D., & Turatto, M. (2019). Getting rid of visual distractors: the why, when, how, and where. *Current Opinion in Psychology*, 29, 135–147. <https://doi.org/10.1016/j.copsyc.2019.02.004>.
- [173] Kim, C.M., Van Rompay, T., & Ludden, G. (2022). “What makes you feel relaxed in nature?”: Exploring nature-based stimuli as inspiration for designing relaxing experiences. In Lockton, D., Lenzi, S., Hekkert, P., Oak, A., Sádaba, J., Lloyd, P. (eds.), DRS2022: Bilbao, 25 June - 3 July, Bilbao, Spain. <https://doi.org/10.21606/drs.2022.454>.
- [174] Kim, C. M., der Heide, E. M. V., van Rompay, T. J. L., & Ludden, G. D. S. (2024). Reimagine the ICU: Healthcare professionals’ perspectives on how environments (can) promote patient well-being. *HERD: Health Environments Research & Design Journal*, 17(2), 97–114. <https://doi.org/10.1177/19375867231219029>.
- [175] Mcsweeney, J., Rainham, D., Johnson, S. A., Sherry, S. B., & Singleton, J. (2015). Indoor nature exposure (INE): a health-promotion framework. *Health Promotion International*, 30(1), 126–139. <https://doi.org/10.1093/heapro/dau081>.
- [176] Jiang, B., Chang, C.-Y., & Sullivan, W. C. (2014). A dose of nature: Tree cover, stress reduction, and gender differences. *Landscape and Urban Planning*, 132, 26–36. <https://doi.org/10.1016/j.landurbplan.2014.08.005>.
- [177] Kisker, J., & Schöne, B. (2024). Regular use of acupressure mats reduces perceived stress at subjective but not psychophysiological levels: Insights from a three-week relaxation training. *Applied Psychology: Health and Well-Being*, vol. 16(1), pp. 338–355. <https://doi.org/10.1111/aphw.12490>.

- [178] Sun, J., Zeng, H., Pan, L., Wang, X., & Liu, M. (2021). Acupressure and Cognitive Training Can Improve Cognitive Functions of Older Adults With Mild Cognitive Impairment: A Randomized Controlled Trial. *Frontiers in psychology*, vol. 12, 726083. <https://doi.org/10.3389/fpsyg.2021.726083>.
- [179] Liu, G., Ma, H.-j., Hu, P.-p., Tian, Y.-h., Hu, S., Fan, J., & Wang, K. (2013). Effects of painful stimulation and acupuncture on attention networks in healthy subjects. *Behavioral and Brain Functions*, vol. 9(23). <https://doi.org/10.1186/1744-9081-9-23>.
- [180] Kurzweg, M., Weiss, Y., Ernst, M. O., Schmidt, A., & Wolf, K. (2024). Survey on haptic feedback through sensory illusions in interactive systems. *ACM Computing Surveys*, vol. 56(8), pp. 1–39. <https://doi.org/10.1145/3648353>.
- [181] Pan, M. K., McGrenere, J., Croft, E. A., & MacLean, K. E. (2014). Exploring the role of haptic feedback in enabling implicit HCI-based bookmarking. *IEEE transactions on haptics*, vol. 7(1), pp. 24–36. <https://doi.org/10.1109/TOH.2014.2309124>.
- [182] Morris, D. Tan, H., Barbagli, F., Chang, T., & Salisbury, K. (2007). Haptic Feedback Enhances Force Skill Learning. *Second Joint EuroHaptics Conference and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems (WHC'07)*, Tsukuba, Japan, 2007, pp. 21-26, doi:10.1109/WHC.2007.65.
- [183] Danthiir, V., Roberts, R. D., Pallier, G., & Stankov, L. (2001). What the nose knows: olfaction and cognitive abilities. *Intelligence*, vol. 29(4), pp. 337-361. [https://doi.org/10.1016/S0160-2896\(01\)00061-7](https://doi.org/10.1016/S0160-2896(01)00061-7).
- [184] Broughan, C. (2002). Odours, emotions, and cognition – how odors may affect cognitive performance. *International Journal of Aromatherapy*, vol. 12(2), pp. 92-98. [https://doi.org/10.1016/S0962-4562\(02\)00033-4](https://doi.org/10.1016/S0962-4562(02)00033-4).
- [185] Oleszkiewicz, A., Abriat, A., Doelz, G., Azema, E., & Hummel, T. (2021). Beyond olfaction: Beneficial effects of olfactory training extend to aging-related cognitive

- decline. *Behavioral Neuroscience*, vol. 135(6), pp. 732–740. <https://doi.org/10.1037/bne0000478>.
- [186] Moss, M., Cook, J., Wesnes, K., & Duckett, P. (2003). Aromas of rosemary and lavender essential oils differentially affect cognition and mood in healthy adults. *International Journal of Neuroscience*, vol. 113(1), pp. 15–38. <https://doi.org/10.1080/00207450390161903>.
- [187] Moss, M., Hewitt, S., Moss, L., & Wesnes, K. (2008). Modulation of cognitive performance and mood by aromas of peppermint and ylang-ylang. *International Journal of Neuroscience*, vol. 118(1), pp. 59–77. <https://doi.org/10.1080/00207450601042094>.
- [188] Spence, C. (2020). Using ambient scent to enhance well-being in the multisensory built environment. *Frontiers in Psychology*, vol. 11. <https://doi.org/10.3389/fpsyg.2020.598859>.
- [189] Marucci, M., Di Flumeri, G., Borghini, G. Sciaraffa, N., Scandola, M., Pavone, E. F., Babiloni, F., Betti, V., & Aricò, P. (2021). The impact of multisensory integration and perceptual load in virtual reality settings on performance, workload and presence. *Scientific Reports*, vol. 11(4831). <https://doi.org/10.1038/s41598-021-84196-8>.
- [190] De Oliveira, T. C. G., Soares, F. C., De Macedo, L. D. E. D., Diniz, D. L. W. P., Bento-Torres, N. V. O., & Picanço-Diniz, C. W. (2014). Beneficial effects of multisensory and cognitive stimulation on age-related cognitive decline in long-term-care institutions. *Clinical Interventions in Aging*, vol. 9, pp. 309–321. <https://doi.org/10.2147/CIA.S54383>.
- [191] Donohue, S. E., Green, J. J., & Woldorff, M. G. (2015). The effects of attention on the temporal integration of multisensory stimuli. *Frontiers in Integrative Neuroscience*, vol. 9. <https://doi.org/10.3389/fnint.2015.00032>.

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Orchida Dianita

Publications

Original Article

1. Dianita, O., Kitayama, L., Ueda, K., Ishii, H., Shimoda, H., Obayashi, F. (2024). Systematic micro-breaks affect concentration cognitive comparison tasks: Quantitative and qualitative measurements. *Advances in Computational Intelligence*, vol. 4(7), 1-10.

<https://doi.org/10.1007/s43674-024-00074-6>.

2. Dianita, O., Higashimaki, T., Abe, R., Ueda, K., Ishii, H., Shimoda, H., Obayashi, F. (2024). The effect of systematic auditory stimuli micro-refresh on intellectual work performance and subjective measurement. *Results in Engineering*, 24, 1-10.

<https://doi.org/10.1016/j.rineng.2024.103259>

3. Dianita, O., Nomura, K., Higashimaki, T., Abe, R., Ueda, K., Ishii, H., Shimoda, H., Obayashi, F. (2024). Systematic visual stimuli micro-refresh evaluation on cognitive work performance. *Displays*. [Under Review]

4. Dianita, O., Higashimaki, T., Abe, R., Ueda, K., Ishii, H., Shimoda, H., Obayashi, F. (2024). Does sound stimulus make me feel more refreshed? Investigation of sound stimuli as a micro-refresh during intellectual work. [On progress]

Proceedings

1. Dianita, O., Yamamoto, R., Ueda, K., Ishii, H., Shimoda, H., Obayashi, F. (2022). ACT-R intellectual cognitive models on individual's different strategy to perform a simple mathematical task [Paper presentation]. Proceedings at the 6th International Conference on Ambient Intelligence and Ergonomics in Asia, Kaohsiung, Taiwan.

2. Dianita, O., Takeuchi, K., Ueda, K., Ishii, H., Shimoda, H., Obayashi, F. (2023, February). The Influence of Worker's Motivation on Intellectual Concentration by ACT-R Cognitive Models. [Paper presentation]. Proceedings at the 6th International Conference on Intelligent Human Systems Integration: Integrating People and Intelligent Systems (IHSI 2023), Venice, Italy. <http://doi.org/10.54941/ahfe1002834>.
3. Dianita, O., Kitayama, K., Ueda, K., Ishii, H., Shimoda, H., Obayashi, F. (2023). The Effect of Micro-Breaks on Intellectual Concentration Work: An Individual's Characteristics Measurement. [Paper presentation]. Proceedings at the 5th International Conference on Human Systems Engineering and Design: Future Trends and Applications (IHSED 2023), Dubrovnik, Croatia. <http://doi.org/10.54941/ahfe1004109>.
4. Dianita, O., Higashimaki, T., Abe, R., Ueda, K., Ishii, H., Shimoda, H., Obayashi, F. (2024). The Investigation of Systematic Micro-refresh with Auditory Stimuli on Intellectual Work. [Paper presentation]. Proceedings at the 15th International Conference on Applied Human Factors and Ergonomics (AHFE 2024), Nice, France. <http://doi.org/10.54941/ahfe1004942>.
5. Kitayama, K., Dianita, O., Ueda, K., Ishii, H., Shimoda, H., Obayashi, F. (2023). Micro-refresh to Restore Intellectual Concentration Decline during Office Work: An Attempt at Quantitative Effect Evaluation. [Paper presentation]. Proceedings at the 6th International Conference on Intelligent Human Systems Integration: Integrating People and Intelligent Systems (IHSI 2023), Venice, Italy. <http://doi.org/10.54941/ahfe1002824>.
6. Abe, R., Higashimaki, T., Nomura, K., Dianita, O., Ueda, K., Ishii, H., Shimoda, H., Obayashi, F. (2024). An Experimental Study on the Effect of Short-term Airflow on Concentration during Intellectual Work. [Paper presentation]. Proceedings at the 15th International Conference on Applied Human Factors and Ergonomics (AHFE 2024), Nice, France. <http://doi.org/10.54941/ahfe1004943>.