Assessing thermal responses of Indonesian and Japanese students in summer and winter

(夏と冬のインドネシア人学生と日本人学生の温熱反応の評価)

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Abstract

Thermal comfort is crucial in satisfaction and maintaining quality sleep and next-day performance for occupants. This study investigated the comfort temperature in the bedroom at night, sleep quality, and next-day performance (brain response) for Indonesian and Japanese students during summer and winter. The main objective of this study is to investigate the effect of thermal comfort on sleep quality and next-day brain response in Indonesian living in Japan and Japanese. This main objective is further divided into some sub-objectives, i.e., (1) to investigate the sleep quality and next-day brain response of Indonesian and Japanese groups in the summer season, (2) to investigate the sleep quality and next-day brain response of Indonesian and Japanese group in the winter season, (3) to analyze the effect of thermal comfort on sleep quality of Indonesian and Japanese group, (4) to analyze the effect of thermal comfort on brain response of Indonesian and Japanese group, and (5) to analyze the effect of sleep quality on next-day brain response.

In the summer and winter study, the comfort temperature, sleep quality, and subsequent performance of Indonesian and Japanese students were compared. During sleep, actigraphy was used to evaluate sleep quality. Prior to sleep, all participants completed a survey regarding thermal sensation, physical condition, and subjective sleep sensations. Additionally, the temperature and relative humidity of the participants' bedrooms were recorded. After waking up, the participants completed the sleep sensation questionnaire and continued to the next-day performance experiment. In the next day performance, the brain response (event-related potentials with a late positive component and latency ~300 milliseconds; hereafter referred to as "P300" in the present study) and reaction time of Indonesian students, as tropical natives living in Japan, and Japanese students were investigated and compared in natural (hot during summer and cold during winter) and comfort conditions (with cooling and heating).

The average bedroom temperature and relative humidity of Indonesian and Japanese groups were comparable during the summer. Moreover, Indonesian group had a higher comfort temperature than Japanese group and previous studies conducted in Japan. The Griffiths' method indicated *that the summer's means of comfort temperature for Indonesian and Japanese were 28.1 °C and 26.1 °C. Indonesian students' bedtime (duration on bed) and sleep minute were comparable to those of Japanese students during the summer. However, the sleep rate of Indonesian students was lower than that of Japanese students. In the next-day brain response experiment, the current study showed that there were no differences in P300 potential and latency of participants (Indonesian and Japanese groups) between cooling and hot conditions. Moreover, after performing Uchida Kraepelin (U-K) test during comfort conditions (cooling during summer), the reaction time (RT) and the number of lapse (RT > 500ms) of Indonesian group showed delayed and increased significantly, respectively.*

This study also indicated that the bedroom temperature of Indonesian students was significantly warmer than Japanese students during winter. In winter, majority of Indonesian students prefer "warm" in contrast to the preference of Japanese who mostly prefer "neutral." According to the thermal comfort survey, Indonesian had a lower value than Japanese in winter. Moreover, there was a significant difference in the wake-up time of Japanese students in the sleep quality study. Actigraphy measurements indicated that the Indonesian participants' waking time coincided with sunrise. Japanese participants, on the other hand, awoke later than Indonesian students. In the comfort temperature, the Griffiths' method indicated that the winter means of comfort temperature for Indonesian and Japanese were 23.5 °C and 16.0 °C. In the next-day brain response experiment, there were no differences in P300 potential, P300 latency, and RT of Indonesian and Japanese groups between cold and heating conditions in the winter. Moreover, after performing the U–K test at heating condition, the RT of Indonesian group showed a significant delay.

Principal component analysis showed the following results: eight variables of thermal sensation questionnaire in sleep survey can be simplified with two factors (TS1 and TS2, 59 % of cumulative variability), seven variables of sleep sensation questionnaire in sleep survey can be simplified with two factors (SS1 and SS2, 72 %), and seven variables of thermal sensation questionnaire in brain response experiment can be simplified with two factors (TE1 and TE2, 77%). In the sleep quality of Indonesian group, TS1 was correlated with sleep rate and sleep latency. In Japanese group, TS2 was correlated with sleep rate, sleep efficiency, and SS1. In brain *response of Indonesian group, TE2 was correlated P300 latency. In Japanese group, TE1 was correlated with P300 potential and TE2 was correlated with P300 potential and latency. In the correlation analysis between sleep quality sensation and next-day brain response, the duration on bed, sleep minute, and sleep rate were correlated with P300 latency. In the sleep sensation, SS1 was correlated with P300 latency, sleep vote, endurance, and speed of U-K test, SS2 was correlated with P300 potential, consistency, accuracy, and correct rate of U-K test.*

The methodology might be replicated in the future study, which is evidently useful to investigate sleep quality and next-day brain response in the natural and comfortable environment setting. This research contributes a piece of new knowledge regarding sleep quality, thermal comfort, next-day brain response, particularly for tropical natives living or working in Japan.

Keywords: *thermal comfort, sleep quality, P300, reaction time, nationality*

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Wiwik Budiawan

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List of Abbreviations

AH	Absolute humidity
AVG	Average
BMI	Body mass index
BSA	Body surface area
Cond.	Controlled condition during experiment
ERP	Event related potential
IDN	Indonesian group or participants
JPN	Japanese group or participants
JST	Japan standard time
MRT	Mean radiant temperature
MST	Mean skin temperature
PMV	Predicted mean value
Post-	Task or test after Uchida-Kraepelin test
Pre-	Task or test before Uchida-Kraepelin test
PVT	Psychomotor vigilance task
RH	Relative humidity
RT	Reaction time
SD	Standard deviation
Sig.	Significancy of statistical analysis at $p < 0.05$
SOFI	Swedish occupational fatigue inventory
Ta	Air temperature
TC	Thermal comfort
TCV	Thermal comfort vote
To	Outdoor temperature
TP	Thermal preference
TSV	Thermal sensation vote
U-K test	Uchida-Kraepelin test
TS1	Factor 1 of thermal sensation in sleep survey
TS2	Factor 2 of thermal sensation in sleep survey
TS3	Factor 3 of thermal sensation in sleep survey
SS1	Factor 1 of sleep sensation in sleep survey
SS2	Factor 2 of sleep sensation in sleep survey
TE1	Factor 1 of thermal sensation in experimental room
TE2	Factor 2 of thermal sensation in experimental room
TE3	Factor 3 of thermal sensation in experimental room

Chapter 1
General Introduction

Sleep quality and brain response introduction, research question, and objectives

In the general introduction chapter, the motivation for this study is discussed. The Chapter begins by describing the context in which this study (viz. sleep quality and brain response) was conducted and providing background information on the researcher. The following section discusses the research question and theoretical framework. Finally, a summary of the study's objectives is given.

1.1 Sleep quality

1.1.1 Sleep quality, health risk, and next-day performance

Sleep is behavior in fundamentally. It was detected and defined based on the changes of posture, maintained behavior during sleep, and increased arousal threshold (Ogilvie, 2001). Sleep is an important daily activity for maintaining good health (Fabbri et al., 2014) and occupies about one-third of the day (Lee, 1997). A good night's sleep enables the body to recover and prepares people to face the day. Sleep has the function of relieving physical and mental fatigue (Hirshkowitz et al., 2015) and for improving work efficiency and maintaining good health at work and school (Japan Ministry of Health Labour and Welfare, 2014). A person goes through four to six sleep cycles during a normal sleep period (A. K. Patel et al., 2021). A newborn need to sleep for 12–18 hours. Between the ages of five and ten, children's sleep requirements decrease to 10 hours. The demand decreases further as teenagers require between 8 and 9 hours and adults require between 7 and 8 hours (Truong, 2021).

The quality of sleep is distinct from the quantity of sleep. A person's sleep quantity is measured by how much sleep they get each night, whereas their sleep quality is measured by how well they sleep. Taking the time to measure sleep quantity is simple because it allows you to quickly determine if you are getting the recommended amount of sleep per night.

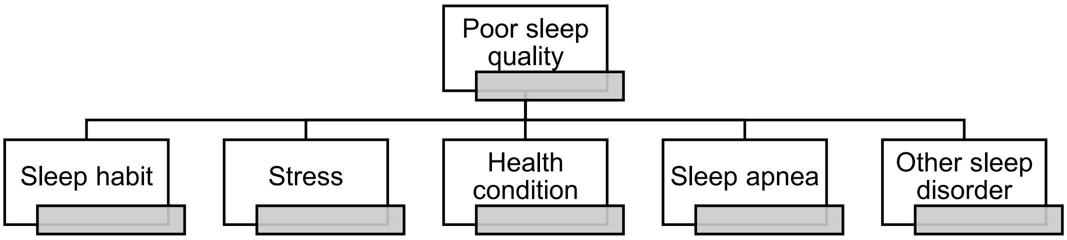


Figure 1-1. Potential causes of poor sleep (Rehman, 2021)

As a general rule, good sleep quality is characterized by the following characteristics: quick fall asleep, less number waking up, duration of sleep as the age recommendation (Hirshkowitz et al., 2015), quick fall back asleep, and clear headedness in the morning. Otherwise, Rehman (2021) summarized that there are a variety of factors that could be contributing to poor sleep quality (Figure 1-1).

It has been noted that insufficient sleep may impair health, and that the risk of health damage is significantly increased in people who sleep less than 6 hours or more than 8 hours (Kripke et al., 2002). In the United States, 35.2 % of all adults report sleeping an average of less than seven hours per night on a daily basis (CDC, 2017). Moreover, the national sleep foundation (Truong, 2021) summarized several sleep disorders, namely: Insomnia (30-48 % of over adults suffer insomnia (D. Patel et al., 2018) , women have a 40% higher lifetime risk of insomnia than men (Mong & Cusmano, 2016)), obstructive sleep apnea or OSA (15-30 % of males (Young et al., 2009) and 10-30 % of females suffer OSA (Peppard et al., 2013), 2-9 % of adults in USA suffer OSA), central sleep apnea or CSA, restless leg syndrome, narcolepsy, grinding teeth, talk in sleep, sleep walking, and sleep paralysis. Furthermore, it has been demonstrated that sleep apnea causes several medical consequences i.e. hypertension, right ventricular hypertrophy, arrhythmia, and other abnormal heart rhythms, as well as ischemic heart disease and cerebrovascular dementia (Kiley et al., 1994).

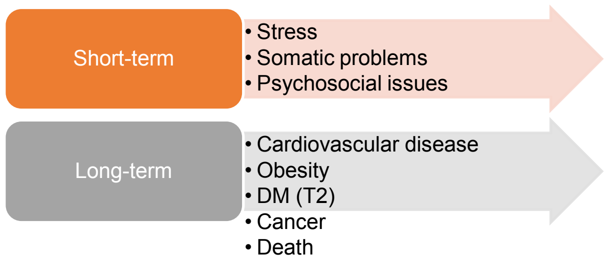


Figure 1-2. Short-term and long-term effect of sleep disorder (Medic et al., 2017)

Meanwhile, having a sleep disorder is frequently associated with sleep disruption. According to current research, as seen in Figure 1-2, sleep disruption has both short- and long-term detrimental health consequences (Medic et al., 2017).

Sleep deprivation, impaired attention, and judgment decreased work efficiency and physical strength all impair not only quality of life, but also contribute to major accidents. Additionally, sleep disturbances impair immune function and biological defense and maintenance functions (Dinges et al., 1995). As seen in the Figure 1-3, the public may be unaware of the decrease in work efficiency caused by drowsiness, and even with less sleep, work efficiency decreases, increasing the risk of accidents and human error (Japan Ministry of Health Labour and Welfare, 2014).

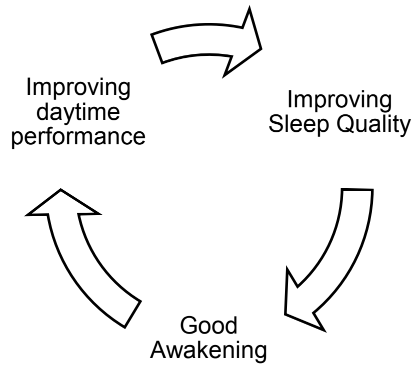


Figure 1-3. Sleep and daytime performance cycle

Moreover, between 15% and 35% of adults experience regular sleep disruptions, such as excessive sleep onset latency, insufficient sleep duration, or frequent waking during the night (Mollayeva et al., 2016). Reduced sleep quality can be attributed to a variety of factors, including abnormal circadian rhythms (Lack et al., 2008), environmental factors (high ambient temperature and humidity, noise, and shift work) (Okamoto-Mizuno et al., 1999; Tsuzuki et al., 2018), psychological factors (anxiety), and physiological factors (pain, fatigue, and recovery needs) (Lack et al., 2008). Regarding the effect of sleep on the next day's performance, studies on the impact of sleep on athletes' sports performance and student performance are being conducted. Insufficient sleep time, sleep disturbances due to external factors, and sleep deprivation has reduced performance (Charest & Grandner, 2020; Cusick et al., 2018; Okamoto-Mizuno & Tsuzuki, 2010; Tsuzuki, Mori, et al., 2015), depressed mood and poor memory or concentration (Dinges et al., 2005). Nevertheless, research on the impact of sleep quality on more specific performance, such as brain reaction, is still limited.

1.1.2 Ethnical difference on sleep quality

Optimal health and quality of life are dependent on good sleep, which is a changeable health habit that is only partly a choice. To be more precise, "sleep health," which encompasses a variety of factors such as adequate sleep length and quality, sleep continuity or efficiency, sleep scheduling, alertness/sleepiness, and satisfaction/quality, all of which should occur on a continuous basis, differs by race and ethnicity (Buysse, 2014; Johnson et al., 2019). In a sleep study of Asian adults, after adjusting for age, gender, and research location, Chen et al. (2005) found that when comparing Blacks, Hispanics, Whites, and Chinese (Asian), it was found that they had much shorter sleep durations than Whites. In comparing Blacks and Whites, Blacks had the lowest average nightly sleep duration and were more likely to have sleep apnea syndrome, poor sleep quality, and daytime drowsiness than Whites (Chen et al., 2015). Moreover, in Asian population study, among the whole sample of Malay and Indian individuals who visited one of two public primary care clinics, a study discovered a high prevalence of self-reported insufficient sleep (44 percent), defined as less than 7 hours of sleep on weekdays and a lower prevalence on weekends (26 percent) (Tan et al., 2016). In a research of Japanese residents ranging in age from adolescents to the elderly (10–89 years old), it was discovered that there were substantial age- and gender- related changes in sleep features (timing: time in bed, in bed time, get up time, duration: total sleep time, and quality: sleep efficiency and sleep latency) in naturalistic study (L. Li et al., 2021).

On the other hand, since ancient times, seasonal variation in behavior and physiology has been recognized (Sato, 1997), including in sleep quality. Additionally, numerous studies have documented seasonal variation in sleep and mood, in particular (Suzuki et al., 2019). However, migration (both short- and long-term) to the new region is a difficulty for all people and an additional challenge in unfamiliar season, including Indonesian residents as tropical natives living in Japan. Some behaviors in daily life, such as sleeping patterns, will be altered as a result. As a subtropical country, Japan consists of four seasons. A climate that ranges from subarctic in the north to subtropical in the southern defines Japan's four distinct seasons. Between the Pacific and the Sea of Japan, there are significant differences in weather and other factors.

In the seasonal term, during sleep, the human body is sensitive to air temperature (L Lan et al., 2017). Generally, poor sleep quality and fatigue are associated with the discomfort associated with summer heat (Fujii et al., 2015). According to a 2003 survey conducted by the Japan Meteorological Agency, the most common summer symptoms were "sleep disorders" (over 50% of respondents) and "fatigue/ not feeling well" (around 30 percent)(Ministry of The Environment of Japan, 2009). Previous Nordic epidemiology reported that sleep quality was poor in summer (Ohayon & Partinen, 2002) and in middle of winter (Husby & Lingjaerde, 1990; Ståle Pallesen et al., 2014). Meanwhile, in temperate zone, the sleep duration of the residents was longer during the winter than summer (Okawa et al., 1996; Rosen & Rosenthal, 1991; Tsuzuki et al., 2011). Occupants had longer sleep experiences and fewer complaints (Okawa et al., 1996; S. Pallesen et al., 2001; Suzuki et al., 2019; Volkov et al., 2007).

Scientific evidence established a link between photoperiod and sleep duration (Wehr, 1992). Additionally, this difference in sleep duration between summer and winter may be due to ethnicity and culture (Budiawan & Tsuzuki, 2021; Suzuki et al., 2019). Kume et al. (2017) revealed that Japanese participants slept significantly less and were more active at night during the summer, whereas Thai participants (living in Thailand) maintained a poor state of night sleeping all year. Nonetheless, research on the seasonal effect on sleep in individuals of different nationalities, particularly those who live in the same temperate zone, is scarce. Due to the absence of daylight saving time in Japan, natural seasonal variability in sleep measures can be investigated properly (Hashizaki et al., 2018).

1.1.3 Thermal comfort and sleep quality

Numerous previous studies on indoor thermal environments, particularly the microenvironment (for example, the sleeping space or bedroom), have demonstrated that maintaining a comfortable temperature is critical for sleep quality (Budiawan & Tsuzuki, 2021; van Loenhout et al., 2016; Zheng et al., 2019). Variation in indoor temperatures across seasons may have a varying effect on sleep measures. The indoor temperatures had a strong correlation with the outdoor temperature during the summer and a weak correlation with the outdoor temperature during the cooler months (Nguyen et al., 2014). Thermal comfort is typically improved by adhering to the applicable standard's recommendations. However, thermal comfort standards (ASHRAE 55, ISO 7730) are universally applied to all individuals regardless of ethnic origin or nationality. In individuals from other countries, Havenith et al. (2020) demonstrated that several standards for calculating thermal comfort by combining an adaptive model.

The adaptive comfort temperature research has been widely conducted in Japan. Previous research investigated the comfort temperatures in offices (Damiati et al., 2016; Mustapa et al., 2016), in residences during summer (Rijal et al., 2013, 2014, 2019), and during four seasons (Rijal et al., 2017). Those researches mostly assessed occupant's daily activity. Only limited studies feature the investigation in sleep and only few involve foreigners living outside their home countries. Being natives of a tropical region (06°12'0.00" S, 106°48'59.9" E Jakarta, Indonesia), Indonesian university students may show long-term adaptation to Japanese season (>20 years), similar to the case of Japanese Brazilians (Katsuura et al. 1992). However, once relocating to a temperate zone (34º46'9″ N, 137º23'29.5″ E Toyohashi, Japan), they probably need to expend a considerable effort to adapt to this new environment.

On the other hand, in general information, humans live in houses that are suitable for the climate and changes in seasonal weather and sunshine. Sleep is regarded as a living activity in a house, especially in a bedroom, but the temperature and humidity in the room are affected by the outdoor climate (hot and humid in summer and cold in winter). When the indoor environment at night is high, even a healthy person with no sleep disorder may interfere with sleep, and the high temperature increases awakening during sleep, resulting in poor sleep quality (Okamoto-Mizuno & Tsuzuki, 2010). Therefore, there is an increasing need to control the bedroom to an appropriate environment or comfort condition, i.e., open the window, turn on air conditioner, fan, and heater. The thermal environment in the bedroom affects sleep and depth of sleep, and if the thermal environment is too hot or too cold, it will be difficult to fall asleep (Japan Ministry of Health Labour and Welfare, 2014). Especially in summer and winter, the effect becomes greater as the temperature rises and falls. Haskell et al. showed that in hot and cold thermal environments, mid-wake and light sleep increased and rapid eye movement (REM) and deep sleep decreased compared to neutral temperatures (Haskell et al., 1981).

In addition, it can be said that the factors that affect sleep can be broadly classified into two types. One is the physical factors such as bedroom temperature, humidity, sound, light and wind as described above. The other is physiological factors such as daytime activity, psychological state, physical fatigue, and mental fatigue. Unless both factors are in the right conditions, it is difficult to get a good night's sleep. These factors are not determined solely during sleep, but also include daytime activities and life cycles, and to get a good night's sleep, during the day, before bedtime, during sleep, and immediately after waking up.

Physical factors due to differences in housing style and physiological factors due to living environment may affect the factors that determine sleep quality. For example, there is a difference in the number of things in the room and the heat capacity between the room of living alone in the apartment and the room of each house, and there might be a slight difference in the environment setting. In addition, a difference in psychological amount might exist due to the difference between living alone in an unfamiliar land and living in the land where they were born and raised. It is necessary to consider not only the difference in the indoor sleeping environment but also the difference depending on the way of living.

1.2 Brain response

1.2.1 Event related potential: P300

In previous studies, Fabbri et al., (2014) revealed that poor sleep quality affected daytime activity. In order to confirm good quality sleep, sleep onset latency is short, the number and time of awakening are small, and sleepiness is low when waking up. Must be set appropriately. For this purpose, first it is necessary to find out the cause of the deterioration of sleep quality, and then take appropriate measures and improvement measures for the cause, that is, to set the factors that affect sleep to the appropriate state and level. It is important to prepare and review lifestyle habits (Kitado, 2005).

In a previous study, event-related potentials (ERP) were used to measure cognitive functions, including attention, expectation, and memory update (Duncan et al., 2009). The P300 wave (also known as P3) of an ERP is a parietocentral positivity brain response that occurs when a participant detects a relevant stimulus (Picton, 1992). Its potential peak appears approximately 300 milliseconds (ms) after the participant makes a stimulus discrimination (responds to the target stimulus and ignores the non-target stimulus). Previous studies have shown that P300 potential varies with seasons as a function of the average sunshine, whereas no seasonal variation was observed for P300 latency (Deldin et al., 1994; Polich & Geisler, 1991). Currently, there is no convincing scientific evidence that winter impairs cognition (Brennen, 2021). Recent studies on Japanese people have shown shortened P300 latency and reaction time and reduced P300 potential during severe heat stress (Shibasaki et al., 2016). In addition, during severe cold stress, P300 latency was delayed but the P300 potential did not change (Nakata et al., 2019). However, according to Wijayanto et al. (Wijayanto et al., 2017), participants from southeast Asia (tropical native) had better resistance to a performance decrease than Japanese participants (native) during heat exposure (i.e., leg immersion in 42°C water).

Moreover, acclimatized individuals with improved physiological function to tolerate heat stress should demonstrate greater resistance to performance losses caused by heat stress than non-acclimatized individuals (Ramsey, 1995). Consequently, an objective examination of the effect of various thermal conditions (including natural and occupant-controlled conditions), in different ethnicities is required.

1.2.2 Thermal comfort and brain response

Research in thermal comfort has been widely conducted all over the world and mainly assessed the occupant's subjective sensations and daily activities. In Japan, thermal comfort is one of the important issues in the office because it is an environment where air conditioning is essential, such as heating and cooling (Damiati et al., 2016; Mustapa et al., 2016). Meanwhile, the study of thermal comfort on cognitive performance is still limited. Earlier researches reported that heat stress might impair cognitive function influenced by task complexity or a combination of task complexity and duration (Hancock & Vasmatzidis, 2003; Hocking et al., 2001; Kazama et al., 2012; Shibasaki et al., 2016). Moreover, the cognitive function might also be affected by cold exposure (Castellani & Tipton, 2016; Nakata et al., 2019). Cold stress and the environment potentially have an effect on cognitive performance such as reaction time and error rate in recent studies (Muller et al., 2012; Nakata et al., 2019; Taylor et al., 2016; Watkins et al., 2014). However, it is worth noting that evaluating cognitive performance in response to heat and cold exposure is contingent on the subjects' subjective responses, which are influenced by skill level and motivation (Nakata et al., 2019; Shibasaki et al., 2016). Additionally, other methodological distinctions (environmental and physiological conditions) cast doubt on cognitive function (Gaoua, 2010; Shibasaki et al., 2016).

Located in the equatorial region, Indonesia experiences a tropical climate with a rainy and dry season. Indonesia receives approximately 12 h of sunlight. The average maximum and minimum temperatures remain nearly constant year-round at ~24°C in highlands and approximately 28°C in lowlands (BMKG, 2021). Conversely, Japan has temperate climate with four different seasons (summer, autumn, winter, and spring), in which extreme thermal conditions may occur during summer (35°C or above are occasionally in western Japan) and winter (-20°C is frequently recorded in Hokkaido) (Japan Meteorology Agency, 2021). Being a subtropical country, the daylight hours in Japan differs approximately 285 min between the summer and winter (Japan Meteorology Agency, 2020). This seasonal variability may affect human performance (Fujii et al., 2015; González-Hidalgo et al., 2011; Ohayon & Partinen, 2002). Several previous studies on indoor thermal environments revealed that ambient temperature and thermal comfort are crucial in task performance (Cui et al., 2013; Kaida et al., 2012; Li Lan et al., 2011; Roelofsen, 2002; Wijayanto et al., 2017).

1.3 Research question

For students who have grown up in Indonesia for 20 years, the summer and winter environment of Japan may be an unexpected challenge. Being natives of a tropical region (06°12′0.00″ S, 106°48′59.9″ E Jakarta, Indonesia), Indonesian students may show long-term adaptation to Japanese season (>20 years), similar to the case of Japanese Brazilians (Katsuura et al., 1992). However, once relocating to a temperate zone (34°46′9″ N, 137°23′29.5″ E Toyohashi, Japan), they probably need to expend a considerable effort to adapt to this new environment, including in sleep and work or study. Adjustment abilities may have an impact on both sleep quality and work or study performance in unfamiliar environments.

In task performance, Indonesian might have better performance in hot temperature considering the previous study (Wijayanto et al., 2017). Once relocated to a different climate, such as Japan, considerable effort may be expected to adapt to this new environment (Pepler, 1958; Radakovic et al., 2007; Ramsey, 1995). To adapt to the changing environmental conditions, one would expect a longer exposure to these conditions. Thermal comfort questionnaire was used to collect data related to thermal sensation and comfort sensation. Occupants could control their indoor environment using an air conditioner (AC) and adapt their clothing to the indoor thermal environment. In office activity, many office buildings in Indonesia were putting temperatures lower than the standard (21 to 23 °C) to meet comfortable (Karyono & Bahri, 2005). However, in Japanese office, the Cool Biz campaign promotes for a minimum AC setting of 28 °C for cooling and the Warm Biz campaign promotes for maximum AC setting of 20 °C for heating (Nakashima, 2013). Meanwhile, previous studies demonstrated that comfort temperature of Indonesian was 24–29 °C (Alfata et al., 2012; Karyono, 2000). According to the preceding description, the study's questions are as follows: How does thermal comfort affect sleep quality and brain response in two ethnic groups (Japanese and Indonesian living in Japan) during the summer and winter?

1.4 Objectives of research

1.4.1 Objectives

The main objective of this study is to investigate the effect of thermal comfort on sleep quality and brain response in Indonesian living in Japan and Japanese. This main objective is further divided into some sub-objectives as follows:

1. To investigate the sleep quality and brain response of Indonesian and Japanese group in summer season
2. To investigate the sleep quality and brain response of Indonesian and Japanese group in winter season
3. To analyze the effect of thermal comfort on sleep quality of Indonesian and Japanese group
4. To analyze the effect of thermal comfort on brain response of Indonesian and Japanese group
5. To analyze the effect of sleep quality on brain response

1.4.2 Hypothesis

A field survey of bedroom comfort temperatures was conducted in Indonesian living in Japan and Japanese during the summer and winter seasons. Additionally, sleep qualities were assessed to determine the relationship between the thermal environment of the actual bedroom and the participants' sleep quality. In the sleep investigation, the hypothesis is winter would be more difficult for someone who had previously lived in a tropical zone.

In the brain response investigation, additional evidence is required in the form of an objective examination of the effect of various thermal conditions (including natural and occupant-controlled condition), specifically for different ethnicity. Therefore, the hypothesis is participants from Indonesia would be able to maintain their P300 performance and reaction time when exposed to natural conditions (hot during summer and cold during winter).

1.5 Organization of the thesis

The current thesis entitled "Assessing thermal responses of Indonesian and Japanese students in summer and winter" is organized into five chapter in line with the objectives explained in sub chapter 1.4.1 page 11.

- Chapter 1 explains the background, general introduction, and objectives of the research. This chapter also provides a literature review to clarify the position of the previous studies.
- Chapter 2 describes the location and climate during summer and winter, instrument, and procedure of research.
- Chapter 3 describes the summer and winter sleep survey and next-day brain response experiment during the day of two groups participants.
- Chapter 4 explores the effect of thermal comfort on sleep quality and brain response. This chapter describes the data preparation, principal component analysis, distribution of all variable and explore the correlation among variables.
- Chapter 5 presents the overall conclusions.

Chapter 2
Methodology

Research location, period, instruments, procedures, analysis methods, and participants information.

In the chapter 2, research location and climate, period, analysis methods and participants information were explained. Moreover, the instruments and procedure for each study (thermal comfort survey and sleep quality measurement and the next-day brain response experiment) were described.

2.1 Location and climate

Current research was conducted in Toyohashi city, Aichi prefecture, Japan (lat 34°46′9″ N, long 137°23′29.5″ E). Toyohashi is classified as having a Köppen-Geiger climate classification of Cfa: humid subtropical climate (Japan Meteorology Agency, 2020; Kottek et al., 2006; Figure 2-1).

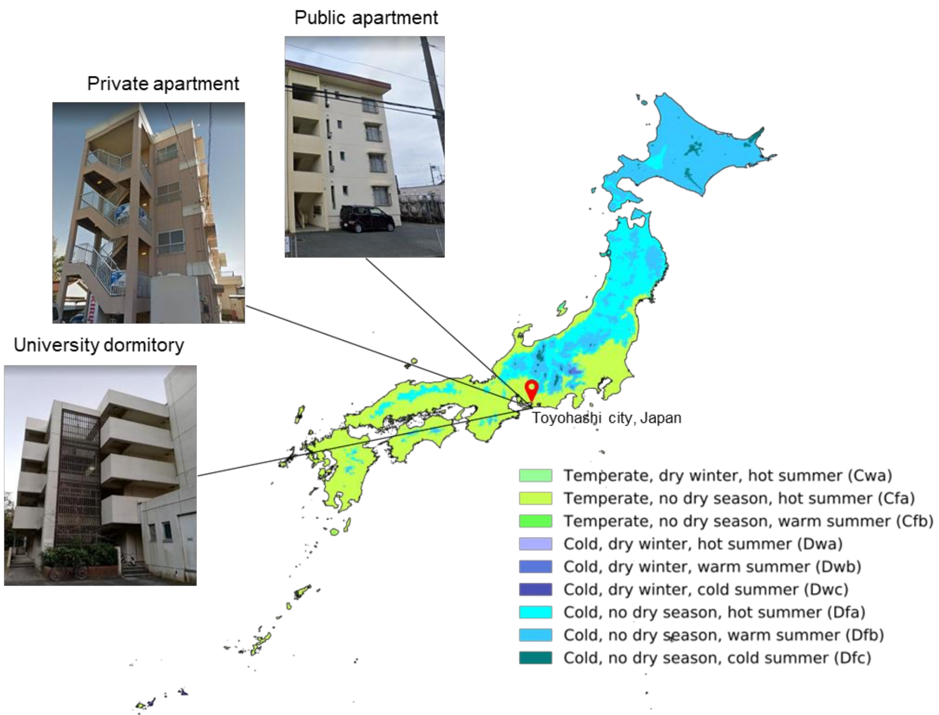


Figure 2-1. Toyohashi city climate classification (Kottek et al., 2006) and participant's apartment type

In the current city, summers are hot and humid, and winters are relatively mild. The sleep survey was conducted in a participant's home that utilized a similar type of ventilation system (natural). The cooling and heating modes were not specified. The sleep survey was performed in the participants' apartments, which included three distinct residential apartments: university dormitory, private apartment, and public apartment. This design of building included a small vent or opening in the bedroom for natural ventilation. However, participants did not control natural ventilation. During the summer, occupants used split-type and window air conditioning (AC). AC was used to adjust the bedroom's air temperature to the participant's preference.

2.2 Research period

The outdoor environment data was provided by the Japan Meteorological Agency (JMA)(Japan Meteorology Agency, 2020). The survey and experiment were conducted during summer 2019 (August to September 2019), summer 2020 (July to September 2020), and winter 2020 (January to March 2020, Figure 2-2).

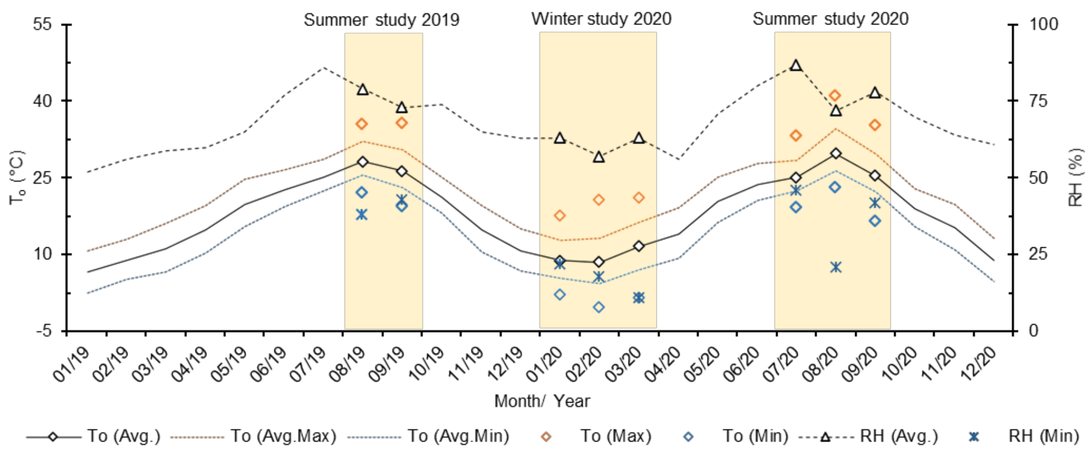


Figure 2-2. Outdoor air temperature and relative humidity during summer and winter survey and experiment. Abbreviations: To, outdoor air temperature; Avg., average; Max, maximum; Min, minimum; RH, relative humidity

The average monthly outdoor temperature reached its maximum in August 2020 (avg: 29.7°C, min: 23.2°C, max: 41.1°C) and the average monthly outdoor temperature reached its minimum in February 2020 (avg: 8.5°C, min: -0.3°C, max: 20.7°C). For the average monthly outdoor relative humidity, the maximum reached in July 2020 (avg: 87%, min:

46%) and the minimum reached in February 2020 (avg: 57%, min: 18%) (Japan Meteorology Agency, 2020).

The period of summer survey and experiment were consisted of two periods (period 1: August to September 2019; period 2: July to September 2020) and the winter survey and experiment were consisted of one period (January to March 2020). The sleep survey and the following day's (brain response) experiments were part of a series. Moreover, the days of the survey and experiment were not sequential in order to accommodate the academic calendar and the lifestyles of students (Figure 2-3).

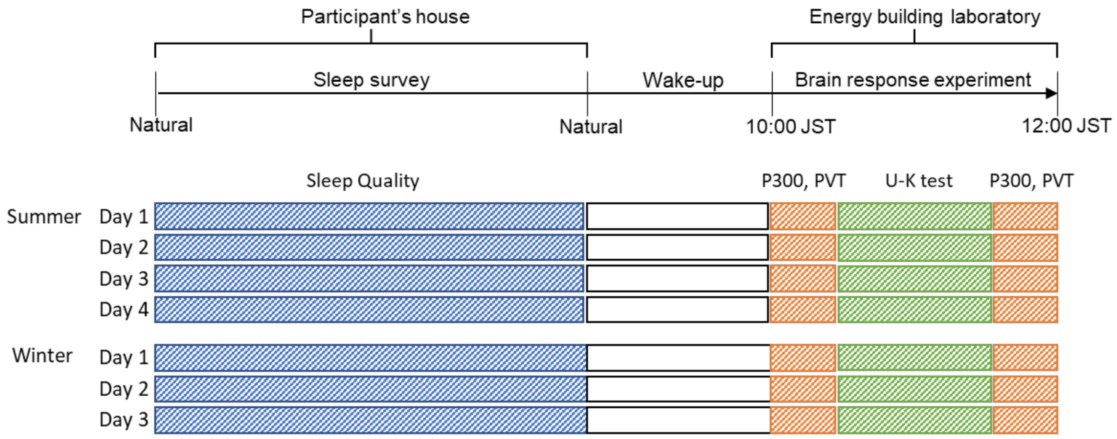


Figure 2-3. Time procedure of the research during summer and winter

2.3 Instruments and procedures

2.3.1 Instruments and procedure of sleep survey

Participants were asked to wear an actigraphy (Micro-mini, Ambulatory Monitoring, Inc., NY, USA) to measure the sleep parameters (duration on bed, sleep duration, sleep rate, and sleep efficiency) based on wrist activity (Cole RJ,Kripke DF, Gruen W, Mullaney DJ, 1992) and set a thermal recorder (TR-74Ui, T&D Corp., Matsumoto, Japan) for temperature and relative humidity measurement of the bedroom environment during the sleep. The following formulas were used to calculate the sleep rate and efficiency.

Equation 2-1:

$$Sleep\ rate\ (\%) = \frac{Sleep\ duration\ (min)}{Duration\ on\ bed\ (min)} \times 100\%$$

Equation 2-2:

$$Sleep\ efficiency\ (\%) = \frac{Sleep\ duration\ (min)}{Sleep\ duration\ (min) + Wake\ up\ duration\ (min)}$$

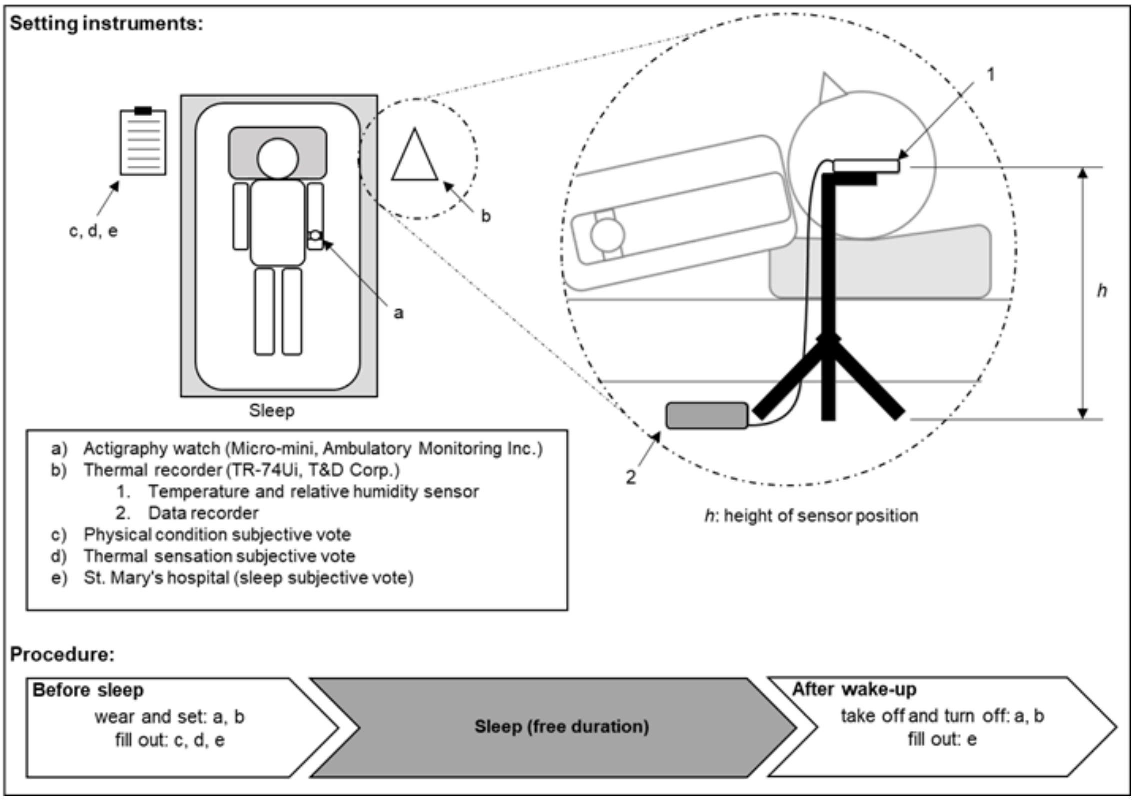


Figure 2-4. Setting of instruments and experimental procedure

The experimental instruments were prepared and calibrated before experiment. Figure 2-4 shows the setting instruments during sleep measurement, and Table 2-1 summarizes the type of instrument, parameter, and accuracy. The type of house and furniture may affect the bedroom air temperature (T_a) and relative humidity (RH). Previous studies reported that the temperature and humidity variation are influenced by proximity to heat or humidity sources (laundry, shower, and kitchen) (Wallace et al., 2002). However, the behavior of respondents in indoor thermal regulations, such as opening windows (Wallace et al., 2002), using fan/AC/heater (Hibino et al., 2012; Tsuzuki, Morito, et al., 2015), and clothing and bedding (Okamoto-Mizuno et al., 2005; Okamoto-Mizuno & Tsuzuki, 2010) might vary, over a season (Nguyen et al., 2014). Thus, respondents placed the sensor and data logger closer and parallel to the head while sleeping.

Table 2-1. Types of instruments and parameters in thermal comfort survey and sleep quality measurement

Parameter	**Instrument Name**	**Brand**	**Instrument model**	**Range / Accuracy**
Air temperature and relative humidity	Illuminance UV Recorder	T and D	TR-74Ui (logger):  THA-3151 (sensor): 	0-55 ºC (± 0.5 ºC) 10-95 % of RH (±5%)
Objective Sleep Quality	Motion-logger Micro	Ambulatory Monitoring Inc. (AMI)	Motion-logger Actigraphy: 	/

The questionnaire consisted of two sections. The first section was about participants demographic information (e.g., age and gender). In the second section, the questions were related to standard nine-point thermal sensation scale, thermal comfort sensation, thermal preference, and thermal satisfaction, as described in Appendix A. The thermal sensation questionnaire recorded thermal perception before sleep. The thermal sensation answer presented nine-point standards from the society of heating, air-conditioning, and sanitary engineers of Japan (SHASE) thermal sensation scale.

The physical condition survey was adapted from previous studies undertaken by Tsuzuki et al. (2011). The physical condition survey was filled out before sleep. The questionnaire consisted of 12 questions were written in English for Indonesian students and in Japanese for Japanese students (Appendix B). St. Mary's Hospital (SMH) was used as a subjective sleep survey. The SMH was adapted from previous studies undertaken by Shahid et al. (2012). In the SMH, the survey was completed after wake-up. The participants were asked to answer 14 questions about subjective sleep sensations (Appendix C).

2.3.2 Instruments and procedure of brain response experiment

In this study, the participants were subjected to four conditions to assess brain response in different days for each condition (Table 2-2). Natural conditions (without AC) were referred to as "hot" in the summer and "cold" in the winter, as a natural stimulation. Meanwhile, in comfort conditions (i.e., "cooling" and "heating"), participants could adjust the ambient thermal environment of the experimental room by controlling the AC within a temperature range of 20–26 ◦C, within the Indonesian comfort standard (Badan Standardisasi Nasional, 2011). During the summer experiments, the participants wore briefs (0.04 clo), T-shirts (0.08 clo), and straight trousers (thin, 0.15 clo), to a total clothing insulation score of 0.27 clo. Conversely, in the winter, the participants wore briefs (0.04 clo), long underwear bottoms (0.15 clo), straight trousers (thick, 0.24 clo), long underwear top (0.20 clo), long- sleeved sweatshirt (0.34 clo), and ankle-length athletic socks (0.02 clo), to a total clothing insulation score of 0.99 clo.

Table 2-2. Controlled condition during summer and winter brain response experiment

Season	Cond.	AC	Mode	T (°C)	MR (met)	Clo (clo)
Summer	Hot	-	-	-	1	0.27
	Cooling	AC	Cooling	20–26	1	0.27
Winter	Cold	-	-	-	1	0.99
	Heating	AC	Heating	20–26	1	0.99

Abbreviations: Cond., condition; AC, air conditioner; T, setting temperature; MR, metabolic rate; Clo, clothing insulation.

The experiment used both physical measurements to assess objective parameter and questionnaires to assess subjective sensations. Each participant received a complete explanation of the experimental procedure one day before the experiment. The physical and mental conditions of the participants were assessed from their responses to a questionnaire survey (Swedish occupational fatigue inventory, Figure 2-5). During the experiment, participants were prohibited from consuming any caffeine, alcohol, or medication.

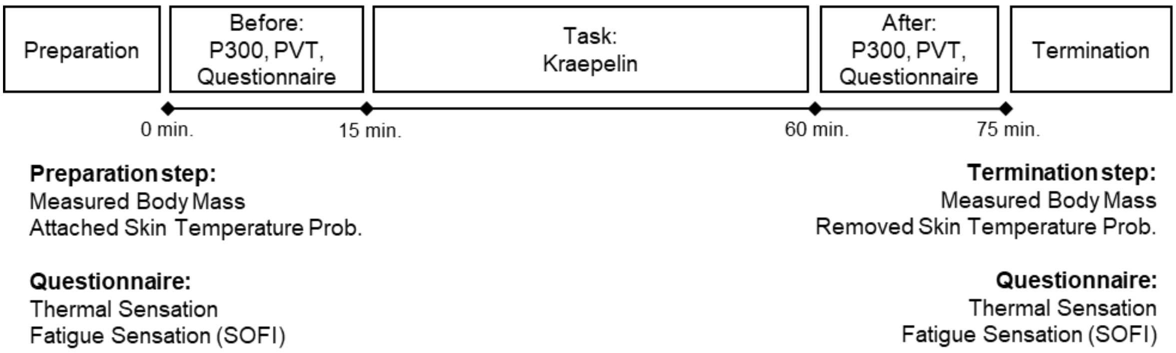


Figure 2-5. Experimental protocol. Abbreviations: P300, brainwave response at approximately 300ms; PVT, psychomotor vigilance task; SOFI, Swedish Occupational Fatigue Inventory

The skin surface temperature was measured by attaching probes for skin temperature measurement (LT ST0812, Gram Co., Ltd., Saitama, Japan) with surgical tape to the skin surface of the subject and attaching the probe to a skin thermometer (LT 8A, Gram Co., Ltd., Saitama, Japan). The skin temperature was measured with reference to Hardy Dubois's 7-point method: forehead (T_1, °C), chest (T_2, °C) & back (T_8, °C), upper arm (T_3, °C), back of the non-dominant hand (T_4, °C), thigh (T_5, °C), lower leg (T_6, °C) and foot of non-dominant side (T_7, °C) (Ramanathan, 1964). Skin temperatures were monitored every 30 s. The following formula (Equation 2-3) was used to calculate the average skin temperature (T_{sk}, °C).

Equation 2-3:

$$\mathrm{T}_{sk} = 0.07\mathrm{T}_1 + (0.175\mathrm{T}_2 + 0.175\mathrm{T}_8) + 0.14\mathrm{T}_3 + 0.05\mathrm{T}_4 + 0.19\mathrm{T}_5 + 0.13\mathrm{T}_6 + 0.07\mathrm{T}_7$$

Body weight (W, kg) and height (H, cm) were measured using a GP 100K weight scale (A & D Corporation, Tokyo, Japan) and a GL1955BL tape measure (TJM design, Tokyo, Japan). The following equations were used to calculate body mass index (BMI, Equation 2-4) and body surface area (BSA, Equation 2-5).

Equation 2-4:

$$BMI = 10000 \times W/H^2$$

Equation 2-5:

$$BSA = 71.84 \times W^{0.425} \times H^{0.725} \times 10^{-4}$$

The temperature and relative humidity of the experimental room were measured using an illuminance UV recorder (TR-74Ui, T&D Corp., Matsumoto, Japan). The air velocity and mean radiant temperature (MRT) in the experimental room were measured using a 6332D air flow transducer (Kanomax Japan Inc., Tokyo, Japan) and a globe temperature probe, respectively, all of which were recorded on a GL840 data logger (Graphtec Corp., Yokohama, Japan). Probes were placed at the center of the room (Figure 2-10). The predicted mean vote (PMV) was calculated by combining the data from physical factors, including air temperature, radiant temperature, air velocity, relative humidity, and human factors, including the amount of clothing insulation and metabolic rate (Fanger, 1970). PMV is represented on a numeric scale from −3 to +3 (−3, cold; −2, cool; −1, slightly cool; 0, neutral; 1, slightly warm; 2, warm; and 3, hot).

Event Related Potential P300

Brain response was examined by an electroencephalogram (EEG) to identify P300. The P300 wave is an ERP generated by the EEG. During ERP, the potential of the brain changes over time owing to external or internal events, and the change in EEG during P300 occurs about 300 ms following target stimulus (Picton, 1992). Participants completed the performance measurements pre- and post-Uchida Kraepelin (U-K) test. The EEG of the ERP was measured using a microdata acquisition terminal (Intercross 415, Intercross Corp., Tokyo, Japan) at three scalp locations (frontal zero, Fz; central zero, Cz; parietal zero, Pz; Figure 2-6 and Figure 2-7) according to the International 10–20 system method (Böcker et al., 1994). The sampling frequency for EEG measurements was 1000 Hz. The brain wave was recorded with the filter set to 0.5 Hz, and the low-pass filter was set to 40 Hz. A sound stimulus generator (Intercross 511, Intercross Corp., Tokyo, Japan) was used to measure the P300, during which participants listened to the sound through earphones connected to the sound stimulus generator.

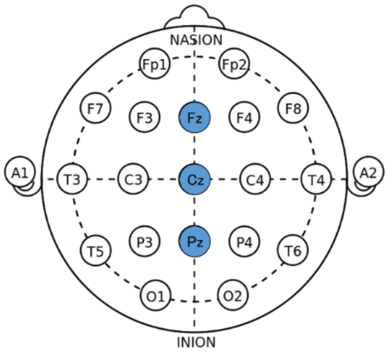


Figure 2-6. Scalp locations based on the International 10-20 system method. Abbreviation: Fz, frontal zero; Cz, central zero; Pz, parietal zero

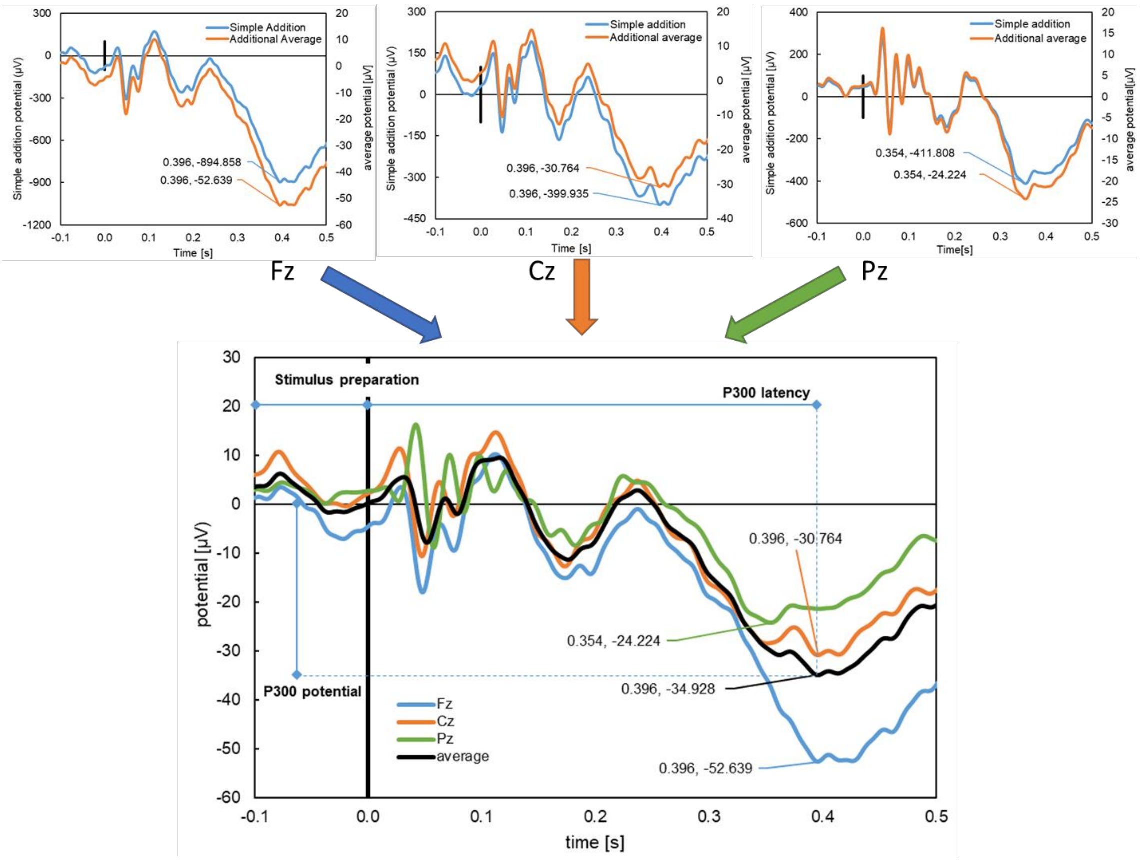


Figure 2-7. Filtering and calculation of P300 during brain response experiment. Abbreviation: Fz, frontal zero; Cz, central zero; Pz, parietal zero

An oddball paradigm task was performed using a sound stimulus to induce P300. The non-target stimulus was 1 kHz, and the target stimulus was 2 kHz. The appearance frequency for non-target and target stimuli was set to 70% and 30%, respectively. The appearance interval of the sound stimulus was 1.5 s, and the task was terminated when the sound stimulus appeared 100 times. Each participant was instructed to press the button on the sound stimulus generator immediately upon hearing the target and then focus on the task. During this assignment, participants were also instructed to stare at a cross point installed on the wall to minimize noise in the EEG due to eye movement (Figure 2-8a).

(a) (b)

Figure 2-8. (a) P300 test and (b) PVT. Abbreviations: P300, brainwave response at approximately 300 ms; PVT, psychomotor vigilance task

Psychomotor Vigilance Task

The PVT is a preferred measure of behavioral alertness as it not only is more appropriate for studying sleep deprivation but also has psychometric advantages over other cognitive tests (Lim & Dinges, 2008). It measures the simple reaction time (RT) on a stimulus that appears at random interstimulus intervals (ISI) (Kay et al., 2013). RT exhibits significant correlation with awareness in several studies (Basner & Dinges, 2011). The stimulus on the PVT-192 Psychomotor Vigilance Task monitor (CWE Inc., Pennsylvania, USA) is a red number on the screen. In many applications, ISI randomly varies from 2 to 10 s. The standard test time was 10 min, although a 5-min test can also be used with the same performance results (Loh et al., 2004). In our test, the participants were asked to respond to the stimulus immediately. If the button was pressed when the counter was not displayed on the screen, it was counted as a false start (Figure 2-8b).

Uchida Kraepelin Test

In the main task, each participant took a 30-row (1 min per row) U-K test with a 1-min break after 15 rows (Figure 2-9). The U-K tests are simple summation tests for mathematical problems that indicate the condition or personality of the participant (Kashiwagi et al., 1985; Sugimoto et al., 2009). The objective results of the U-K test represent speed, correct answering rate, accuracy, and consistency and are strongly influenced by sensory perception and motor response (Freeman, 1950). Speed is calculated as the average number of correct sums per line (in 1 min), whereas the correct rate is the mean of the correct rates (number of correct answers divided by the number of answers) for each row.

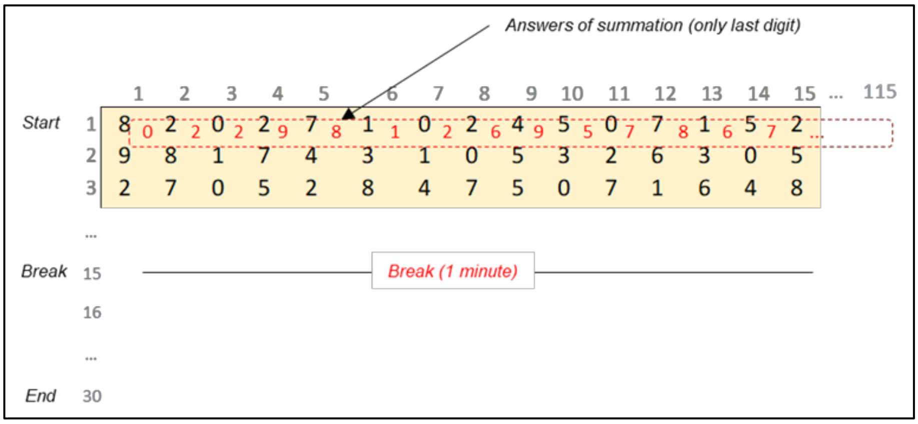


Figure 2-9. The Uchida Kraepelin test simulation

Before and after the U-K test, participants were asked to complete the thermal sensation questionnaire (Appendix D) and fatigue sensation (Appendix E). The thermal sensation questionnaire was used to collect data related to thermal comfort and sensation vote. Thermal sensation was rated on a nine-point scale standard from the Society of Heating, Air-Conditioning, and Sanitary Engineers of Japan (−4, −3, −2, −1, 0, +1, +2, +3, and +4, corresponding to very cold, cold, cool, slightly cool, neutral, slightly warm, warm, hot, and very hot, respectively). Thermal comfort was rated on a seven-point scale from −3 to +3, corresponding to very uncomfortable, uncomfortable, slightly uncomfortable, neutral, slightly comfortable, comfortable, and very comfortable, respectively. Thermal comfort was investigated in detail with respect to thermal parameters and seasons.

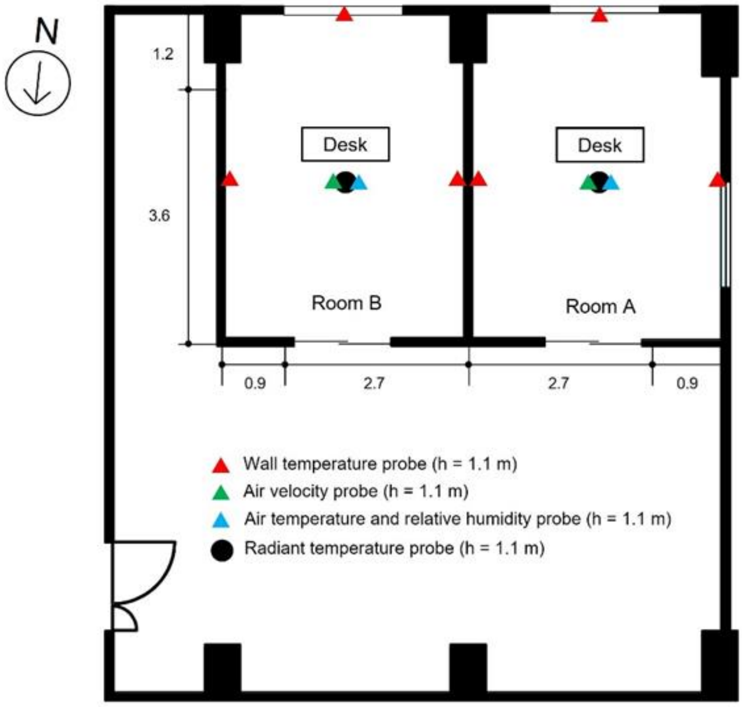


Figure 2-10. Experimental room setup. Abbreviations: h, height; N, north direction

Table 2-3. Types instruments and parameters in the next-day brain response

Parameter	**Instrument Name**	**Brand**	**Instrument Model**	**Accuracy**
Air temperature and relative humidity	Illuminance UV Recorder	T and D	TR-74Ui (logger):  THA-3151 (sensor): 	0-55 ºC (± 0.5 ºC) ±5%
Wall temperature	Thermocouple cable	Graphtec	T-type thermocouple cable: 	

Table 2-3. Types instruments and parameters in the next-day brain response (continued)

Parameter	Instrument Name	Brand	Instrument Model	Accuracy
Radiant temperature	Globe thermometer	Sibata	Sibata 080340-150: 	
Air velocity	Air Flow Transducer	Kanomax	6332D (Kanomax Sensor): 	±3%
	Logger	Graphtec	Mini logger GL800: 	

Table 2-4. Physiological instruments and parameter in the next-day brain response experiment

Parameter	Instrument Name	Brand	Instrument Model	Accuracy
Body mass	Weight scale	A & G	GP 100K: 	±1g
Skin temperature	Skin temperature logger	Gram corporation	LT-8 Series (skin temperature logger) and 409 J (Thermistor probe) : 	±0.1 °C

Table 2-4. Physiological instruments and parameter in the next-day brain response experiment (continued)

Parameter	Instrument Name	Brand	Instrument Model	Accuracy
Reaction time	Psychomotor Vigilance Task	Ambulatory Monitoring Inc. (AMI)	PVT-192: 	±1 ms
P300 of Event Related Potential	Electroencephalogram (EEG)	Intercross	Intercross 415 (micro data acquisition):  Intercross 511 (stimulus generator): 	/

2.4 Data collection and analysis

2.4.1 Thermal comfort survey and sleep quality measurement

The survey and experiment were designed as longitudinal (repeated measurements of the same variables and a limited number of participants). The study was conducted for four nights during summer and three nights during winter. Two-sample t-tests and analysis of variance (ANOVA) were implemented. One-way ANOVA for repeated measures was performed to analyze the indoor environment and sleep quality. Pearson's correlation was conducted to evaluate the correlation between the thermal environment (indoor and outdoor) and sleep quality.

2.4.2 Next-day brain response experiment

Two or paired sets of samples were compared, and the effects of the controlled conditions were analyzed using a paired-sample t-test and analysis of variance

(ANOVA). Two-way ANOVA for repeated measures was used to statistically test differences among the P300 potential, the P300 latency, the reaction time and U-K test score: group (Indonesian and Japanese): df, 1; condition (hot and cooling): df, 1; combination group and condition: df, 1, 1). Two-sample t-tests were conducted to compare sleep quality between the two seasons. In this study, a *p*-value less than 0.05 was considered as statistically significant. All data were investigated using Minitab version 19 (Minitab, LLC, State College, PA, USA) and XLstat (Addinsoft Inc., New York, USA).

2.4.3 Principal component analysis and correlation analysis

The analysis is divided into two parts analyses, i.e., thermal comfort effect on sleep quality and thermal comfort effect on brain response. In the end, the effect of sleep quality on brain response was investigated.

Effect of thermal comfort on sleep quality

In analyzing thermal comfort effect on sleep quality, four main data in the current study were prepared, i.e., thermal environment, thermal sensation, sleep quality, and sleep sensation. The thermal sensation and sleep sensation variables were reduced using the principal component analysis (PCA). Then, the descriptive statistic was stored for each variable (including additional variables). To test the correlation between thermal comfort (viz.: thermal environment, thermal sensation, and additional thermal sensation variable) and sleep quality (viz.: sleep quality, sleep sensation, and additional sleep quality variable).

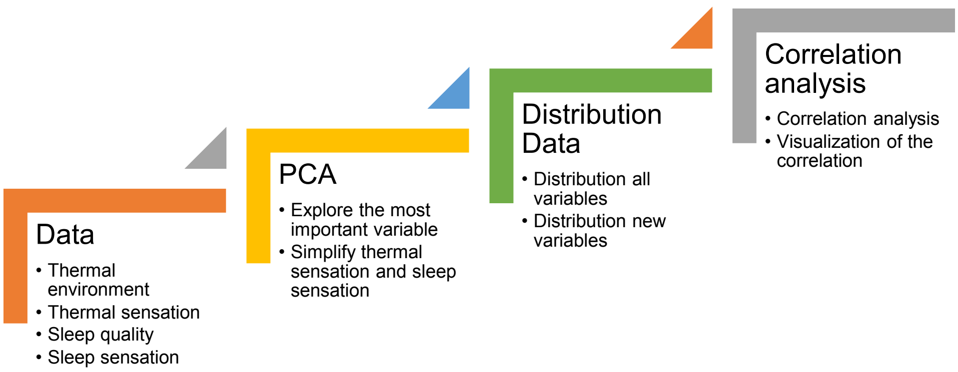


Figure 2-11. Methodology of analysis effect of thermal comfort on sleep quality

Data from the summer and winter study was used. The number of data is 115 records (summer: 64 records, winter: 51 records). In the data set preparation, the thermal sensation consisted of eight variables, and sleep sensation consisted of seven variables. The data obtained was examined using Microsoft Excel and the add-in tool Data Analysis, as well as the add-in program XLstat (Addinsoft Inc., New York, USA) to calculate PCA. The algorithm for analysis and calculations followed and modified the explanation by Zavecz et al. (2020).

Effect of thermal comfort on brain response

In analyzing thermal comfort effect on brain response, the analysis used the same methodology (Figure 2-11). Five main data in the current study were prepared, i.e., thermal environment, thermal sensation, brain response, reaction time, and Uchida-Kraepelin. The thermal sensation variables were reduced using the PCA. Then, the descriptive statistic was stored for each variable (including additional variables). To test the correlation between thermal comfort (viz.: thermal environment, thermal sensation, and additional thermal sensation variable) and brain-response (viz.: P300 potential, P300 latency, the reaction time of PVT, and Uchida-Kraepelin test).

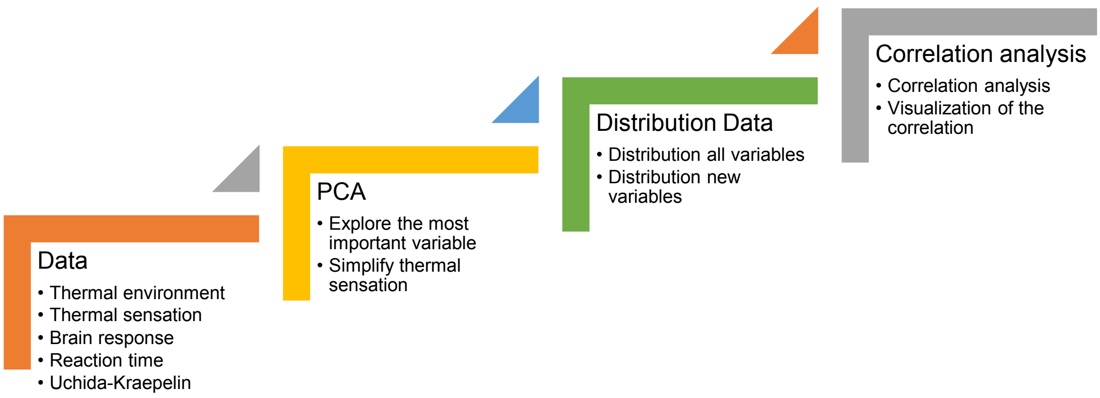


Figure 2-12. Methodology of analysis effect of thermal comfort on brain response

2.5 Participant's information

The 16 healthy males students (8 Indonesian and 8 Japanese) participated in the summer study and 18 healthy males students (10 Indonesian and 8 Japanese) participated in the winter study. The Indonesian (IDN) group was born and raised in Indonesia as tropical country, which are defined as country with hot and humid weather, two seasons (dry and rainy), with temperatures averaging: 28°C on the coastal plains, 26°C on the inland and mountain areas, and 23°C on the higher mountain regions, and the relative humidity in the area is extremely high: ranging between 70 and 90 %. The Japanese (JPN) group was born and raised in Japan. The participants were undergraduate and graduate students at Toyohashi University of Technology, Japan. The following physical characteristics of the participants were measured are summarized in the Table 2-5 for summer study and Table 2-6 for winter study. The body mass index was measured with the Equation 2-4 and surface area with Equation 2-5.

Table 2-5. Demographic data of participants during summer study

Nationality	**N**	**Age (years)**	**Height (cm)**	**Weight (kg)**	**BMI (kg/m²)**	**BSA (m²)**
Indonesia	8	28 ± 4	169 ± 3	63.2 ± 9.4	22.2 ± 3.5	1.7 ± 0.1
Japan	8	23 ± 1	171 ± 5	60.9 ± 8.6	20.8 ± 2.2	1.7 ± 0.1

Note: data are presented as mean ± standard deviation.

Table 2-6. Demographic data of participants during winter study

Nationality	**N**	**Age (years)**	**Height (cm)**	**Weight (kg)**	**BMI (kg/m²)**	**BSA (m²)**
Indonesia	10	30 ± 4	169 ± 2	77.3 ± 13	27.2 ± 4.9	1.9 ± 0.2
Japan	8	23 ± 0	169 ± 6	58.9 ± 7.9	20.5 ± 1.8	1.7 ± 0.1

Note: Data are presented as mean ± standard deviation.

The participants in both groups (IDN and JPN) were all students who participated in a similar level of physical activity. Most of the subjects did not participate in any endurance sports activities at the study, either individually or as part of a group activity.

Chapter 3
Thermal comfort, sleep quality and brain response

Data summary, results, discussion

The field survey and experiment were planned and conducted in summer 2019 and 2020, and winter 2020. The study consisted of two parts, i.e., 1) thermal comfort survey and sleep quality measurement in their bedroom, and 2) the next-day brain response experiment in the Energy Building Laboratory, Toyohashi University of Technology. This chapter explained the data summary, results, and discussion.

3.1 Sleep survey

3.1.1 Bedroom environment

Figure 3-1 and Figure 3-2 present the average bedroom air temperature and relative humidity during sleep in the summer and winter, respectively (cut the average data from 0:00 to 07:00 AM, Japan standard time). The results of the investigation of the thermal environment of two nationalities' bedrooms during summer and winter are summarized in Table 3-1. In the summer, the average of bedroom air temperature and relative humidity were not significant different between IDN and JPN groups. However, the average bedroom air temperature and relative humidity significantly differed between the IDN and JPN groups.

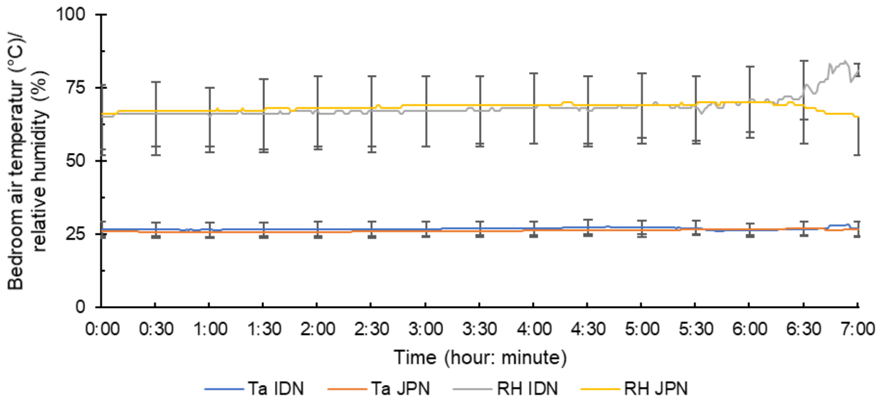


Figure 3-1. Bedroom air temperature and relative humidity of IDN and JPN group during sleep in the summer

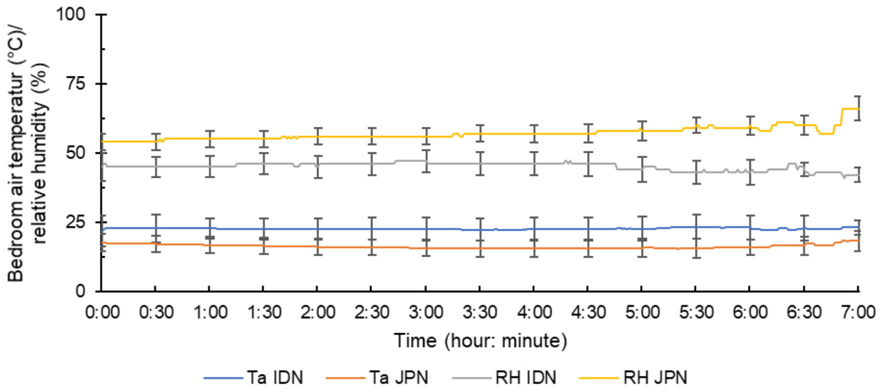


Figure 3-2. Bedroom air temperature and relative humidity of IDN and JPN group during sleep in the winter

In the summer study, sunrise was at 05:07 ± 19 min and sunset was at 18:27 ± 28 min (the daylight hours were 799 min ± 47 min). Moreover, in the winter study, the sunrise was at 06:27 ± 25 min and sunset was at 17:25 ± 24 min (the daylight hours were 657 min ± 49 min).

Table 3-1. Indoor thermal environment during summer and winter study

	Summer			Winter		
Parameters	**IDN**	**JPN**	**Sig.**	**IDN**	**JPN**	**Sig.**
Bedroom T_a (°C)	26.8 ± 2.2	26.1 ± 2.0	$p = 0.25$	22.2 ± 3.7	15.9 ± 2.4	$p < 0.05$
Bedroom RH (%)	67 ± 12	68 ± 13	$p = 0.77$	45 ± 12	56 ± 12	$p < 0.05$
Bedroom AH (g/m3)	17.2 ± 4.3	16.8 ± 4.9	$p = 0.71$	8.9 ± 3.5	7.6 ± 3.2	$p < 0.05$
Clothing insulation	0.2 ± 0.1	0.2 ± 0.1	$p = 0.84$	0.5 ± 0.2	0.7 ± 0.3	$p < 0.05$
Bedding insulation	2.3 ± 1.2	2.2 ± 1.1	$p = 0.30$	3.1 ± 1.2	6.0 ± 1.1	$p < 0.05$

Abbreviations: T_a, air temperature; RH, relative humidity; AH, absolute humidity; IDN, Indonesian group; JPN, Japanese group; Sig., significancy.

The indoor air temperature and relative humidity were grouped (in 1°C for Ta and 10% for RH) and analyzed the frequency distribution. Frequency distribution of the indoor air temperature within each bin was presented in Figure 3-3 for summer and in Figure 3-4 for winter. The indoor air temperature with the highest frequency was 26 °C and 28 °C for Indonesian students and 27 °C for Japanese students during summer. In the winter, the indoor air temperature with the highest frequency was 20 °C and 21 °C for IDN group and 16 °C for JPN group.

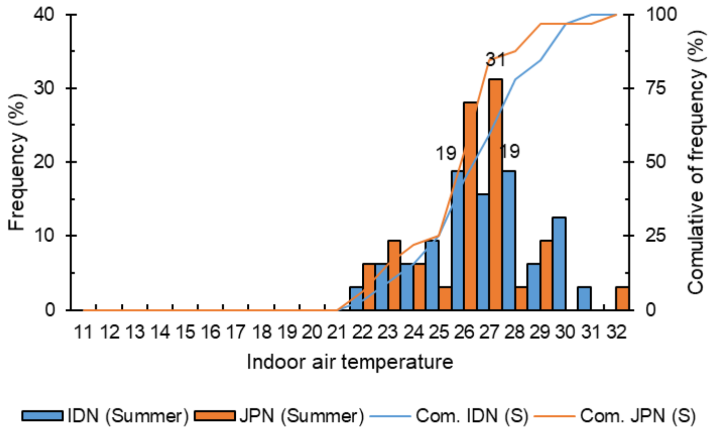


Figure 3-3. Frequency distribution of indoor air temperature during summer

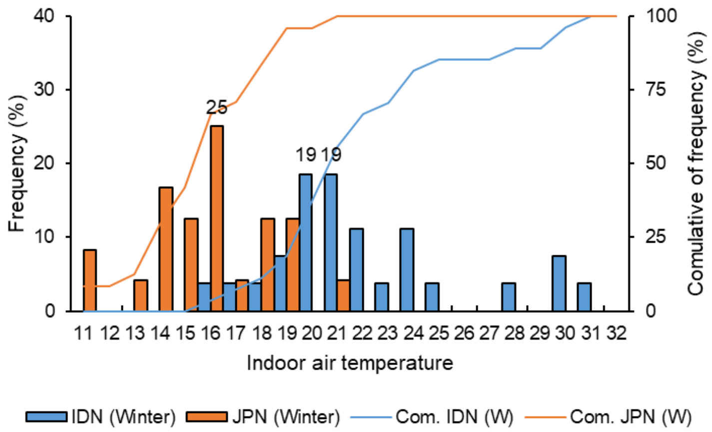


Figure 3-4. Frequency distribution of indoor air temperature during winter

The frequency distribution of indoor relative humidity is shown in Figure 3-5 for summer and in Figure 3-6 for winter. The minimum indoor relative humidity was same for Indonesian and Japanese students during summer (35% of RH). In the winter, the minimum indoor relative humidity was 25% for IDN and 35% for the JPN group during winter.

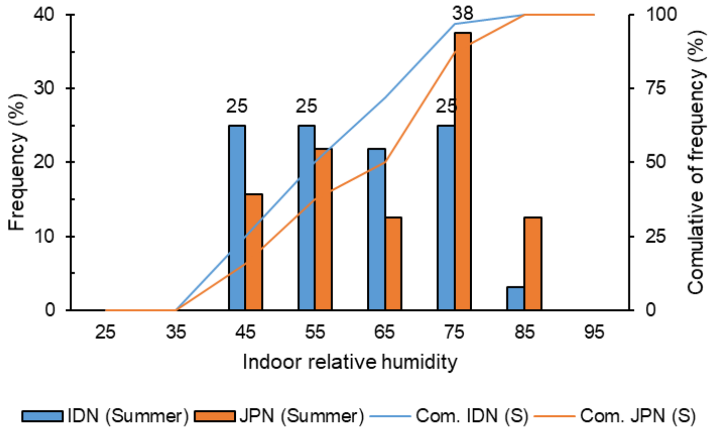


Figure 3-5. Frequency distribution of indoor relative humidity during summer

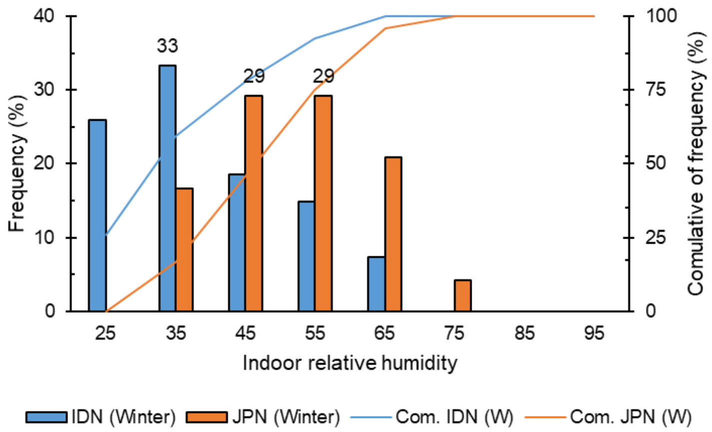


Figure 3-6. Frequency distribution of indoor relative humidity during winter

In the summer, 96.9 % and 84.4 % of IDN group, respectively, and 100 % and 78.1 % of JPN group, respectively, slept in short sleeves and short pants. In order to improve their sleeping comfort, IDN group protect their bodies with thick blankets on average during the summer. However, JPN group protected their bodies on average with a thin blanket and a very thick blanket during the summer. Meanwhile, in the winter, 44.4 % and 33.3 % of IDN group, respectively, continued to wear short sleeves and short pants. By contrast, 95.8 % and 100 % of JPN group, respectively, wore long sleeves and long sweatpants. In order to improve their sleeping comfort, IDN group protects their bodies with thick blankets on average during the winter. However, JPN group protected their bodies on a very thick blanket during winter.

3.1.2 Thermal sensation and thermal comfort prior to sleep

Before going to sleep, participants completed questionnaires (thermal sensation: Appendix A and physical condition: Appendix B). The thermal sensation percentages for each nationality in summer and winter prior to sleep are summarized in Figure 3-7 and Figure 3-8 . In the summer, 41% of IDN group reported feeling slightly cool, compared to 41% of JPN group reported feeling neutral. Although, the bedroom air temperature was comparable, the highest percentage of thermal sensation was different between IDN and JPN groups. In the winter, the 33% of IDN group reported feeling neutral and slightly cool, compared to 50% of JPN group. The highest percentage of JPN group felt neutral during winter, whereas the indoor air temperature was lower.

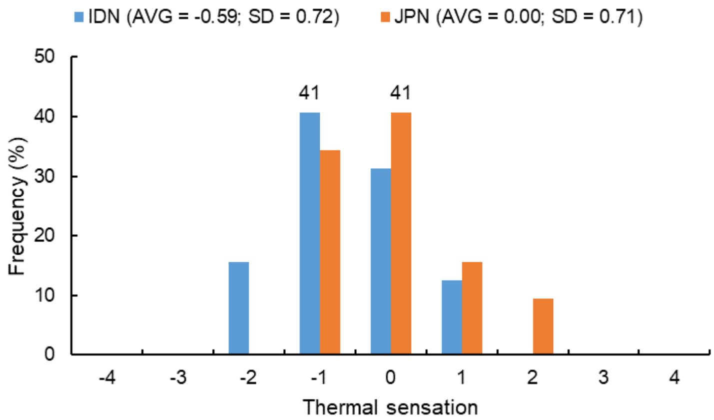


Figure 3-7. Frequency distribution of thermal sensation votes during summer

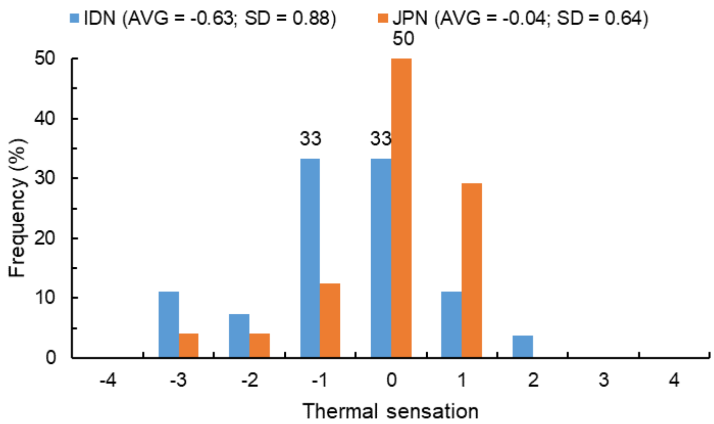


Figure 3-8. Frequency distribution of thermal sensation votes during winter

Furthermore, in the thermal comfort sensation, 47% of IDN group and 38% of JPN group were feeling slightly comfortable during summer. In the winter, 26% of the IDN group were feeling neutral and slightly uncomfortable, while 38% of the JPN group felt slightly comfortable during winter.

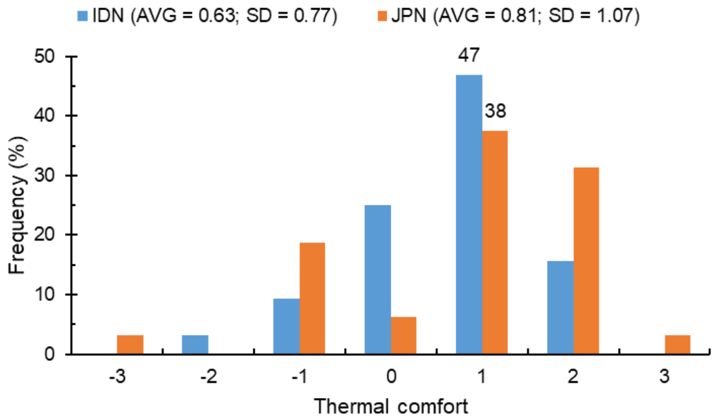


Figure 3-9. Frequency distribution of thermal comfort votes during summer

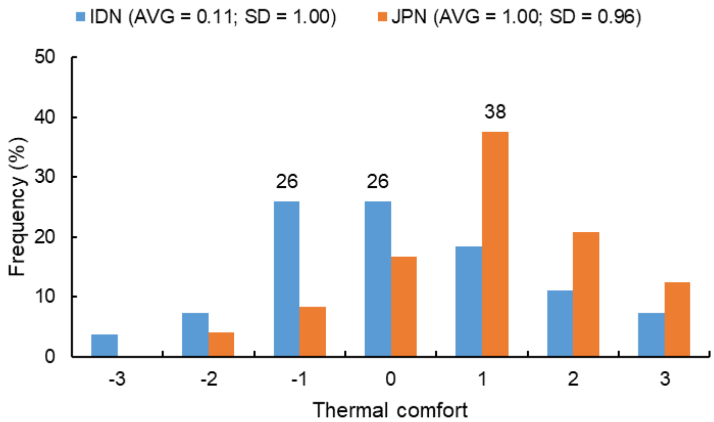


Figure 3-10. Frequency distribution of thermal comfort votes during winter

Additionally, the relationship between the two subjective sensations and the indoor air temperature were analyzed. In calculation the frequency of correlation between physical and subjective measurements, the indoor air temperature was rounded to one degree Celsius. Figure 3-11 and Figure 3-12 illustrates the frequency and correlation between indoor air temperature and thermal sensation vote (TSV). Figure 3-13 and Figure 3-14 illustrates the frequency and correlation between indoor air temperature and thermal comfort (TC).

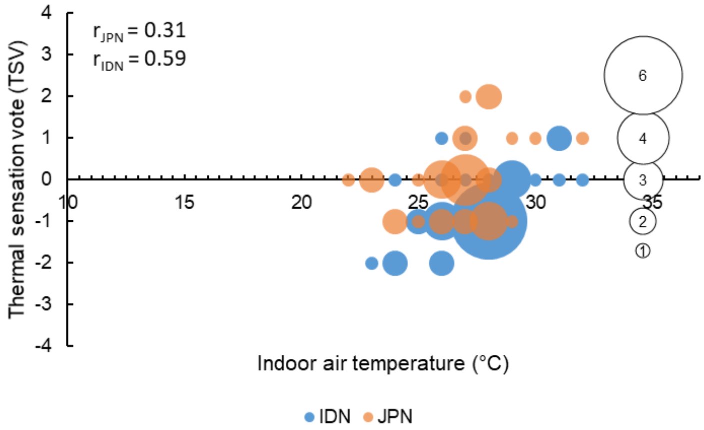


Figure 3-11. Correlation between indoor air temperature and thermal sensation during summer

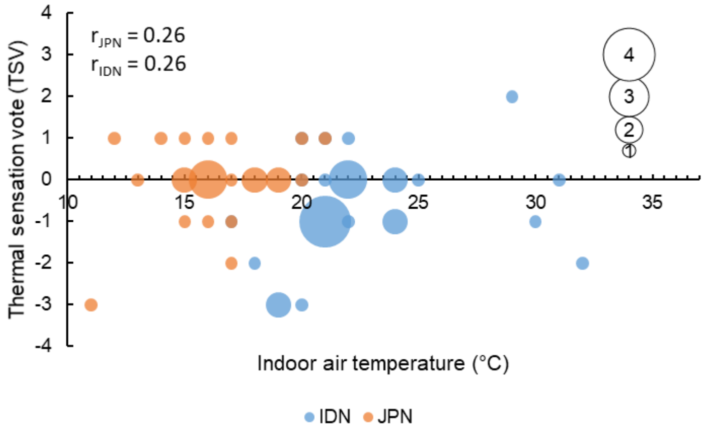


Figure 3-12. Correlation between indoor air temperature and thermal sensation during winter

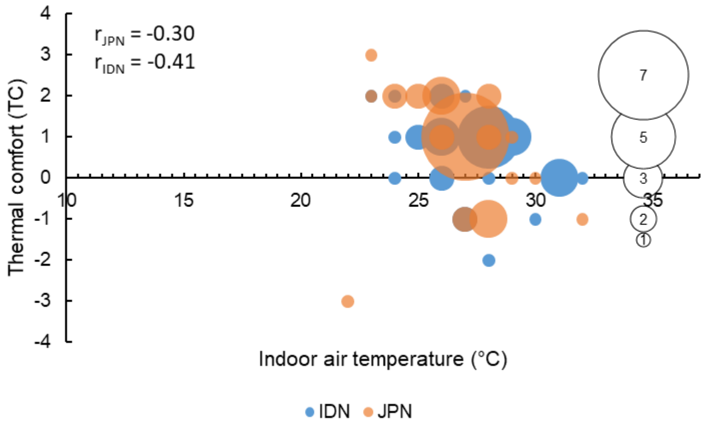


Figure 3-13. Correlation between indoor air temperature and thermal comfort during summer

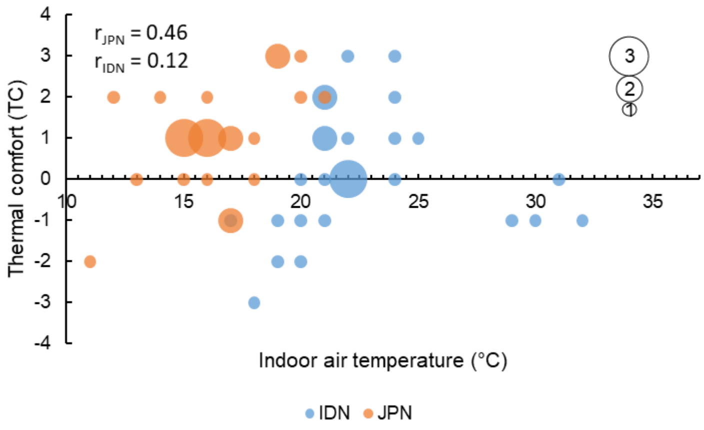


Figure 3-14. Correlation between indoor air temperature and thermal comfort during winter

The indoor environment's highest thermal preference prior to sleep was analyzed. 41% of IDN group and 59% of JPN group were feeling neutral during summer (Figure 3-15). Moreover, during the summer, the mean temperature for participants with a thermal preference (TP) of "0: neutral" was 26.3 °C for IDN group and 26.1 °C for JPN group. In the winter, 63% of IDN group were feeling "prefer warm," and 67% of JPN group were feeling "prefer neutral," which indicates that the IDN group prefers to change their indoor environment so that it is perceived to be a little warmer than it is currently is (Figure 3-16). The mean temperature for participants with a thermal preference (TP) of "0: neutral" was 23.1 °C and 17.1 °C for IDN and JPN groups, respectively. The percentages of thermal preference are summarized in Figure 3-15.

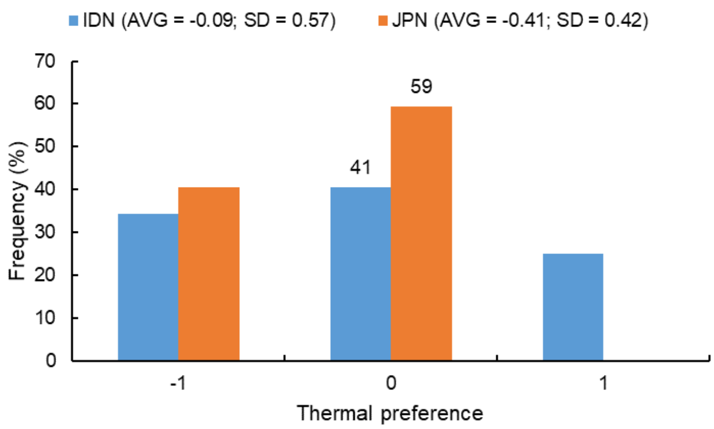


Figure 3-15. Frequency distribution of thermal preference during summer

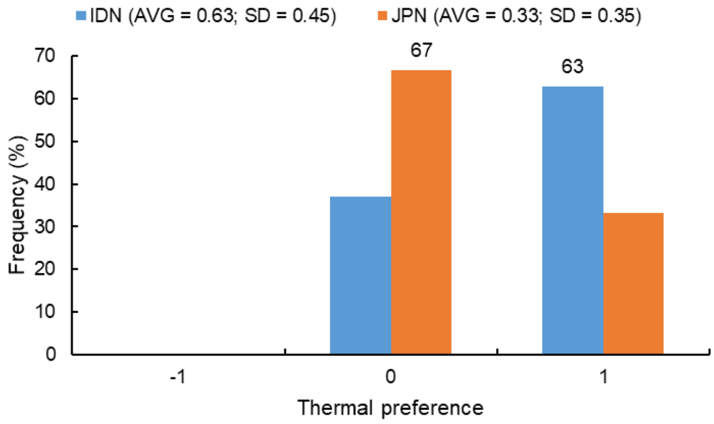


Figure 3-16. Frequency distribution of thermal preference during winter

3.1.3 Sleep quality and sleep sensation during summer

The students' physical states (physical condition, sleepiness, and mental state) prior to sleeping (Appendix B) were analyzed. Table 3-2 summarizes the average subjective assessment of physical conditions. There were significant differences in sleepiness between IDN and JPN groups during the summer ($p < 0.05$) and in physical condition and sleepiness during the winter.

Table 3-2. Physical condition before sleep

	Summer			**Winter**		
Parameters	**IDN**	**JPN**	**Sig.**	**IDN**	**JPN**	**Sig.**
Physical condition (1 to 5)	3.0 ± 0.4	3.1 ± 0.5	*p* = 0.62	3.5 ± 0.7	2.9 ± 0.5	p < 0.01
Sleepiness (1 to 5)	3.2 ± 0.5	2.8 ± 1.0	*p* < 0.05	3.3 ± 0.6	2.8 ± 0.9	p < 0.05
Mental feeling (1 to 5)	3.0 ± 0.6	3.0 ± 0.6	*p* = 0.84	3.4 ± 0.8	3.0 ± 0.7	p = 0.10

IDN group went to bed at 23:49 (95 min) and woke up at 05:50 (108 min) and JPN group went to bed at 01:20 (74 min) and woke up at 08:42 (39 min) during summer. Moreover, 21.9 % of Indonesian students and 34.4 % of Japanese students napped during the day. In the winter, IDN group went to bed at 23:30 (111 min) and woke up at 06:15 (76 min), and JPN group went to bed at 01:19 (73 min) and woke up at 08:28 (73 min). Further, 16.7 % of IDN group and 12.5 % of JPN group napped on the day during winter.

In the comparison between wake-up and sunrise time, there was significantly different between wake-up time of JPN group and sunrise time in summer and winter ($p < 0.01$), whereas the IDN group was not different. Average of IDN group woke-up by sunrise time during summer and winter were identified.

Table 3-3 summarizes the average of sleep quality parameters (duration on bed, sleep duration, sleep rate, sleep efficiency, and sleep latency) based on actigraphy data. The significant differences in sleep quality parameters were observed between nationality during summer. ANOVA was conducted with the sleep quality parameters (duration on bed, sleep duration, sleep rate, sleep efficiency, and sleep latency) as the dependent variables and nationality (IDN, JPN) as the independent variables. In the summer, the duration on bed and sleep duration were significantly different between IDN and JPN groups ($p < 0.01$, $p < 0.01$, respectively). Moreover, a significant difference in sleep rate ($p < 0.05$), sleep efficiency ($p < 0.01$), and sleep latency ($p < 0.05$) during winter was found.

Table 3-3. Sleep quality during summer and winter

	Summer			**Winter**		
Parameters	**IDN**	**JPN**	**Sig.**	**IDN**	**JPN**	**Sig.**
Duration on bed (min)	361.9 ± 62.1	442.2 ± 60.5	$p < 0.01$	406.1 ± 89.7	429.8 ± 102	p = 0.69
Sleep duration (min)	311.5 ± 72.9	370.9 ± 62.7	$p < 0.01$	338.3 ± 93.8	380.3 ± 99.4	p = 0.24
Sleep rate (%)	85.6 ± 10.3	84.6 ± 13.3	$p = 0.75$	82.7 ± 11.7	88.4 ± 8.2	p < 0.05
Sleep efficiency (%)	92.4 ± 8.5	91.1 ± 11.6	$p = 0.61$	88.5 ± 9.1	94.5 ± 5.9	p < 0.01
Sleep latency (min)	25.4 ± 24.7	28.8 ± 26.4	$p = 0.61$	24.7 ± 31.4	9.3 ± 15.0	p < 0.05

Sleep sensation (sleep depth, wellness, and clear-headed in the morning) was analyzed using the St. Mary's Hospital (SMH) questionnaire (Appendix C). In the summer, there was a significant difference between IDN and JPN groups in all sensation parameters (sleep depth, wellness, and clear-headedness in the morning) ($p < 0.05$, $p < 0.01$, and $p < 0.01$, respectively). In the winter, there was a significant difference in clear-headedness in the morning between IDN and JPN groups ($p < 0.01$).

Table 3-4. Sleep sensation during summer and winter

	Summer			**Winter**		
Parameters	**IDN**	**JPN**	**Sig.**	**IDN**	**JPN**	**Sig.**
Sleep-depth (1 to 8)	5.3 ± 1.2	4.5 ± 1.6	$p < 0.05$	5.0 ± 1.2	4.9 ± 1.5	p = 0.69
Wellness (1 to 6)	4.2 ± 0.7	3.6 ± 1.1	$p < 0.01$	4.5 ± 0.6	4.1 ± 0.9	p < 0.10
Clear-headedness (1 to 6)	3.9 ± 0.5	2.0 ± 0.6	$p < 0.01$	3.5 ± 0.8	2.3 ± 0.9	p < 0.01

IDN group felt better sleep sensation than JPN group during summer. Moreover, although sleep duration of IDN group was shorter than JPN group, Interestingly IDN group felt better in clear-headed in the morning than JPN group.

3.1.4 Comfort temperature using Griffiths' method

Current sub chapter used the equation of thermal sensation vote in Figure 3-11 and Figure 3-12. The mean of indoor air temperature for the thermal sensation vote (TSV) equaled to "-1, 0, +1 (extended neutral)" was 28.1 °C for IDN group and 26.2 °C for JPN group during summer and was 22.1 °C for IDN group and 17.0 °C for JPN group during winter. However, Rijal (2014) mentioned that linear regression model was not appropriate to predict the comfort temperature. Thus, the Griffiths' method was used to predict each participant's thermal comfort temperature based on their TSV votes (Griffiths, 1988).

Equation 3-1:

$$TC_g = T_a + \frac{(0 - TSV)}{\alpha}$$

Equation 3-2:

$$TP_g = TC_g + \frac{(0 - TCV)}{\alpha}$$

where, TC_g is Griffiths' comfort temperature, T_a is indoor air temperature (°C), TP_g is preferred temperature, the number 0 indicates neutral in TSV and no change in TP, and α is regression coefficient. Griffiths' method was calculated using the following seven-point thermal sensation coefficients: 0.25, 0.33, 0.50 (Humphreys et al., 2013; Rijal et al., 2008). The three regression coefficients for the nine-point thermal sensation in the current study were calculated using the Honjo et al conversion: 0.33, 0.44, 0.67 (Honjo et al., 2012). TP was observed using the same method. The following table summarizes the Griffiths method's calculation of the comfort air temperature.

In the two investigated groups (IDN and JPN) during summer and winter, the estimated mean comfort of IDN group was higher than JPN group. The mean value of the IDN comfort temperature is 28.1 °C in the summer and 23.5 °C in the winter as indicated in

Table 3-5. The comfort temperature of JPN group is 26.1 °C in the summer and 16.0 °C in the winter.

Table 3-5. Comfort air temperature calculated by Griffiths' method during summer and winter

		Summer			Winter		
	α	**IDN**	**JPN**	**Sig.**	**IDN**	**JPN**	**Sig.**
TC_g (°C)	0.33	28.6(2.2)	26.1(2.9)	$p < 0.01$	24.0(4.5)	16.0(3.4)	$p < 0.01$
	0.44	28.1(1.9)	26.1(2.5)	$p < 0.01$	23.5(3.9)	16.0(2.9)	$p < 0.01$
	0.67	27.7(1.7)	26.1(2.1)	$p < 0.01$	23.0(3.6)	15.9(2.6)	$p < 0.01$
	Avg	28.1(1.9)	26.1(2.5)	$p < 0.01$	23.5(4.0)	16.0(2.9)	$p < 0.01$
TP_g (°C)	0.33	27.1(2.8)	27.4(3.1)	$p = 0.68$	20.2(4.3)	14.8(3.4)	$p < 0.01$
	0.44	27.0(2.4)	27.1(2.8)	$p = 0.91$	20.7(4.1)	15.1(3.1)	$p < 0.01$
	0.67	26.9(2.3)	26.7(2.5)	$p = 0.78$	21.2(4.0)	15.4(2.9)	$p < 0.01$
	Avg	27.0(2.5)	27.1(2.8)	$p = 0.91$	20.7(4.1)	15.1(3.1)	$p < 0.01$

Abbreviations: TC_g, Griffiths' comfort temperature; TP_g, Griffiths' preference temperature

3.2 Next-day brain response experiment

3.2.1 Experimental room environment

The next-day brain response experiment conducted two contrasting thermal condition during summer (hot and cooling) and winter (cold and heating). In the comfort conditions during summer (cooling), the participants adjusted the ambient thermal environment of the experimental room by controlling the AC within a temperature range of 20°C–26°C (cooling mode) and wore clothing with different insulation (0.27 clo. during summer). In the winter, the participants adjusted the ambient thermal environment of the experimental room by controlling the AC within a temperature range of 20°C–26°C (heating mode) and wore clothing with 0.99 for clothing insulation.

Table 3-6. Physical environment parameter during summer experiment

Cond.	Ta	RH	MRT	Wall 1	Wall 2	Wall 3	AV
Hot	31.0 ± 1.6	64.2 ± 11.7	31.4 ± 1.8	30.8 ± 1.8	31.9 ± 2.9	31.2 ± 1.6	0.1 ± 0.2
Cooling	24.5 ± 1.8	49.1 ± 9.6	25.4 ± 2.2	26.0 ± 2.3	26.9 ± 2.8	27.5 ± 2.9	0.2 ± 0.3
Cold	13.9 ± 2.3	53.1 ± 11.7	14.5 ± 2.0	13.9 ± 2.0	15.0 ± 2.9	13.6 ± 2.2	0.0 ± 0.0
Heating	21.8 ± 1.2	37.6 ± 9.7	22.3 ± 1.3	20.5 ± 1.3	22.3 ± 2.3	20.0 ± 1.6	0.1 ± 0.0

Abbreviations: MRT, mean radiant temperature; Wall 1-3, wall temperature side 1-3, AV, air velocity. Note: Ta, RH, MRT, and Wall (1-3) in °C; AV in m/s.

The descriptive statistics of the physiological parameters in the controlled conditions during summer (hot, cooling) and during winter (cold, heating) are presented in Table 3-6. To confirm the differences of the controlled condition, the statistical analysis revealed that the T_a, RH, MRT, and Wall 1-3 for comfort conditions (cooling and heating) were significantly different than those in natural conditions (hot and cold, all $p < 0.05$).

3.2.2 Skin temperature

Local skin temperatures were also continuously recorded by thermistor probes (409 J, Nikkiso-YSI, Tokyo, Japan) attached with surgical tape to the subject's skin, with the probe attached to a data logger (LT 8A, Gram Co., Ltd., Saitama, Japan) as seen in Table 2-3.

Table 3-7. Skin temperature in hot and cooling condition

	Hot			Cooling		
	IDN	JPN	Avg.	IDN	JPN	Avg.
Head	35.7 ± 0.5	35.3 ± 0.6	35.5 ± 0.6	34.8 ± 0.6†	34.9 ± 0.7	34.9 ± 0.6†
Chest	34.9 ± 0.6	34.1 ± 0.9	34.5 ± 0.8	34.6 ± 0.7	33.8 ± 0.9	34.2 ± 0.9
Arm	34.6 ± 0.6	33.9 ± 1.0	34.2 ± 0.9	32.2 ± 1.6†	32.2 ± 1.3†	32.2 ± 1.5†
Hand	34.7 ± 0.7	34.2 ± 1.2	34.5 ± 1.0	32.2 ± 1.8†	32.4 ± 1.2	32.3 ± 1.5†
Thigh	34.0 ± 0.7	33.6 ± 1.0	33.8 ± 0.9	33.3 ± 1.3	32.5 ± 1.1	32.9 ± 1.3†
Leg	33.9 ± 0.6	33.6 ± 0.9	33.7 ± 0.8	32.9 ± 0.7†	32.2 ± 0.6†	32.5 ± 0.7†
Foot	34.5 ± 1.0	34.3 ± 1.0	34.4 ± 1.0	30.9 ± 2.4†	31.2 ± 1.8†	31.0 ± 2.1†
Back	34.7 ± 0.5	33.9 ± 1.1	34.3 ± 0.9	34.0 ± 1.0	33.4 ± 0.8	33.7 ± 0.9
MST (T_{sk})	34.5 ± 0.4	34.0 ± 0.9	34.3 ± 0.7	33.3 ± 0.9†	32.6 ± 0.8†	33.0 ± 0.9†

Note: Data are presented as mean ± standard deviation. † Significantly different between hot and cooling condition at $p < 0.05$.

Table 3-7 and Table 3-8 show the average of T_{sk} at eight sites with reference to Hardy Dubois's 7-point method. In the current study, T_{sk} was calculated using Equation 2-3 (page 19). T_{sk} was not significantly different between IDN and JPN group among controlled conditions. However, T_{sk} of both group in cooling condition was significantly lower ($p < 0.05$) than those in hot condition. Moreover, in comparison between two conditions, T_{sk} of both groups (IDN and JPN) in heating conditions was significantly higher ($p < 0.05$) than those in cold conditions.

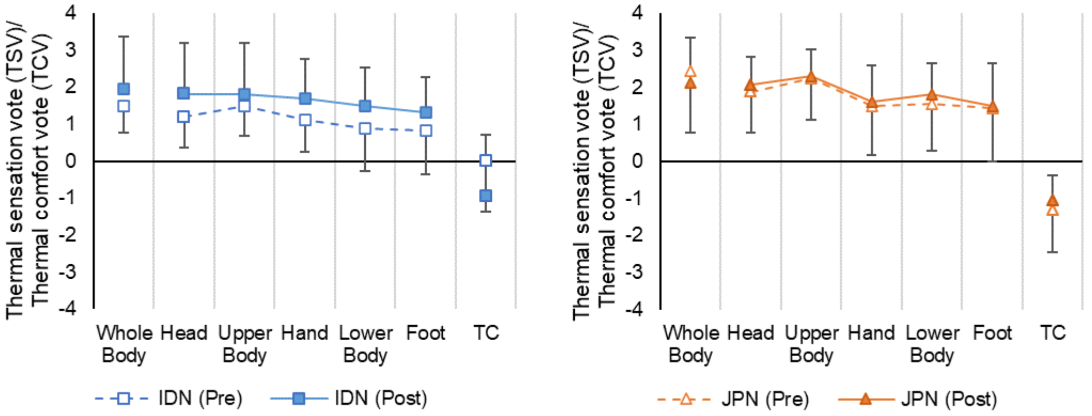
Table 3-8. Skin temperature in cold and heating condition

	Cold			Heating		
	IDN	JPN	Avg.	IDN	JPN	Avg.
Head	32.9 ± 0.9	33.2 ± 1.0	33.0 ± 1.0	34.4 ± 0.5†	34.6 ± 0.6†	34.5 ± 0.6†
Chest	32.8 ± 1.3	32.8 ± 1.5	32.8 ± 1.4	34.6 ± 0.7	34.4 ± 0.8	34.5 ± 0.8
Arm	29.3 ± 1.9	29.4 ± 1.7	29.4 ± 1.7	31.8 ± 1.1†	32.2 ± 1.3†	32.0 ± 1.2†
Hand	26.5 ± 3.0	24.8 ± 2.6	25.7 ± 2.9	30.5 ± 1.4†	30.8 ± 2.1†	30.6 ± 1.7†
Thigh	29.5 ± 1.7	29.7 ± 0.7	29.6 ± 1.3	31.7 ± 1.2†	31.9 ± 0.8†	31.8 ± 1.0†
Leg	30.0 ± 1.0	29.8 ± 0.7	29.9 ± 0.9	31.7 ± 0.6†	32.0 ± 0.9†	31.8 ± 0.8†
Foot	26.5 ± 2.9	26.2 ± 1.2	26.4 ± 2.2	28.9 ± 1.7†	29.9 ± 1.2†	29.4 ± 1.6†
Back	31.7 ± 1.7	32.9 ± 1.2	32.2 ± 1.5	33.8 ± 0.7†	33.8 ± 1.1†	33.8 ± 0.9†
MST (T_{sk})	30.4 ± 1.4	28.4 ± 1.2	29.5 ± 1.6	32.5 ± 0.5†	31.9 ± 1.0†	32.2 ± 0.8†

Note: Data are presented as mean ± standard deviation. † Significantly different between cold and heating condition at $p < 0.05$.

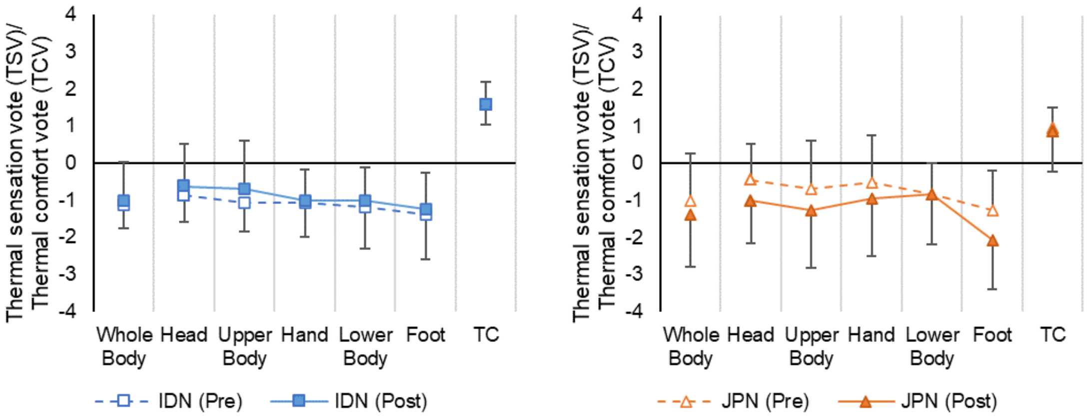
3.2.3 Thermal sensation and thermal comfort pre-/post-task

To confirm thermal comfort sensation, the summaries of thermal sensation votes (TSVs), thermal comfort votes (TCVs), and predicted mean vote (PMV) in hot condition and cooling condition were observed. Figure 3-17 and Figure 3-18 depict the average of TSV, TCV, and PMV TSV of IDN and JPN group. The statistical analysis revealed that TSV was not significantly different between IDN and JPN group for each condition during summer experiment (all $p > 0.05$). In response to the experimental room environment, the TSV was also significantly different ($p < 0.05$) among conditions. Moreover, TCV was also not significantly different between two nationalities ($p = 0.19$). Similar to TSV, TCV was significantly different among conditions ($p < 0.05$).



(a) (b)

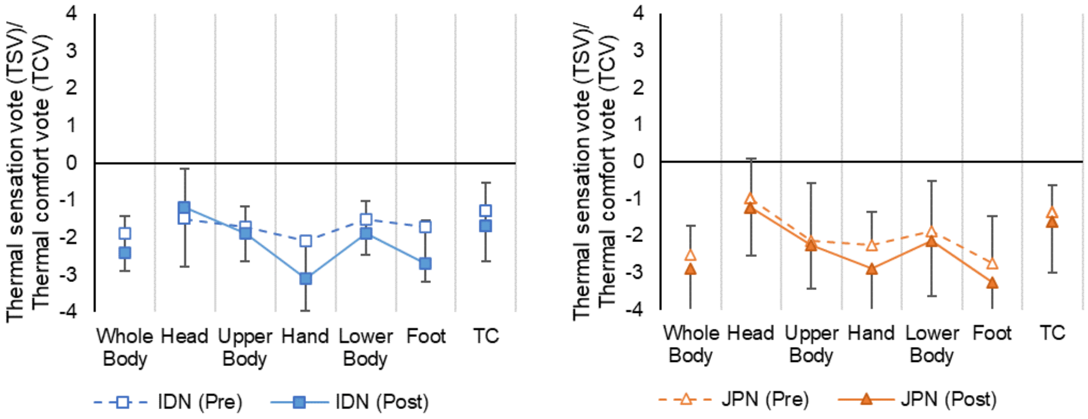
Figure 3-17. TSV and TCV of (a) Indonesian and (b) Japanese group in pre- and post-task during hot condition. Abbreviation: TC, thermal comfort



(a) (b)

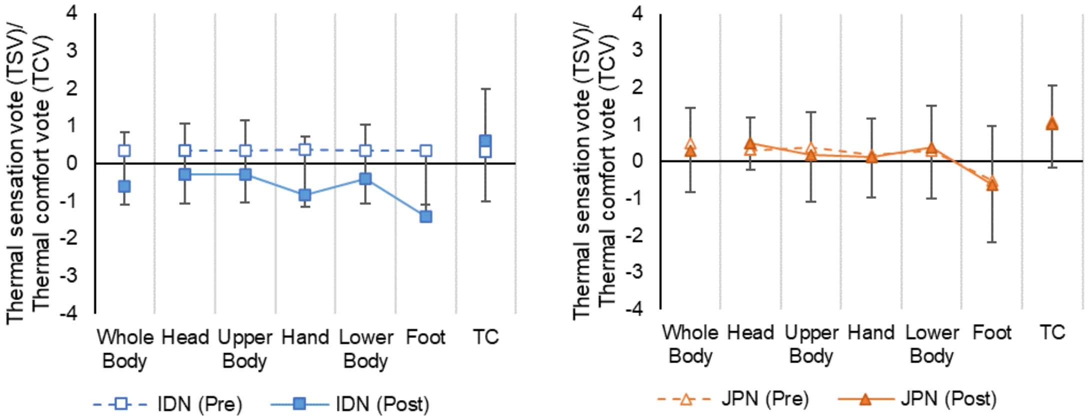
Figure 3-18. TSV and TCV of (a) Indonesian and (b) Japanese group in pre- and post-task during cooling condition. Abbreviation: TC, thermal comfort

Figure 3-19 and Figure 3-20 depict the average of TSV, TCV, and PMV of IDN and JPN groups. The statistical analysis revealed that TSV was not significantly different between the IDN and JPN groups for each condition during the winter experiment (all $p > 0.05$). In response to the experimental room environment, the TSV was also significantly different ($p < 0.05$) among conditions. Moreover, TCV was also not significantly different between the two groups for each condition (all $p > 0.05$).



(a) (b)

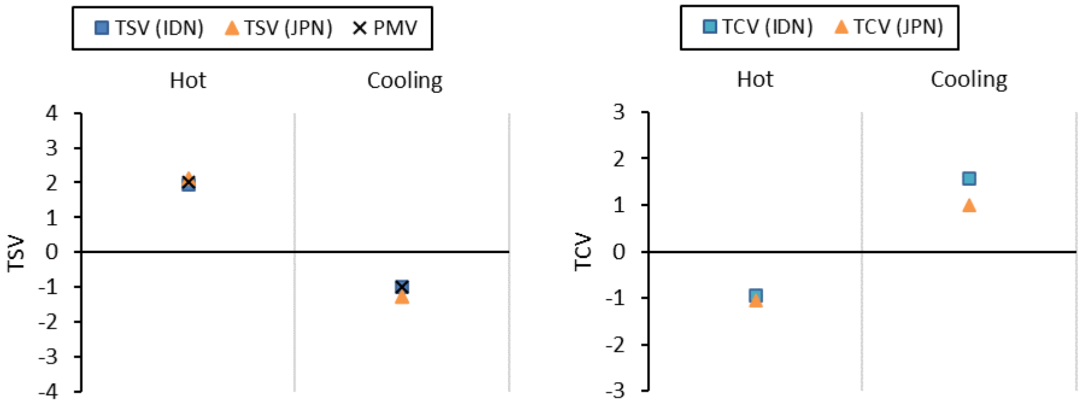
Figure 3-19. TSV and TCV of (a) IDN group and (b) JPN group in pre- and post-task during cold condition. Abbreviation: TC, thermal comfort



(a) (b)

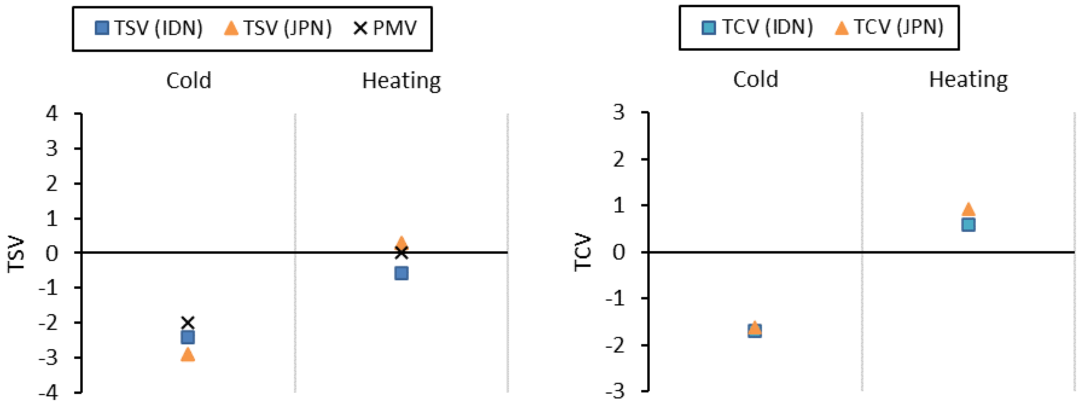
Figure 3-20. TSV and TCV of (a) IDN group and (b) JPN group in pre- and post-task during heating conditions. Abbreviation: TC, thermal comfort

PMV was calculated based on the environmental and personal data collected during the winter survey. In the summer experiment, PMV showed similar results with TSV and TCV that PMV was not significantly different between two nationalities ($p > 0.05$) and significantly different among conditions ($p < 0.05$). Moreover, in the winter experiment, PMV showed similar results with TSV and TCV that PMV was not significantly different between the two groups for each condition ($p > 0.05$). TSV, TCV, and PMV were significantly different among conditions ($p < 0.05$).



(a) (b)

Figure 3-21. The average of (a) TSV, PMV, and (b) TCV during hot and cooling condition



(a) (b)

Figure 3-22. The average of (a) TSV, PMV, and (b) TCV during cold and heating conditions

Moreover, Figure 3-23 and Figure 3-24 depict the correlation between indoor air temperature and TSV of IDN and JPN groups during summer and winter experiment. The mean of T_a (with TSV extended neutral = -1, 0, +1) of IDN group (26.9 °C) and JPN group (26.5 °C) during summer were observed. Moreover, in the winter experiment, the mean of T_a (with TSV extended neutral = -1, 0, +1) of IDN group was 23.9 °C and JPN group was 21.6 °C.

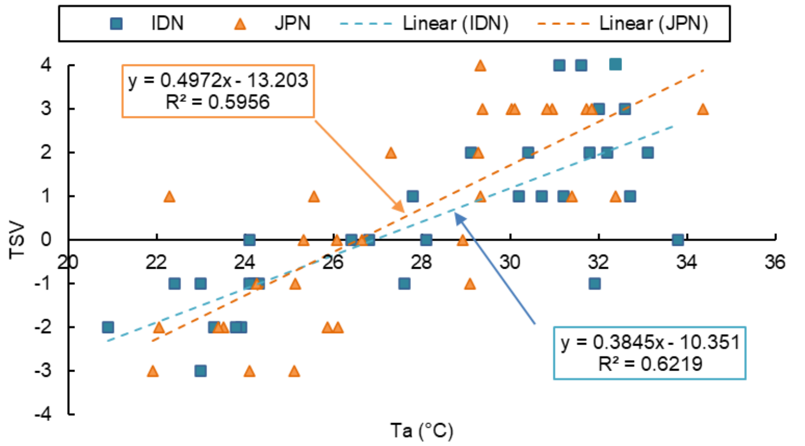


Figure 3-23. Correlation between T_a and TSV during summer experiment

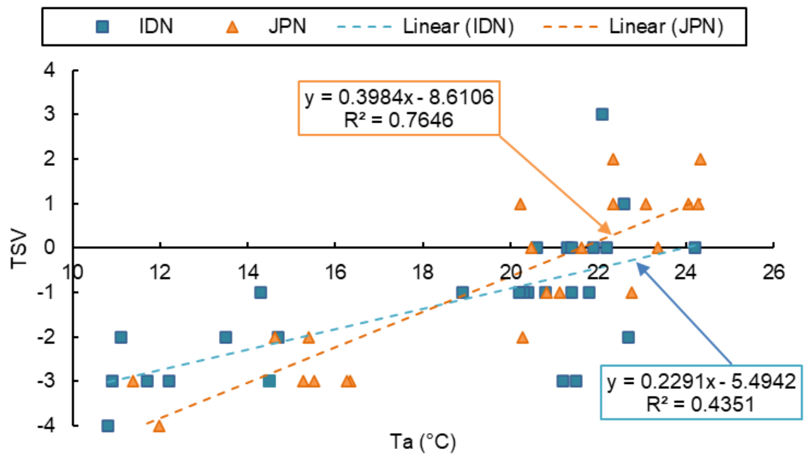


Figure 3-24. Correlation between T_a and TSV during winter experiment

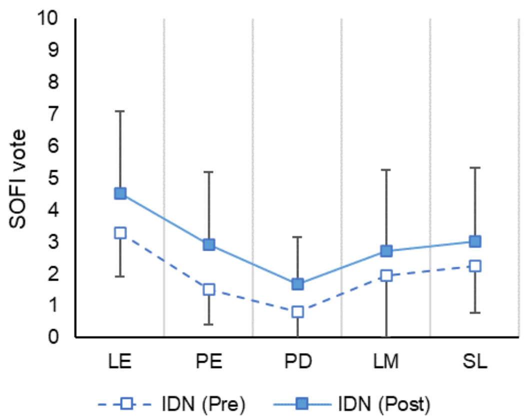
In order to predict the thermal comfort temperature for each participant based on TSV votes during summer, the Griffiths' method (Griffiths, 1988) was used. In the Table 3-9, the comfort temperature was determined by utilizing three regression coefficients for the nine-point thermal sensation (0.33, 0.44, and 0.67) (Rijal et al., 2013).

Table 3-9. Comfort temperature calculated using the Griffiths' method during summer and winter experiment

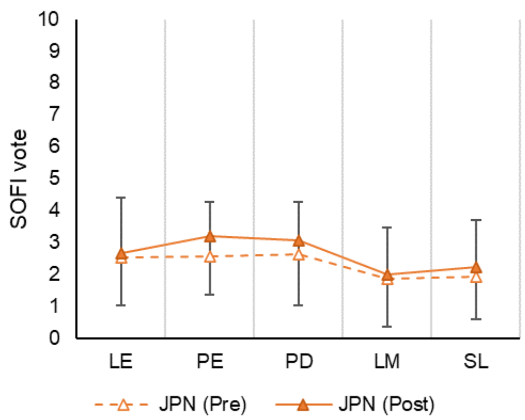
		Summer			Winter		
	α	IDN	JPN	Sig.	IDN	JPN	Sig.
TC_g (°C)	0.33	26.7 ± 3.6	26.2 ± 4.6	p = 0.96	22.3 ± 3.7	21.9 ± 2.8	p = 0.98
	0.44	27.1 ± 2.7	26.5 ± 3.2	p = 0.88	21.3 ± 3.4	21.3 ± 2.0	p = 1.00
	0.67	27.4 ± 2.4	26.8 ± 2.2	p = 0.78	20.4 ± 3.4	20.7 ± 2.0	p = 0.95
	Avg	27.1 ± 2.7	26.5 ± 3.2	p = 0.88	21.3 ± 3.4	21.3 ± 2.0	p = 1.00

3.2.4 Fatigue sensation

Figure 3-25 and Figure 3-26 depict SOFI of IDN and JPN group in pre- and post-U-K test during hot and cooling condition, respectively. SOFI represented of lack of energy (LE), physical exertion (PE), physical discomfort (PD), lack of motivation (LM), and sleepiness (SL) in pre- and post U-K test during hot and cooling condition for each group using a paired T-test. In paired T-test analysis, the statistical analysis revealed that the SL of IDN was increased after U-K test during colling condition ($p < 0.05$).

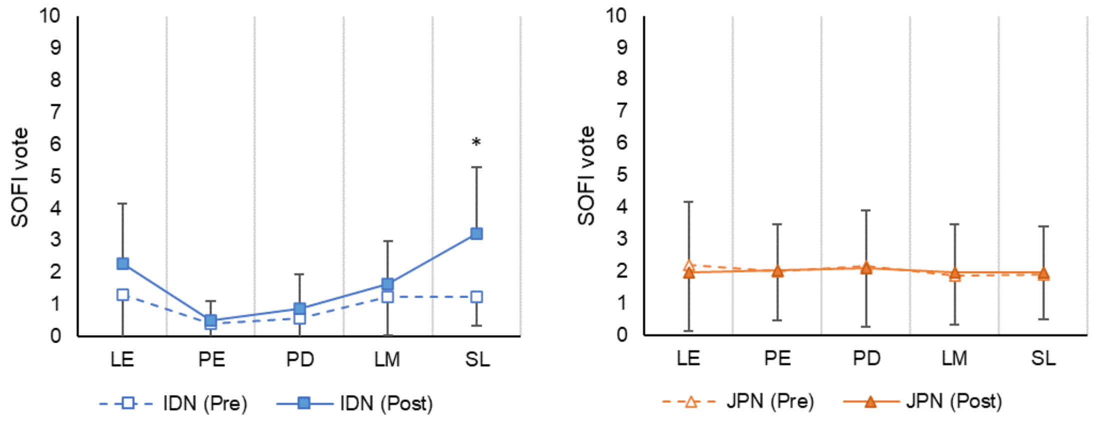


(a)



(b)

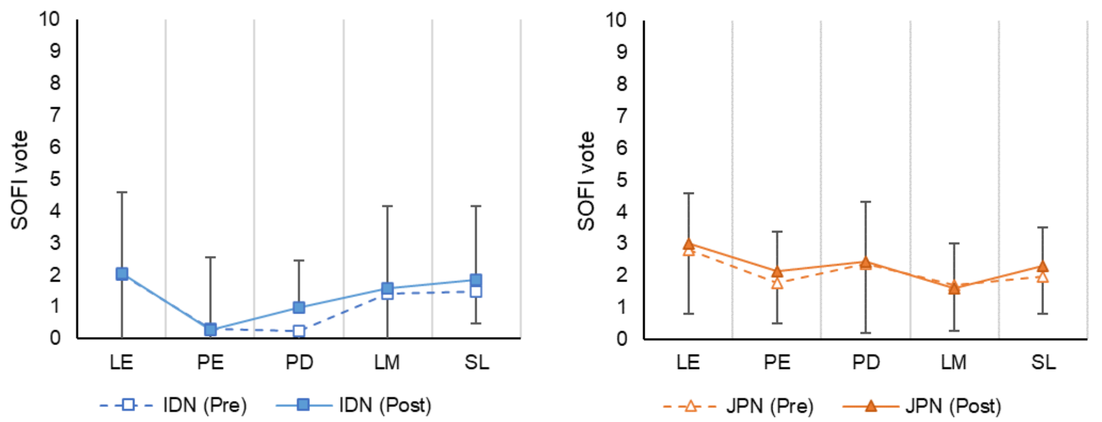
Figure 3-25. Fatigue sensation of (a) Indonesian and (b) Japanese group in pre- and post-task during hot condition. Abbreviation: SOFI, Swedish occupational fatigue inventory



(a) (b)

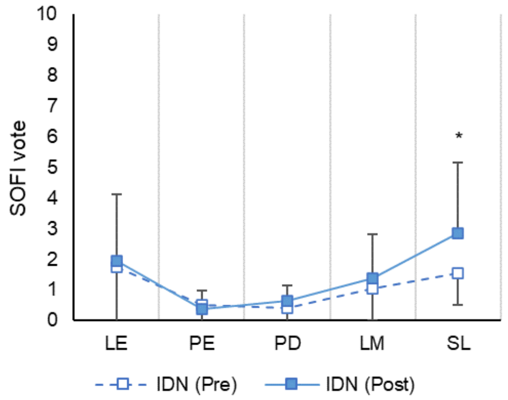
Figure 3-26. Fatigue sensation of (a) Indonesian and (b) Japanese group in pre- and post-task during cooling condition. Abbreviation: SOFI, Swedish occupational fatigue inventory

Figure 3-27 and Figure 3-28 depict SOFI of IDN and JPN group in pre- and post-U-K test during cold and heating conditions, respectively. In paired T-test analysis, the statistical analysis revealed that the SL of IDN was increased after U-K test during heating conditions ($p < 0.05$).

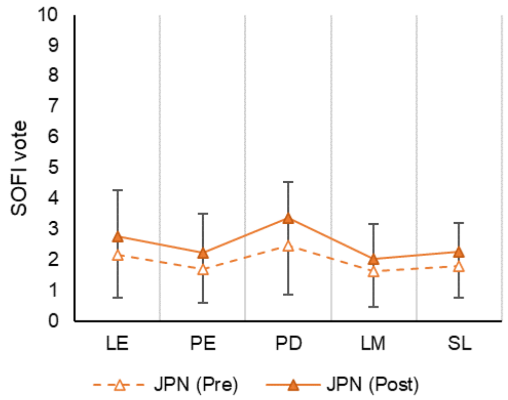


(a) (b)

Figure 3-27. Fatigue sensation of (a) Indonesian and (b) Japanese group in pre- and post-task during cold condition. Abbreviation: SOFI, Swedish occupational fatigue inventory



(a)

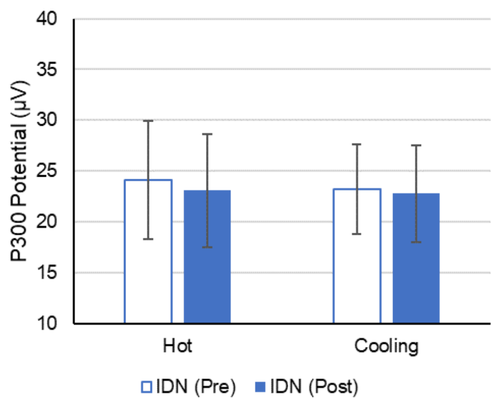


(b)

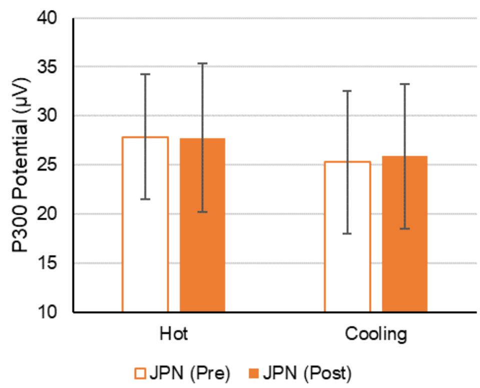
Figure 3-28. Fatigue sensation of (a) Indonesian and (b) Japanese group in pre- and post-task during heating condition. Abbreviation: SOFI, Swedish occupational fatigue inventory

3.2.5 Brain response

Figure 3-29 depicts P300 potential and latency of IDN and JPN group in pre- and post- U-K test during hot and cooling condition. P300 potential in pre- and post U-K test during hot and cooling condition for each group were analyzed using a paired T-test. In paired T-test analysis, the statistical analysis revealed that the P300 potential of IDN and JPN group did not change after U-K test during hot (all $p > 0.05$) and cooling condition (all $p > 0.05$). Moreover, in winter study, the statistical analysis also revealed the same that the P300 potential of IDN and JPN groups did not change after U-K test during cold (all $p > 0.05$) and heating conditions (all $p > 0.05$, Figure 3-30).

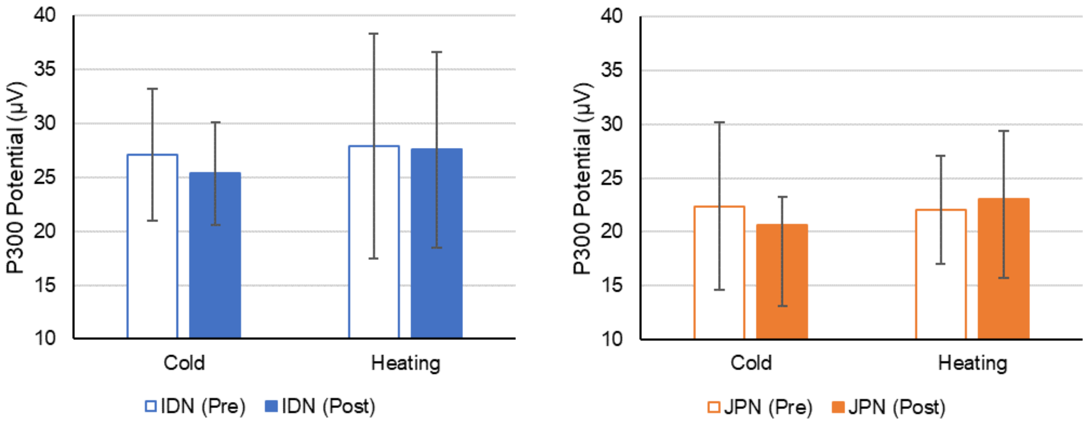


(a)



(b)

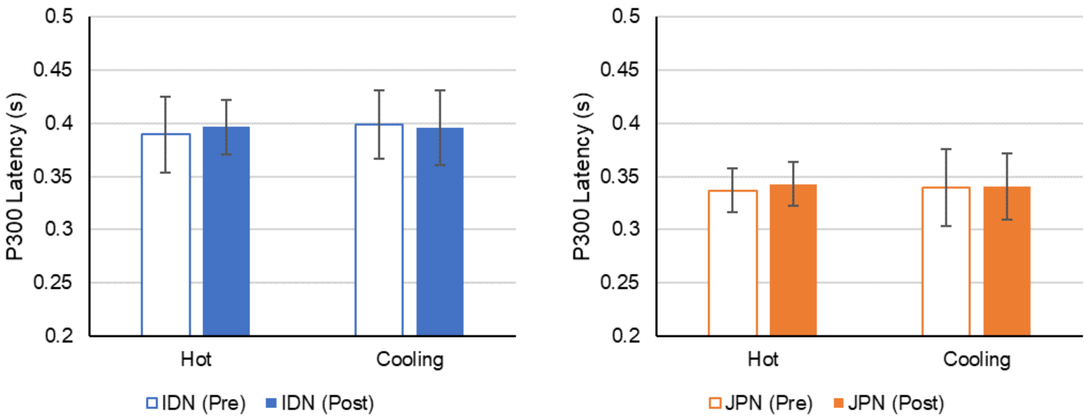
Figure 3-29. P300 potential pre- and post- U-K test of (a) IDN and (b) JPN group in hot and cooling condition



(a) (b)

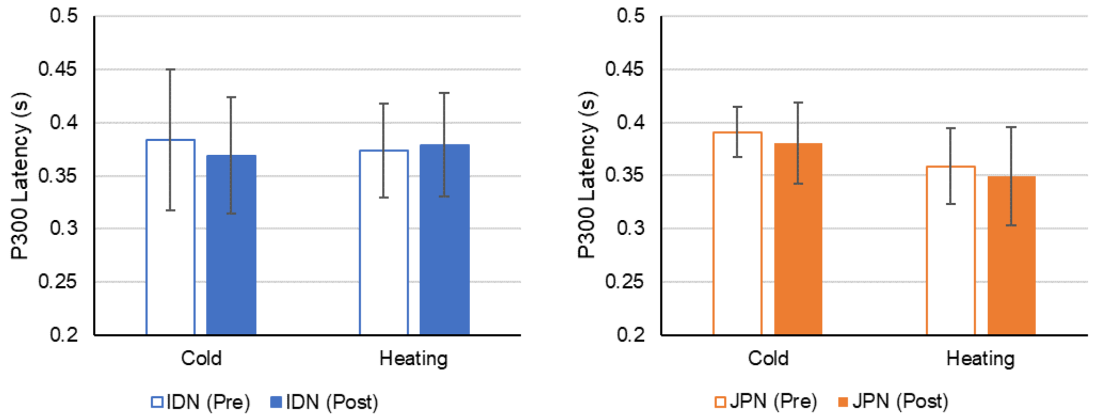
Figure 3-30. P300 potential pre- and post- U-K test of (a) IDN and (b) JPN group in cold and heating conditions

The P300 latency in pre-/ post-U-K test for each group is illustrated in Figure 3-31 (during hot and cooling condition) and Figure 3-32 (during cold and heating condition). The P300 latency of IDN and JPN group did not change after U-K test during hot (all $p > 0.05$) and cooling condition (all $p > 0.05$) in paired T-test analysis. Moreover, the P300 latency of IDN and JPN group also did not change after U-K test during cold (all $p > 0.05$) and heating conditions (all $p > 0.05$).



(a) (b)

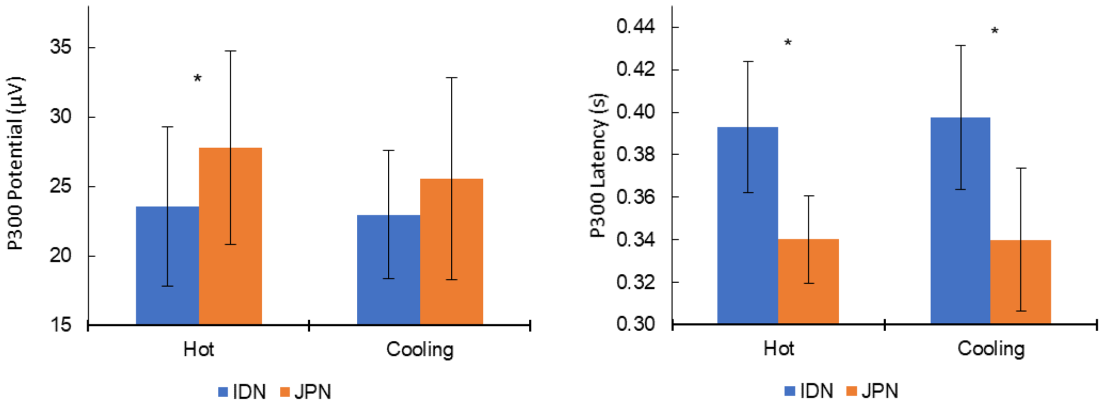
Figure 3-31. P300 latency in pre-/ post- U-K test of (a) IDN and (b) JPN group in hot and cooling condition



(a) (b)

Figure 3-32. P300 latency in pre-/ post- U-K test of (a) IDN and (b) JPN group in cold and heating conditions

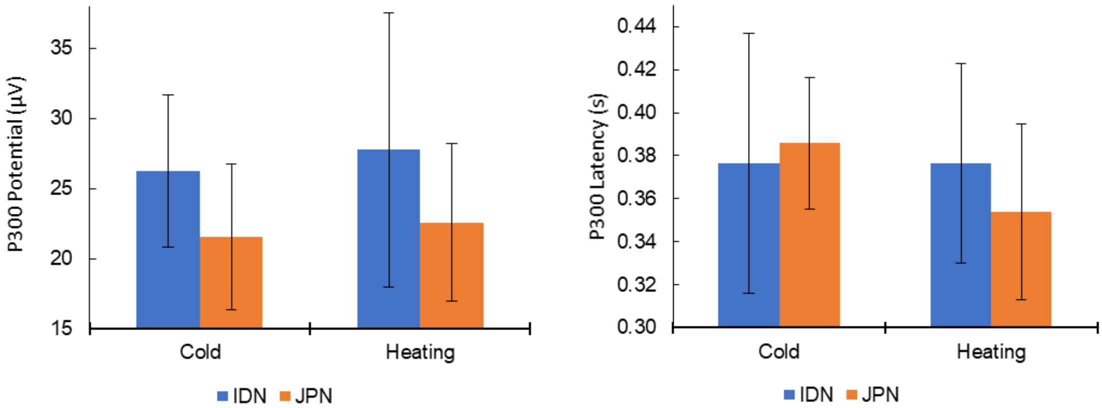
Furthermore, the average of P300 potential and latency for each condition and season were analyzed using ANOVA with the factors: groups (IDN and JPN, df = 1), condition (summer: hot and cooling, df = 1; winter: cold and heating, df = 1), and combination between group and condition (df = 1, 1). In the summer experiment, ANOVA revealed that P300 potential did not differ between two condition (p = 0.08; df = 1; F = 3.00) and interaction between group and condition (p = 0.17; df = 1, 1; F = 1.90). However, it was different between two group ($p < 0.05$; df = 1; F = 21.25). Moreover, in comparison between IDN and JPN group, P300 potential of IDN group showed lower ($p < 0.05$) than JPN group during hot condition (Figure 3-33a). P300 latency was not different between two condition (p = 0.69; df = 1; F = 0.16) and interaction between group and condition (p = 0.68; df = 1, 1; F = 0.17). However, it was different between two group ($p < 0.05$; df = 1; F = 106.03). In comparison between IDN and JPN group, P300 latency of IDN group showed longer ($p < 0.05$) than JPN group during hot and cooling condition (Figure 3-33b).



(a) (b)

Figure 3-33. The average of (a) P300 potential and (b) P300 latency in hot and cooling condition

In the winter experiment, P300 potential did not differ between two groups (p = 0.08; df = 1; F = 3.11), two condition (p = 0.15; df = 1; F = 2.06) and interaction between group and condition (p = 0.51; df = 1, 1; F = 0.44, Figure 3-34). Moreover, P300 latency also was not different between two groups (p = 0.50; df = 1; F = 0.46), two condition (p = 0.10; df = 1; F = 2.75) and interaction between group and condition (p = 0.11; df = 1, 1; F = 2.66).



(a) (b)

Figure 3-34. The average of (a) P300 potential and (b) P300 latency in cold and heating conditions

3.2.6 Reaction time of PVT

Table 3-10 summarizes the PVT performance in pre-/ post-U-K test during hot and cooling condition. The RT of IDN group was delayed and the number lapse (RT > 500 ms) were increased after U-K test during cooling condition (all $p < 0.05$). Meanwhile, the all-PVT performance of JPN group did not change after U-K test during hot and cooling (all $p > 0.05$).

Table 3-10. The average of PVT performance in pre- and post- U-K test of IDN and JPN group in hot and cooling condition

Condition	**PVT Parameter**	**Group**	**Pre**	**Post**	**Sig.**
Hot	RT (s)	IDN	0.25 ± 0.03	0.26 ± 0.04	$p = 0.06$
		JPN	0.25 ± 0.02	0.25 ± 0.04	$p = 0.84$
	RT > 500	IDN	0.94 ± 1.18	1.25 ± 1.39	$p = 0.42$
		JPN	0.81 ± 1.05	1.00 ± 1.86	$p = 0.73$
	TE	IDN	2.00 ± 2.07	1.13 ± 1.96	$p = 0.05$
		JPN	0.75 ± 0.86	1.38 ± 2.68	$p = 0.33$
	RT < 100	IDN	0.25 ± 0.58	0.00 ± 0.00	$p = 0.10$
		JPN	0.06 ± 0.25	0.06 ± 0.25	$p = 1.00$
Cooling	RT (s)	IDN*	0.24 ± 0.02	0.27 ± 0.04	$p < 0.05$
		JPN	0.25 ± 0.04	0.26 ± 0.05	$p = 0.65$
	RT > 500	IDN*	0.38 ± 0.62	1.88 ± 2.09	$p < 0.05$
		JPN	1.63 ± 2.58	1.44 ± 2.97	$p = 0.59$
	TE	IDN	1.44 ± 2.03	1.38 ± 1.41	$p = 0.87$
		JPN	1.56 ± 2.16	1.50 ± 1.79	$p = 0.87$
	RT < 100	IDN	0.06 ± 0.25	0.06 ± 0.25	$p = 1.00$
		JPN	0.19 ± 0.40	0.13 ± 0.34	$p = 0.58$

Abbreviations: RT, reaction time; RT > 500, reaction time more than 500ms; TE, total error; RT < 100, reaction time less than 100ms

The average RT of PVT for each condition was analyzed using ANOVA. In ANOVA, the RT was not different between two groups ($p = 0.89$; df = 1; F = 0.02), between hot and cooling condition ($p = 0.71$; df = 1; F = 0.14), and in interaction between group and condition ($p = 0.87$; df = 1, 1; F = 0.03). Moreover, the other parameters (number of RT > 0.5s, total error, and RT < 0.1) also shown same results (all $p > 0.05$).

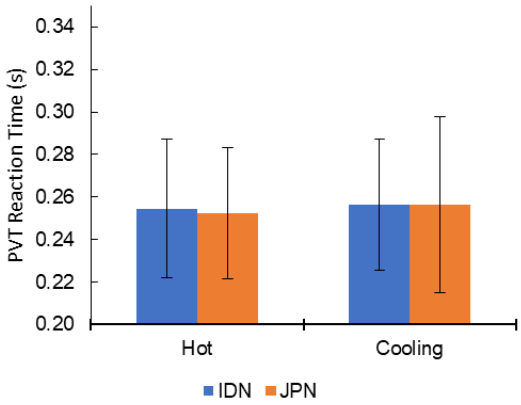


Figure 3-35. The average of RT of IDN and JPN group in hot and cooling condition

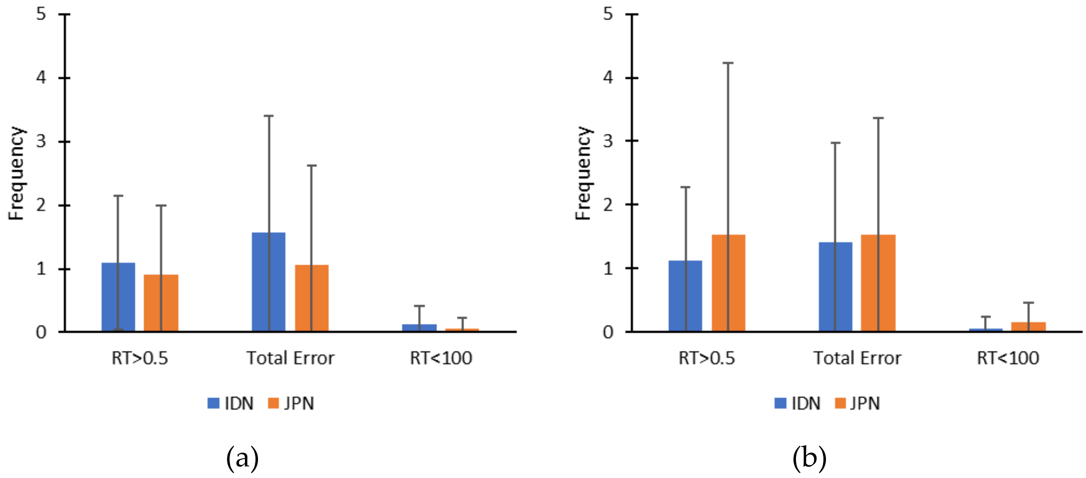


Figure 3-36. The average of number RT > 0.5, total error, and RT < 0.1 in (a) hot and (b) cooling condition

Furthermore, Table 3-11 summarizes the PVT performance in pre-/ post-U-K test during cold and heating conditions. The RT of IDN group was delayed, the number lapse (RT > 500 ms) and the number of total errors were increased after U-K test during heating conditions (all $p < 0.05$). Meanwhile, the all-PVT performance of JPN group did not change after U-K test during cold and heating conditions (all $p > 0.05$).

Table 3-11. The average of PVT performance in pre- and post- U-K test of IDN and JPN group in cold and heating condition

Condition	PVT Parameter	Group	Pre	Post	Sig.
Cold	RT (s)	IDN	0.27 ± 0.05	0.25 ± 0.03	$p = 0.21$
		JPN	0.24 ± 0.02	0.24 ± 0.03	$p = 0.77$
	RT > 500	IDN	0.90 ± 0.88	0.60 ± 0.70	$p = 0.27$
		JPN	0.50 ± 0.76	0.38 ± 0.52	$p = 0.56$
	TE	IDN	1.00 ± 0.94	0.80 ± 1.03	$p = 0.55$
		JPN	1.75 ± 3.11	0.88 ± 1.81	$p = 0.19$
	RT < 100	IDN	0.10 ± 0.32	0.10 ± 0.32	$p = 1.00$
		JPN	0.13 ± 0.35	0.00 ± 0.00	$p = 0.35$
Heating	RT (s)	IDN*	0.25 ± 0.03	0.28 ± 0.04	$p < 0.05$
		JPN	0.23 ± 0.03	0.24 ± 0.03	$p = 0.19$
	RT > 500	IDN*	0.71 ± 0.85	1.65 ± 1.97	$p < 0.05$
		JPN	0.31 ± 0.60	0.63 ± 1.03	$p = 0.29$
	TE	IDN*	1.94 ± 1.95	1.00 ± 1.17	$p < 0.05$
		JPN	1.19 ± 1.33	0.75 ± 1.13	$p = 0.23$
	RT < 100	IDN	0.12 ± 0.49	0.00 ± 0.00	$p = 0.33$
		JPN	0.06 ± 0.25	0.06 ± 0.25	$p = 1.00$

Abbreviations: RT, reaction time; RT > 500, reaction time more than 500ms; TE, total error; RT < 100, reaction time less than 100ms

The average RT of PVT for each condition was analyzed using ANOVA. In ANOVA, The RT was not different between two conditions (p = 0.71; df = 1; F = 0.14), and in interaction between group and condition (p = 0.54; df = 1, 1; F = 0.39). However, it was significant different between two groups (p < 0.05; df = 1; F = 8.89). Moreover, the other parameters (number of RT > 0.5s, total error, and RT < 0.1) also shown same results (all p > 0.05).

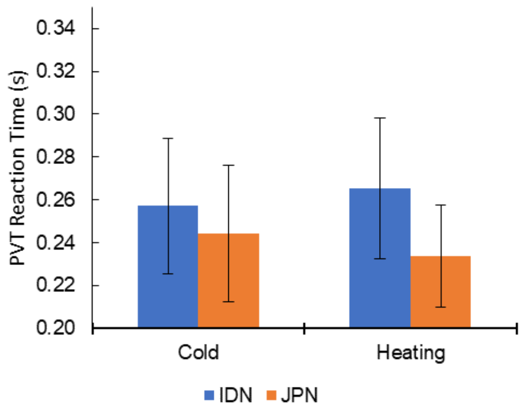
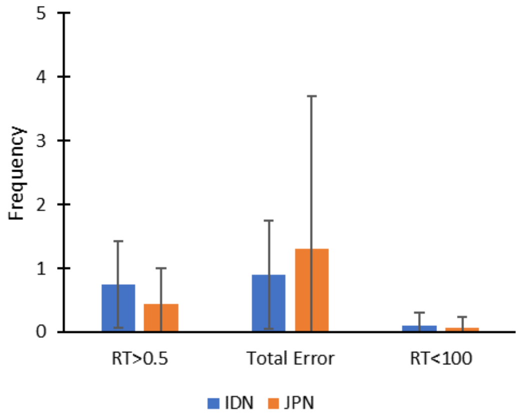
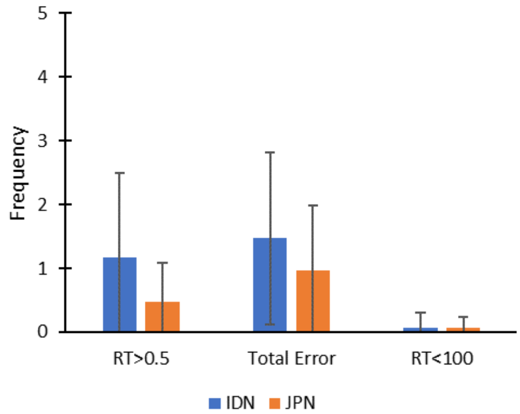


Figure 3-37. The average of RT of IDN and JPN group in cold and heating condition



(a)



(b)

Figure 3-38. The average of number RT > 0.5, total error, and RT < 0.1 in (a) cold and (b) heating condition

3.2.7 Uchida-Kraepelin test

In the U-K test, the ANOVA analysis revealed that accuracy ($p < 0.05$; df = 1; F = 25.39), speed ($p < 0.05$; df = 1; F = 16.87), and correct rate ($p < 0.05$; df = 1; F = 47.00) were different between IDN and JPN group. Further, post-hoc analysis with Tukey comparison showed that accuracy, speed, and correct rate of U-K test was different in both conditions (all $p < 0.05$). However, it was not different among conditions and in interaction between nationality and condition (all $p > 0.05$).

Table 3-12. The average of U-K test parameter of IDN and JPN group during hot and cooling condition

Condition	Kraepelin	IDN	JPN	Sig.
Hot	Consistency	0.77 ± 0.15	0.81 ± 0.14	$p = 0.90$
	Endurance	4.41 ± 8.10	4.35 ± 8.72	$p = 1.00$
	Accuracy*	1.08 ± 0.83	0.34 ± 0.26	$p < 0.05$
	Speed*	53.48 ± 18.41	75.04 ± 19.63	$p < 0.05$
	Correct Rate*	98.42 ± 0.79	99.52 ± 0.35	$p < 0.05$
Cooling	Consistency	0.81 ± 0.13	0.80 ± 0.16	$p = 0.99$
	Endurance	0.08 ± 7.71	3.17 ± 8.12	$p = 0.71$
	Accuracy*	1.22 ± 1.02	0.24 ± 0.24	$p < 0.05$
	Speed*	57.79 ± 17.32	75.95 ± 21.71	$p < 0.05$
	Correct Rate*	98.32 ± 1.03	99.61 ± 0.39	$p < 0.05$

In the U-K test, the ANOVA revealed that speed ($p < 0.05$; df = 1; F = 17.64), and correct rate ($p < 0.05$; df = 1; F = 3.58) were different between IDN and JPN group. Further, as seen in Table 3-13, post-hoc analysis with Tukey comparison showed that speed and correct rate of U-K test were different only in heating condition (all $p < 0.05$).

Table 3-13. The average of U-K test parameter of IDN and JPN group during cold and heating condition

Condition	Kraepelin	IDN	JPN	Sig.
Cold	Consistency	0.84 ± 0.12	0.81 ± 0.10	$p = 0.86$
	Endurance	3.82 ± 3.95	7.34 ± 7.11	$p = 0.58$
	Accuracy	0.65 ± 0.70	0.31 ± 0.33	$p = 0.99$
	Speed	49.08 ± 13.97	64.14 ± 15.31	$p = 0.13$
	Correct Rate	98.73 ± 1.32	99.50 ± 0.55	$p = 0.97$
Heating	Consistency	0.85 ± 0.07	0.84 ± 0.09	$p = 0.97$
	Endurance	1.95 ± 5.69	6.52 ± 6.14	$p = 0.12$
	Accuracy	2.31 ± 4.34	0.26 ± 0.38	$p = 0.11$
	Speed*	53.40 ± 11.03	73.91 ± 17.1	$p < 0.05$
	Correct Rate*	96.29 ± 6.28	99.66 ± 0.47	$p < 0.05$

3.3 Summary

3.3.1 Thermal comfort and sleep quality

The purpose of thermal comfort survey and sleep quality measurement were to compare the thermal environment created by occupants for sleeping during summer and winter between Indonesian group living in Japan and Japanese group. Additionally, sleep quality was compared for Indonesian and Japanese students using objective measurements and subjective sensations. This is the first study to compare the thermal environment and sleep parameters of foreign students from a different climate zone to those of local students. Because Indonesia is located on the equator, the length of the day and the outdoor air temperature are nearly identical throughout the year. However, in Japanese summer, residents of Japan are forced to endure longer daytime hours. This research also had concerns about the Indonesian group's ability to control their bedroom's ambient thermal environment and maintain a healthy sleep environment during the Japanese winter season because the Indonesian group had never encountered a cold climate prior to their arrival in Japan. This seasonal variability may influence sleep quality and performance during the day.

Bedroom environment

In the bedroom environment, the average bedroom temperature and relative humidity of Indonesian and Japanese groups were comparable during the summer. In the winter, the average bedroom temperature of Indonesian group was significantly higher than that of Japanese group in this investigation. Indonesian group used AC with the heating mode or heater during the night-time sleeping period, whereas Japan's ministry of energy, trade, and industry recommends maintaining an indoor temperature of 20°C during the winter (Ministry of Economy, 2017). However, the Japanese group used the air conditioner only briefly before and after sleeping and did not leave it on during the sleeping period. Moreover, in the sleep investigation, during the winter season, Japanese group slept on thick feather bedding and long-sleeved pajama with a long undershirt and long pants. On the other hand, Indonesian group continued to use the heater or air conditioner during the sleeping period. This Japanese habit was discovered in previous studies of Japanese children and adults.

The comfort temperature and preferred temperature values were computed using the Griffiths' method based on the votes of thermal sensation and thermal preference, as well as the related values of the observed bedroom temperature. The average of comfort temperature calculated using the Griffiths' method for Japanese group was similar to that found in previous studies in Fukuoka (26.1 °C for males, 26.8 °C for females) (Mustapa et al., 2016), Tokyo (26.1 °C) (Rijal et al., 2013), Osaka (27.6 °C) (Nakaya et al., 2008), and Kanto (27.1 ° (Rijal et al., 2015). The current study found that Indonesian group had a higher comfort temperature than Japanese group and previous studies conducted in Japan. However, a previous study determined that a thermal environment of less than 28.4 °C was acceptable (Nakaya et al., 2008). Meanwhile, the Indonesian' comfort temperature was similar to that of previous studies (24-29 °C) conducted in Jakarta (Alfata et al., 2012; Karyono, 2000; Karyono et al., 2015), Bandung (Karyono, 2007), Medan, Surabaya, and Makassar (Alfata et al., 2012), and Jogja (Alfata et al., 2012). Moreover, In the winter, according to Tsuzuki et al. (2010), a study conducted on Japanese young people in Tsukuba, Japan for six months in a year (2-month intervals: February, April, June, August, October, and December) found that the ambient temperature before sleeping in December (winter) was 14.5 °C and the average bedroom temperature was ten °C for elderly people in winter (Tsuzuki, Mori, et al., 2015). Indonesians' preference for high room temperatures in the winter may result in increased energy consumption. Additionally, previous research indicated that residents of developing countries consumed more energy than residents of developed countries (Kwong et al., 2014). According to Karyono (2000), air conditioning consumes twelve times as much energy as natural ventilation in Indonesia.

Thermal sensation and thermal comfort

In adaptive action during Japanese season and according to the current study's findings, Indonesian students may accept the Japanese summer. The current findings are the result of Indonesia's climate being predominantly classified as Af: tropical rainforest, Am: tropical monsoon, and Aw: tropical savanna with dry winter characteristics. It is generally warm (in 2020, the average air temperature was 27.3°C). According to this condition, Indonesian group were accustomed to warm temperatures. Due to their previous residence in a tropical country, Indonesian group may have developed a long-term tolerance for heat (more than 20 years), which is similar to the case with Japanese

Brazilians (Katsuura et al., 1992). Additionally, two groups demonstrated distinct thermal adaptive responses in summer. In the summer, the two nationalities adopted nearly identical clothing choices: short sleeves and shorts (sub chapter 3.1.2, page 35). However, when it came to choosing a blanket, the average Indonesian student chose a thick one, while the average Japanese student chose a thin one. However, in the winter, once established in a temperate zone (34°46'9" N Toyohashi, Japan), Indonesian group will almost certainly require additional effort to adapt to their new environment. Not only is there a temperature difference, but also the time between sunset and sunrise varies by a maximum of 41 minutes (Japan Meteorology Agency, 2020). This seasonal variability may influence sleep quality and performance during the day.

Moreover, in the winter, two groups demonstrated distinct thermal adaptive responses. Some Indonesian students wore short sleeves and shorts during the winter. Because there was almost certainly a reaction to using an air conditioner with heating mode and electrical heaters while sleeping. Meanwhile, the majority of Japanese students wore long sleeved shirts, long sweatpants, and extremely thick bed sheets: mattress, warmer mattress cover, winter blanket, and winter blanket. Because Japanese students used an air conditioner with heating mode or an electric heater for a brief period prior to sleeping. They switched off the air conditioning or electric heater before going to bed. Tsuzuki et al. (2010) reported that Japanese adolescents wore clothing with a 1 clothing insulation index for 16.2 °C prior to going to sleep and that this number will be higher at lower ambient temperatures. Although the study's sample size was small, the Japanese students slept in high-quality bedding insulation. These habits regarding clothing selection and air conditioning use may influence the indoor temperature, thermal sensation, and sleep quality of Japanese and Indonesian students.

Table 3-14. Comparison of comfort temperature with existing research

Authors	N	Area	Season	Variable	Mode				
					FR	CL	HT	NS	MM
(Goto et al., 2007)	123	Tohoku and Kanto, Japan	Four seasons	SET*				26 (JPN)	
(Indraganti et al., 2013)	435	Kanto, Japan	Summer	T_a		27.2 (JPN)			
(Rijal et al., 2013)	78	Gifu, Japan	Four seasons	T_a	22.7 (JPN)	27.1 (JPN)	18.9 (JPN)		
(Rijal et al., 2014)	243	Kanto, Japan	Four seasons	T_a	24.1 (JPN)	27.0 (JPN)	20.2 (JPN)		
(Rijal et al., 2015)	239	Kanto, Japan	Summer	T_a	27.0 (JPN)	27.1 (JPN)			
(Imagawa & Rijal, 2015)	31	Kanto, Japan	Summer, autumn	T_a	26.9 (JPN)	26.7 (JPN)			
(Katsuno et al., 2015)	109	Kanto, Japan	Summer	T_a	27.5 (JPN)	27.5 (JPN)			
(Imagawa et al., 2016)	25	Kanto, Japan	Four seasons	T_a	21.9 (JPN)	26.8 (JPN)	16.5 (JPN)		
(Damiati et al., 2016)	325	Malaysia, Indonesia, Singapore, Japan	One year	T_{op}, T_a, T_g	25.7 (TC)	24.9 (TC) 25.8 (JPN)			27.5 (TC) 25.8 (JPN)
(Mustapa et al., 2016)	28	Kyushu, Japan	Summer	T_g	26.7 (JPN)	26.6 (JPN)			
(Rijal et al., 2017)	1350	Kanto, Japan	Four seasons	T_g	25.0 ± 1.7 (JPN)	25.4 ± 1.5 (JPN)	24.3 (JPN)		
(Rijal et al., 2018)	243	Kanto, Japan	Four seasons	T_a	14.3-27.3 (JPN)				
(Draganova et al., 2019)	19	Tokai, Japan	Winter	T_a				20 (JPN) 22 (INT)	

Table 3-14. Comparison of comfort temperature with existing research (continued)

Authors	N	Area	Season	Variable	Mode				
					FR	CL	HT	NS	MM
(Rijal et al., 2019)	244	Kanto, Japan	Summer, winter	T_a	27.0 (JPN) 17.6 (JPN)				
(Draganova et al., 2021)	18	Tokai, Japan	Summer	T_a				25.8 (JPN) 25.3 (INT)	
This study	34	Tokai, Japan	Summer	T_a				26.1 (JPN) 28.1 (IDN)	
		Tokai, Japan	Winter	T_a				16.0 (JPN) 23.5 (IDN)	

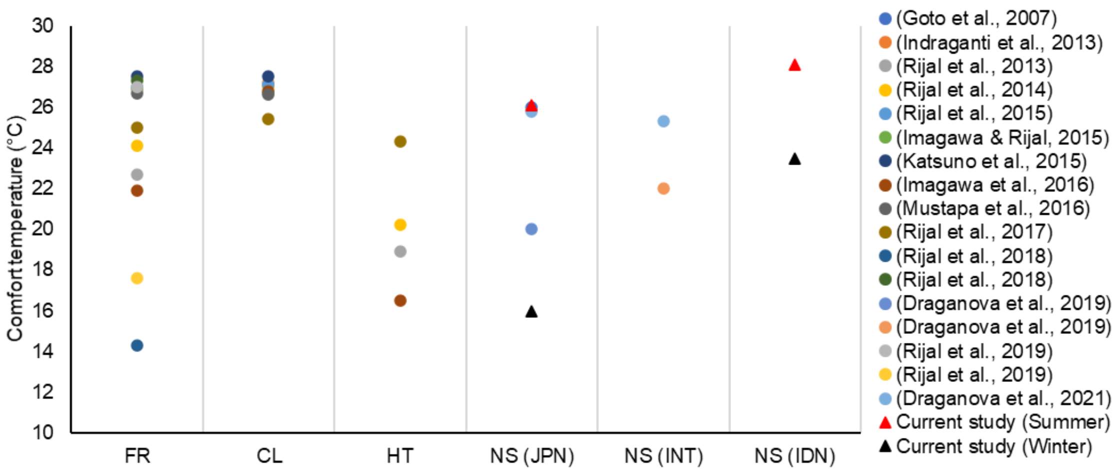


Figure 3-39. Comparison of comfort temperature with existing research

Sleep quality and sleep sensation

In addition to thermal comfort aspect, there was a significant difference in the wake-up time of Japanese students. 17 of the 18 Indonesian participants were Muslims who worshiped in the morning before sunrise. This research discovered that there was no difference between the times of waking up and sunrise. Actigraphy measurements indicated that the Indonesian participants' waking time coincided with sunrise. Japanese participants, on the other hand, awoke later than Indonesian students. In sleep subjective sensation, all parameters (sleep depth, wellness, clear-headed in the morning) of Indonesian students showed better than Japanese students during summer.

In the winter, there was a significant difference in the wake-up time between Indonesian and Japanese groups similar to the summer study. All participants' average duration of sleep was 342 minutes (84 minutes) in the summer and 358 minutes (97 minutes) in the winter. This finding corroborated a previous study that winter sleep duration was greater than summer sleep duration (Okawa et al., 1996; S. Pallesen et al., 2001; Suzuki et al., 2019; Volkov et al., 2007). The current study's average difference (16 minutes) was comparable to Suzuki et al. (2019): 11.4 minutes. Additionally, Suzuki et al. (2019) explained that this difference is due to various factors, including the sampling process, climate, ethnicity or race, and culture or behavior (Suzuki et al., 2019). Seasonal differences in day length between winter and summer may be a significant factor in seasonal sleep duration. Moreover, there was no difference in the times of waking up and sunrise. Actigraphy measurements indicated that the Indonesian participants' waking time coincided with sunrise. Japanese participants, on the other hand, awoke later than Indonesian participants.

3.3.2 Next-day brain response experiment during summer

Thermal sensation and thermal comfort

The current study investigated the effect of natural (hot during summer and cold during winter) and comfort condition (cooling during summer and heating during winter) on the brain response (P300 potential and latency) and reaction time. As a result of thermal sensation and comfort performed in two conditions in the summer experiment, the responses did not differ between Indonesian and Japanese group in all conditions. Moreover, previous studies in Japan have shown that lowering the indoor temperature setting by 1 °C for heating can result in a 10% reduction in energy consumption (Ministry of The Environment of Japan, 2019; Rijal et al., 2021). According to Nakano et al. (Nakano et al., 2002), three factors are contributed as the cause of differences in the neutral temperature: clothing insulation, activity, and expectation. Therefore, it is unsurprising that there were no differences in neutral temperature during summer, as participants wore identical clothing insulation, engaged in similar activities, and were experienced in the warm environment. Moreover, in the winter experiment, the thermal sensation and comfort evaluation responses performed in cold and heating conditions did not differ between Indonesian and Japanese groups in any conditions. Moreover, in a neutral temperature analysis, the current study observed that the neutral temperature of the Indonesian group was higher than that of the Japanese group. This was similar to recent studies revealing differences between Japanese and non-Japanese individuals (Budiawan & Tsuzuki, 2021; Draganova et al., 2019; Nakano et al., 2002). According to Nakano et al. (2002), three factors cause differences in neutral temperature: clothing insulation, activity, and expectation.

Brain response

P300 is defined as a measure of the brain's active potential (potential) and the time required to evaluate a stimulus (latency) (Kutas et al., 1977; Shibasaki et al., 2016). In the summer experiment, there were no differences in P300 potential and latency of participants (Indonesian and Japanese group) between cooling and hot conditions. To account for the indifferences, aspects of the indoor environment and aspects of task simulation were investigated. In the indoor environment aspects, previous study reported significant change in the P300 potential, latency, and reaction time between pre-heat (T_{sk} = 33.6 °C) and heat stress conditions (T_{sk} = 39.4 °C) (Shibasaki et al., 2016). In general, the higher of ambient temperature made the task more difficult (P. A. Bell et al., 1982; Paul A. Bell, 1978; Kosmidis et al., 1998; Picton, 1992). Under specific conditions, heat stress condition (T_a = 24 to 32 °C) has harmful effects on cognitive function in older adults (Trezza et al., 2015). Moreover, previous studies have reported that increased P300 latencies and decreased potentials were due to "equivocation" or information loss (Kim et al., 2008) and difficulty in maintaining sustained attention (Choi et al., 2010). This research considers that the Indonesian group in our study adapted to a hot environment (resided more than 20 years). As a tropical native, Indonesian participants might have been accustomed to performing tasks requiring cognitive effort in a hot environment. Therefore, it is also unsurprising that there were no differences in the P300 potential, latency, and reaction time of participants between hot and colling conditions.

In the winter experiment, there were also no differences in P300 potential and latency of participants (Indonesian and Japanese group) between heating and cold conditions. Previous study reported significant changes in the P300 latency between pre (T_{sk} = 35.0 °C) and cold stress conditions (T_{sk} = 30.4 °C) (Nakata et al., 2019). These differences might indicate that the hot–cooling in the summer experiment (T_{sk} = 34.3–32.9 °C) and cold–heating (T_{sk} = 29.5–32.2 °C) conditions in the winter experiment were not as severe as in previous research (hot condition: T_{sk} = 33.6–39.4 °C; cold condition: T_{sk} = 35.0–30. 4°C; Figure 3-40).

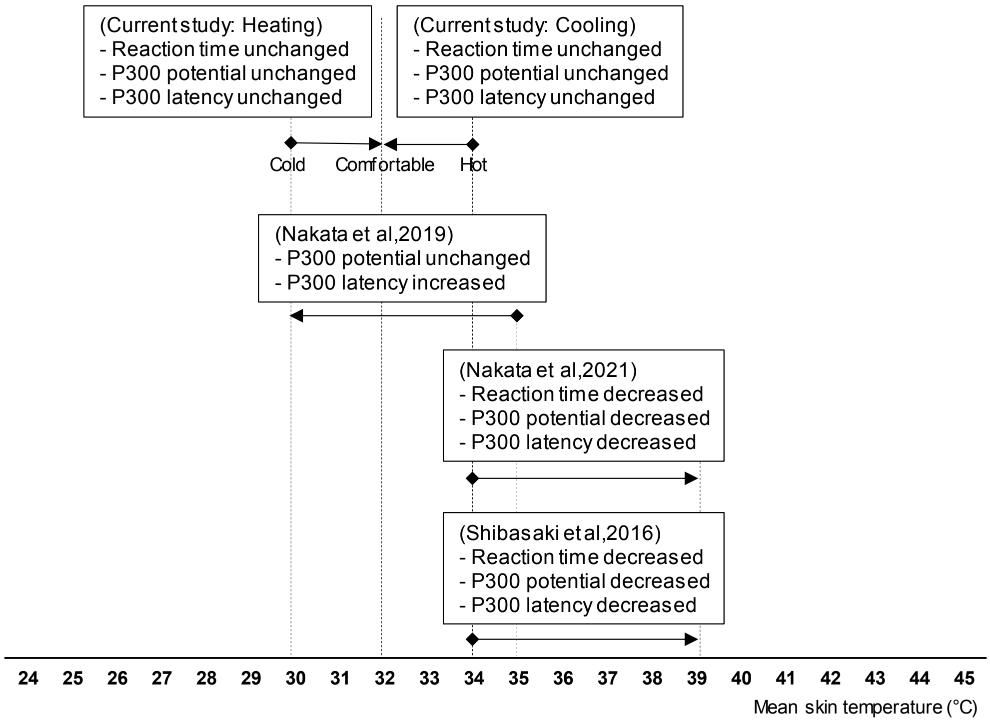


Figure 3-40. Comparison the mean skin temperature response to controlled condition

In the task simulation aspect, attention is influenced by the difficulty level of the task. For a task that requires greater attention, the P300 potential is smaller and the latency is longer as more processing resources are used for task performance (Kok, 2001; Polich, 1987). In this study, performing U-K test with 30 rows (one minute break after 15 rows) did not decrease P300 performance in all conditions. Furthermore, in mental stress measurement, the previous study reported that no significant change in any mental stress parameter during or after U-K test (Sugimoto et al., 2009). It might indicate that performing U-K test with 30 rows did not require greater attention (monotonous simple task).

In comparison between Indonesian and Japanese groups, P300 potential of Indonesian was lower in hot condition during summer, and P300 latency of Indonesian was longer in hot and cooling condition during summer compared with Japanese group. In the context of thermal experience, the Indonesian group were familiar with warm temperatures and inexperienced with Japan's winter conditions (mild). As tropical natives, participants are considered to be adapted to a new climate in the long term (i.e., more than 20 years) (Katsuura et al., 1992). In our study, participants were staying in Japan for about 6 months. In correlation between sleep quality and P300, studies have reported that the P300 potential was significantly smaller and P300 latency was significantly longer after sleep deprivation or a bad night's sleep (Aseem & Hussain, 2019; Devoto et al., 2005; Takeshi et al., 1999). Differences of duration sleep of Indonesian group in the summer (361.9 ± 62.1 min) and winter (406.1 ± 89.7 min) might account for these findings. Regarding the effect of sleep on the next day's performance, studies on the impact of sleep on athletes' sports performance and student performance are being conducted. Insufficient sleep time, sleep disturbances due to external factors, and sleep deprivation has reduced performance (Charest & Grandner, 2020; Cusick et al., 2018; Okamoto-Mizuno & Tsuzuki, 2010; Tsuzuki, Mori, et al., 2015), depressed mood and poor memory or concentration (Dinges et al., 2005).

After performing U-K test during comfort condition (cooling during summer), the RT and number of lapse (RT > 500ms) of Indonesian group showed delayed and increased significantly, respectively. Reaction time is correlated with daytime sleepiness level during subjective measurement (Y. Li et al., 2017) and the time interval between the onset of the stimulus and the measurement of the response (Shibasaki et al., 2016). However, in this study, the contrasting physical environment conditions did not show any difference in each group. A significant difference between pre- and post-U-K test were observed. In the Indonesian group, reaction time was significantly delayed in the cooling condition. As a result, the Indonesian group began to relax in the cooling environment, resulting in a delayed reaction time and increased number of lapse (RT > 500ms). In the previous study, Teichner & Kobrick (1955) found a reduced final limit for visuomotor performance after prolonged exposure to cold. Hancock (Hancock, 1986) claims that vigilance performance is impaired only when the deep body temperature deviates from a normal steady state. However, when participants returned to warm conditions, they demonstrated a rapid return to their expected performance (Enander & Hygge, 2016; Teichner & Kobrick, 1955). Moreover, according to Romeijn et al. (Romeijn et al., 2012) and Kulve et al. (Kulve et al., 2017), the level of alertness and sleepiness is related to skin temperature in response to ambient temperature. Romeijn et al. (2012) predicted that the sleep-promoting maximum temperature capacity peaks at approximately T_{sk} = 34°C and the vigilance-promoting capacity is greatest at approximately T_{sk} = 30°C.

In the winter experiment, the contrasting physical environment conditions did not lead to any differences of RT in each group. However, a significant difference between the pre- and post-U–K test was observed. In the Indonesian group, RT was significantly delayed in the comfort condition (heating). The average outdoor air temperature in the current research was 7.7 ± 3.0 °C (Japan Meteorology Agency, 2020), which means that participants, particularly those from Indonesian, may feel more discomfort due to the cold air. As a result, the Indonesian group began to relax in the heated environment, resulting in a delayed RT. Teichner & Kobrick (1955) found a reduced final limit for visuomotor performance after prolonged exposure to cold. Hancock (1986) claimed that vigilance performance is impaired only when the deep body temperature deviates from a normal steady state. However, when participants returned to warm conditions, they demonstrated a rapid return to their expected performance (Enander & Hygge, 2016; Teichner & Kobrick, 1955). Moreover, according to Romeijn et al. (Romeijn et al., 2012) and Kulve et al. (Kulve et al., 2017), the level of alertness and sleepiness is related to the skin temperature in response to ambient temperature. Romeijn et al. (2012) predicted that the sleep-promoting maximum temperature capacity peaks at approximately T_{sk} = 34 °C and that the vigilance-promoting capacity is greatest at approximately T_{sk} = 30 °C.

Chapter 4
Effect of thermal comfort on sleep quality and brain response

Results and discussion of thermal comfort effect on sleep quality and brain response

The chapter 4 observed the correlation of thermal comfort on sleep quality and brain response. It was motivated by the results from the summer and winter study (Chapter 3, page 31). The current chapter administrated principal component analysis (PCA) to simplify the sensation survey (bedroom thermal sensation, sleep sensation, and experimental room thermal sensation), and to explore the most important variable among the sensation survey. Agglomerative hierarchical clustering (AHC) was grouped the participants into classes in the AHC.

4.1 Effect of thermal comfort on sleep quality

4.1.1 Data preparation

The current section aimed to investigate the effect of thermal comfort on sleep quality. Objective and subjective method were administrated across two studies (summer study and winter study, sub chapter 3.1.2 page 35). In the first step, the data set was prepared (Figure 4-1). The data set is combined by variables in the current measurement, i.e., thermal environment (sub chapter 3.1.1, page 31), thermal sensation (sub chapter 3.1.2, page 35), and sleep quality and sensation (sub chapter 3.1.3, page 39).

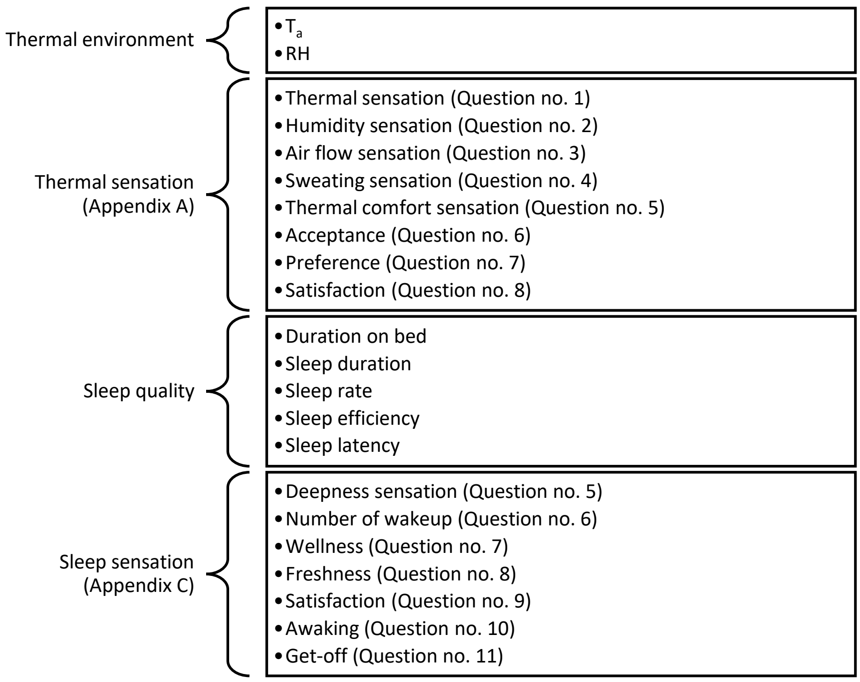


Figure 4-1. Data set list and reference of question number in the sleep survey

4.1.2 Principal component analysis

a. Thermal sensation

The PCA analyzed the correlation between variables and found the important variables for each questionnaire. PCA started with calculated correlation each variable. To calculate the correlation each variable, the correlation matrix was applied (Table 4-1).

Table 4-1. Matrix Correlation of thermal sensation variables in the sleep survey

Variables	TS	HS	AS	SS	TC	AT	PF	ST
TS	**1**	**-0.293**	-0.027	0.117	**0.195**	**0.407**	**-0.391**	**0.294**
HS	**-0.293**	**1**	-0.167	**-0.191**	-0.049	**-0.186**	**0.399**	-0.067
AS	-0.027	-0.167	**1**	**0.466**	**-0.218**	-0.139	-0.099	**-0.240**
SS	0.117	**-0.191**	**0.466**	**1**	**-0.258**	-0.107	**-0.384**	**-0.228**
TC	**0.195**	-0.049	**-0.218**	**-0.258**	**1**	**0.525**	**-0.208**	**0.682**
AT	**0.407**	**-0.186**	-0.139	-0.107	**0.525**	**1**	**-0.428**	**0.482**
PF	**-0.391**	**0.399**	-0.099	**-0.384**	**-0.208**	**-0.428**	**1**	**-0.234**
ST	**0.294**	-0.067	**-0.240**	**-0.228**	**0.682**	**0.482**	**-0.234**	**1**

Note: Values in bold are different from 0 with a significance level alpha = 0.05; Abbreviation: TS, thermal sensation; HS, humidity sensation; AS, air flow sensation; SS, sweating sensation; TC, thermal comfort; AT, acceptance; PF, preference; ST, satisfaction.

Moreover, Table 4-2 and Figure 4-2 discuss eigenvalues, which indicate the quality of a projection from N-dimensional starting table (N=8 in this case) to a smaller number of dimensions. As shown in this analysis, the first eigenvalue is 2.706 and accounts for 34% of the overall variability. This indicates that if the data plot on a single axis, it will show just 34% (round up of 33.825 %) of the total variability. Each eigenvalue is associated with a factor, and each factor is associated with a single dimension. A factor is a linear combination of the starting variables, and all factors are uncorrelated with one another (r = 0). The eigenvalues and related factors are ranked in decreasing order of their contribution to the initial variability (converted to %). In the current investigation, the cumulative variability of two components (with eigenvalues greater than 1) accounts for 59% of overall variability.

Table 4-2. Eigenvalues of thermal sensation variables in the sleep survey

	F1	F2	F3	F4	F5	F6	F7	F8
Eigenvalue	**2.706**	**2.010**	0.827	0.710	0.614	0.508	0.331	0.294
Variability (%)	33.825	25.128	10.342	8.872	7.681	6.347	4.135	3.670
Cumulative %	33.825	58.953	69.295	78.166	85.848	92.195	96.330	100.000

Note: Values in bold are eigenvalues higher than 1. Abbreviation: F1-8, factor 1-8.

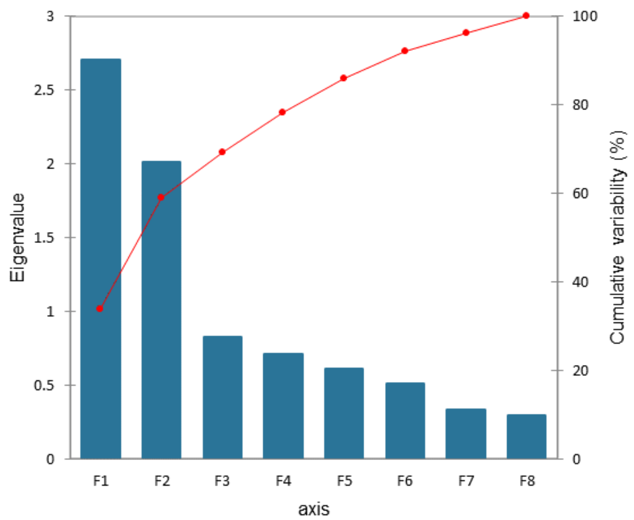


Figure 4-2. Eigenvalue scree plot of thermal sensation variables in the sleep survey

Correlation circle maps (Figure 4-3), which depict the first two components (F1 and F2), are a high-quality projection of the original multi-dimensional table. The first two components account for 58.95 % (cumulative of F1 and F2) of the data's initial variability in this investigation. Although thermal sensation started with eight variables, the number of components has been reduced to five. This is because of the three variables, one of which is adversely connected with other variables (humidity sensation), and two of which are strongly correlated with other variables (air flow sensation and satisfaction).

The correlation circle is useful in interpreting the meaning of the axes. In this analysis, the horizontal axis is linked with thermal sensation, comfort, acceptance and satisfaction, and the vertical axis with airflow, sweating sensation, and preference. These trends will help to interpret the important variables in the thermal sensation questionnaire. The current sub chapter also implemented the PCA biplot to represent the thermal sensation survey and parameters into new space (two factorial axes F1 and F2) for all group (Figure 4-4) and for each group (Appendix K).

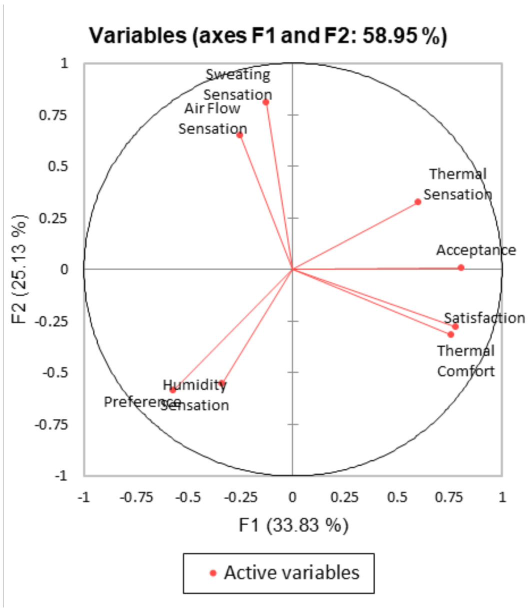


Figure 4-3. Correlation circle (on axes F1 and F2) of thermal sensation variables in the sleep survey. Abbreviation: F1-2, selected factor with the eigenvalue higher than 1

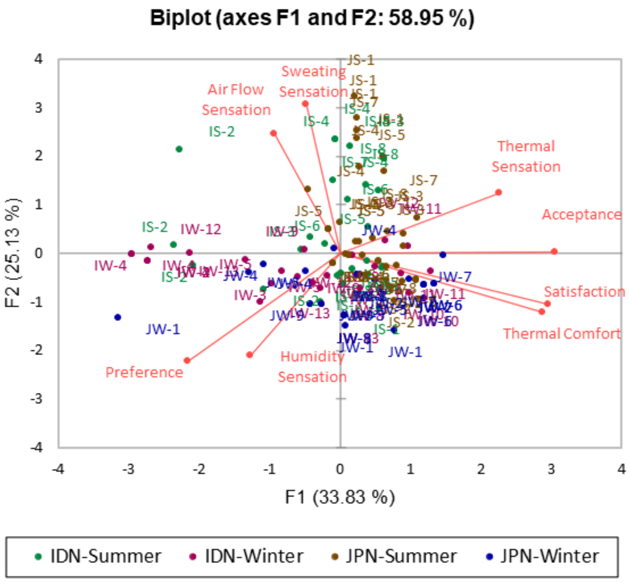


Figure 4-4. Bedroom thermal sensation biplot of participants in the correlation circle

Moreover, to confirm that a variable is well linked with an axis, the variables were summarized into a squared cosines table: the greater the squared cosine, the greater the link with the corresponding axis. The variables were found in the horizontal axis (F1), i.e., thermal sensation, thermal comfort, acceptance, and satisfaction. Other three variables were revealed in the vertical axis (F2) viz., air flow sensation, sweating sensation, and preference. According to squared cosines of thermal sensation variables (Table 4-3), four variables in the F1 (horizontal axis) represented the new thermal sensation variable TS1, and two variables in the F2 (vertical axis) represented the TS2, and one variable in the F4 represented the TS3.

Table 4-3. Squared cosines of thermal sensation variables in the sleep survey

	F1	F2	F3	F4	F5	F6	F7	F8
Thermal Sensation	**0.357**	0.106	0.132	0.127	0.253	0.015	0.000	0.010
Humidity Sensation	0.114	0.307	0.173	**0.386**	0.002	0.005	0.012	0.001
Air Flow Sensation	0.062	**0.419**	0.255	0.058	0.154	0.026	0.025	0.000
Sweating Sensation	0.017	**0.652**	0.068	0.072	0.029	0.051	0.108	0.003
Thermal Comfort	**0.575**	0.102	0.128	0.030	0.000	0.010	0.020	0.135
Acceptance	**0.647**	0.000	0.003	0.008	0.000	0.282	0.035	0.025
Preference	0.329	**0.346**	0.000	0.024	0.171	0.002	0.120	0.008
Satisfaction	**0.605**	0.078	0.069	0.006	0.004	0.117	0.011	0.110

Note: Values in bold are different from 0 with a significance level alpha = 0.05

The following analysis process was clustering using AHC. AHC is a clustering (or classification) technique that demonstrates the progressive grouping of data. Its advantages include dissimilarities between the items to be clustered together. The factor scores of each participant data from PCA were used to find the node and to calculate the dissimilarity between all data.

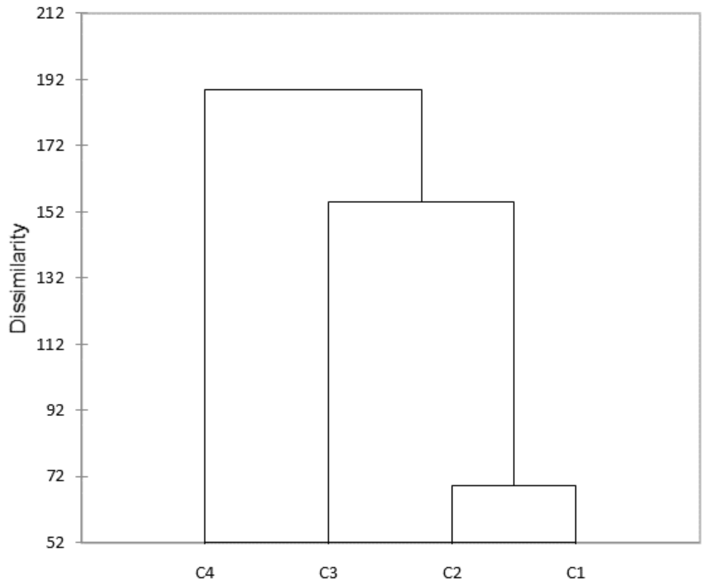


Figure 4-5. Dendrogram of bedroom thermal sensation factors

Table 4-4. Results by class of bedroom thermal sensation factors

Class	1	2	3	4
Objects	35	57	14	9
Sum of weights	35	57	14	9
Within-class variance	3.370	3.331	3.069	4.465
Minimum distance to centroid	0.982	0.474	0.956	1.183
Average distance to centroid	1.667	1.700	1.644	1.824
Maximum distance to centroid	3.599	3.169	2.143	3.694
Indonesian-Summer	3%	16%	6%	3%
Indonesian-Winter	13%	6%	0%	4%
Japanese-Summer	2%	20%	6%	0%
Japanese-Winter	12%	8%	0%	1%

The results, shown in Figure 4-5 (more details in Appendix N), indicate that four clusters were formed. Table 4-4 shows that cluster three is more homogeneous than the other (confirmed by within-class variance). The cluster one is dominated by Indonesian and

Japanese winter. Indonesian and Japanese summer dominate the cluster two and three. These clusters (c1: cluster one, c2: two, and c3: three) clearly indicate the close of thermal sensation between Indonesian and Japan during summer and winter. Meanwhile, cluster four is less homogenous than the other with the highest within-class variance.

b. Sleep sensation

Table 4-5 shows correlation matrix of sleep sensation variables, In the sleep sensation analysis, the same methodology was performed to thermal sensation analysis. To calculate the correlation of the variables, the correlation matrix was applied. The following Table 4-6 and Figure 4-6 discuss eigenvalues, which indicate the quality of a projection from an N-dimensional starting table (N=7 in this case) to a smaller number of dimensions. As shown in this research, the first eigenvalue is 3.439 and accounts for 49% (round up of 49.130 %) of the overall variability. This indicates that if the data plot on a single axis, it will show 49% of the total variability. In the current investigation, the cumulative variability of two components (with eigenvalues greater than 1) accounts for 72% of overall variability (cumulative of F1 and F2).

Table 4-5. Correlation matrix of sleep sensation variables

Variables	Deepness	Wakeup	Wellness	Freshness	Satisfaction	Awaking	Get off
Deepness	**1**	-0.170	**0.686**	0.143	**0.569**	-0.032	**-0.414**
Wake Up	-0.170	**1**	-0.055	**0.318**	0.073	**-0.282**	-0.163
Wellness	**0.686**	-0.055	**1**	**0.364**	**0.706**	-0.153	**-0.564**
Freshness	0.143	**0.318**	**0.364**	**1**	**0.679**	**-0.598**	**-0.570**
Satisfaction	**0.569**	0.073	**0.706**	**0.679**	**1**	**-0.458**	**-0.632**
Awaking	-0.032	**-0.282**	-0.153	**-0.598**	**-0.458**	**1**	**0.465**
Get off	**-0.414**	-0.163	**-0.564**	**-0.570**	**-0.632**	**0.465**	**1**

Note: Values in bold are different from 0 with a significance level alpha=0.05

Table 4-6. Eigenvalues of sleep sensation variables

	F1	F2	F3	F4	F5	F6	F7
Eigenvalue	**3.439**	**1.609**	0.705	0.422	0.399	0.262	0.164
Variability (%)	49.130	22.989	10.069	6.023	5.698	3.742	2.349
Cumulative %	49.130	72.119	82.188	88.211	93.909	97.651	100.000

Note: Values in bold are eigenvalues higher than 1. Abbreviation: F1-7, factor 1-7.

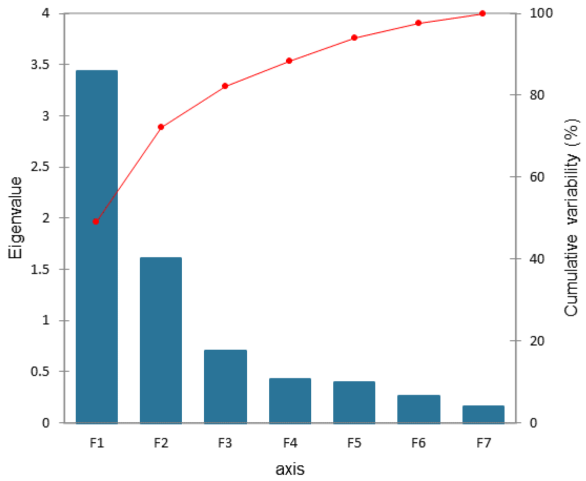


Figure 4-6. Eigenvalue scree plot of sleep sensation variables

In the correlation circle of this investigation, the first two components account for 72.12% of the data's initial variability. Although sleep sensation was started with seven variables, the number of components has been reduced to five. This is because of the five variables, two of which are adversely connected with other variables (get off and deepness), and three of which are strongly correlated with other variables (wellness, freshness, and awaking). The current sub chapter also implemented the PCA biplot to represent the sleep sensation survey and parameters into a new space (two factorial axes F1 and F2) for all groups (Figure 4-8) and for each group (Appendix L).

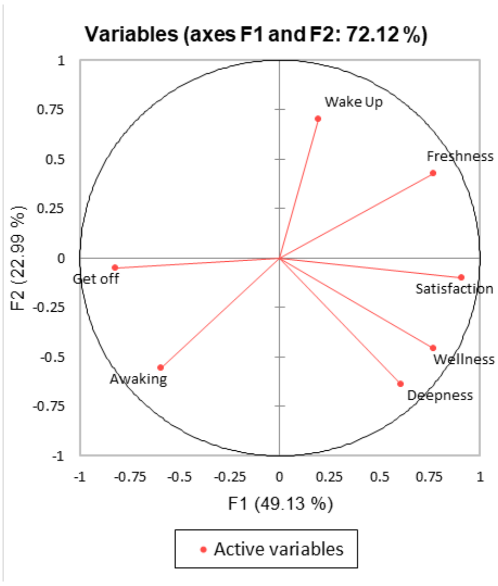


Figure 4-7. Correlation circle (on axes F1 and F2) of sleep sensation variables. Abbreviation: F1-2, selected factor with the eigenvalue higher than 1

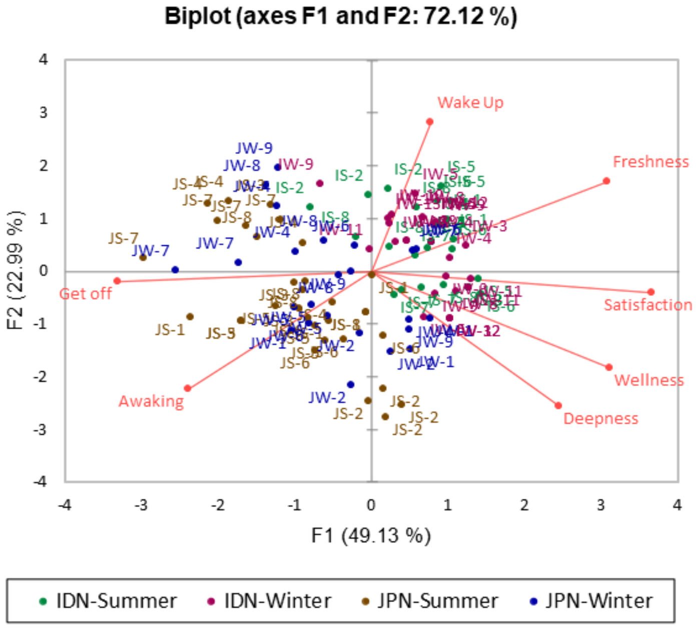


Figure 4-8. Sleep sensation biplot of participants in the correlation circle

In the correlation circle map (Figure 4-7), the horizontal axis is linked with satisfaction after waking up, and the vertical axis is with sensation during sleep. In the horizontal axis (F1), PCA found variables, i.e., wellness, freshness, satisfaction, awaking, and get off. PCA found other two variables in the vertical axis (F2) viz., wake up and deepness.

Table 4-7. Squared cosines of sleep sensation variables

	F1	F2	F3	F4	F5	F6	F7
Deepness	0.369	**0.408**	0.040	0.017	0.085	0.072	0.009
Wake Up	0.037	**0.490**	0.464	0.001	0.008	0.000	0.001
Wellness	**0.594**	0.209	0.033	0.005	0.002	0.143	0.015
Freshness	**0.587**	0.180	0.020	0.132	0.016	0.026	0.039
Satisfaction	**0.825**	0.010	0.003	0.058	0.006	0.000	0.098
Awaking	**0.352**	0.309	0.145	0.066	0.113	0.014	0.001
Get off	**0.676**	0.003	0.000	0.144	0.169	0.007	0.002

Note: Values in bold correspond for each variable to the factor for which the squared cosine is the largest

According to squared cosines of thermal sensation variables, five variables in the F1 (horizontal axis) represented the new sleep sensation with the label SS1, and two variables in the F2 (vertical axis) represented the SS2. The subsequent analysis process is clustering using AHC. The results, shown in Figure 4-9 (more details in Appendix O), indicated that two clusters were formed. Table 4-8 and Table 4-4 shows that is more homogeneous than cluster two (c2, confirmed by within-class variance). The cluster one is dominated by Indonesian. The cluster two is dominated by Japanese. This clearly indicates that sleep sensation was different between Indonesian and Japanese.

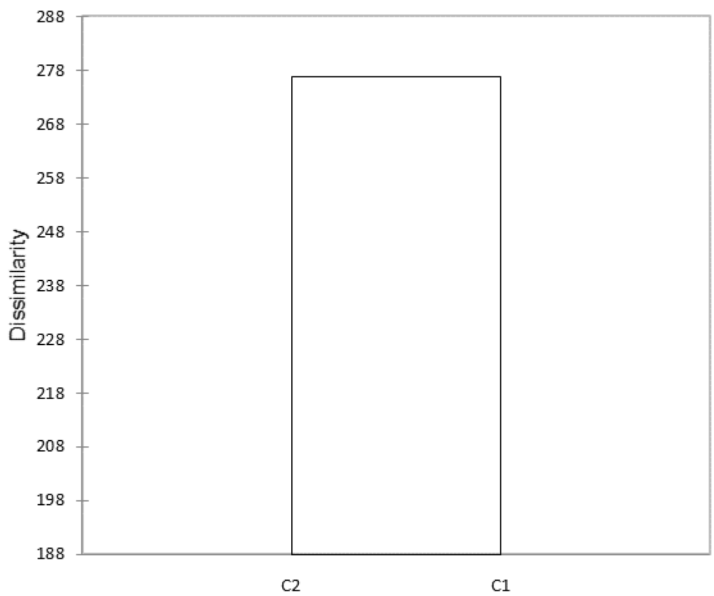


Figure 4-9. Dendrogram of sleep sensation factors

Table 4-8. Results by class of sleep sensation factors

Class	1	2
Objects	72	41
Sum of weights	72	41
Within-class variance	3.701	5.082
Minimum distance to centroid	0.850	1.069
Average distance to centroid	1.795	2.126
Maximum distance to centroid	3.566	3.816
Indonesian-Summer	26%	2%
Indonesian-Winter	22%	1%
Japanese-Summer	8%	20%
Japanese-Winter	8%	13%

4.1.3 Distribution of all variables

Table 4-9 summarizes the descriptive statistic of thermal environment and sensation. The data is a combination of two groups during two studies (as seen in the sub chapter

4.2.1). The descriptive statistic described mean, standard deviation (SD), minimum, quartile 1 (Q1), median, quartile 3 (Q3), and maximum of population.

Table 4-9. Summary of descriptive statistic of thermal environment and sensation

Variable	Mean	SD	Minimum	Q1	Median	Q3	Maximum
T_a	23.2	5.0	10.9	19.5	24.4	27.1	31.5
RH	60	15	25	49	58	73	89
TS1	0	1.7	-5.2	-0.4	0.3	1.0	2.4
TS2	0	1.4	-2.3	-0.9	-0.4	0.4	4.6
TS3	0	0.8	-2.2	-0.5	0.0	0.5	2.9

Abbreviation: Ta, air temperature; RH, relative humidity; TS1-3, thermal sensation factor 1-3

Table 4-10 summarizes the descriptive statistic of sleep quality and sensation. It performed similar steps as Table 4-9. The data are combination of two groups during two studies.

Table 4-10. Summary of descriptive statistic of sleep quality and sensation

Variable	Mean	SD	Minimum	Q1	Median	Q3	Maximum
Duration	409.2	83.8	232.0	358.8	410.0	451.0	766.0
Sleep Minutes	349.0	85.3	130.0	293.0	346.0	405.5	704.0
Sleep Rate	85.3	11.2	38.2	78.7	88.2	94.1	99.8
Sleep Efficiency	91.5	9.3	38.4	88.6	94.3	97.8	100.0
Sleep Latency	23.8	31.2	0.0	0.0	15.0	34.0	154.0
SS1	0.0	1.9	-5.5	-1.5	0.4	1.5	2.7
SS2	0.0	1.3	-3.5	-1.0	0.0	1.1	2.5

Abbreviation: SS1-2, sleep sensation factor 1-2

4.1.4 Correlation between thermal comfort and sleep quality

As explained in the methodology above (sub chapter 4.1), to investigate the correlation between thermal comfort and sleep quality, PCA was administrated to simplify the sensation survey. The thermal sensation was simplified to three main factors and sleep sensation was simplified to two main factors. The current sub chapter investigated correlation for each group (IDN and JPN groups) using Pearson correlation method. The Pearson correlation coefficient was used to determine the strength and direction between two continuous variables.

a. Correlation between thermal comfort and sleep quality in IDN group.

In IDN group, the T_a did not show any correlation with the sleep quality and sleep sensation. However, RH showed moderate negative correlation with duration on bed and weak negative correlation with sleep minute (all $p < 0.05$; Table 4-11). The simplified thermal sensation (TS1 and TS2) and sleep quality were performed with similar analysis. TS1 showed weak correlation with sleep rate and sleep efficiency. Further, TS3 (humidity sensation) showed weak correlation with duration on bed and sleep minute (Table 4-12).

Table 4-11. Correlation between thermal environment and sleep quality of IDN group

Variable	N	Correlation	95% CI	Sig.
T_a				
Duration	58	-0.04	(-0.291, 0.225)	$p = 0.79$
Sleep Minutes	58	0.02	(-0.241, 0.276)	$p = 0.89$
Sleep Rate	58	0.10	(-0.166, 0.346)	$p = 0.47$
Sleep Efficiency	58	0.17	(-0.089, 0.413)	$p = 0.19$
Sleep Latency	58	0.05	(-0.208, 0.307)	$p = 0.69$
SS1	57	-0.03	(-0.291, 0.229)	$p = 0.81$
SS2	57	0.01	(-0.250, 0.271)	$p = 0.94$
RH				
Duration*	58	-0.41	(-0.605, -0.171)	$p < 0.01$
Sleep Minutes*	58	-0.33	(-0.541, -0.076)	$p < 0.01$
Sleep Rate	58	-0.01	(-0.264, 0.252)	$p = 0.96$
Sleep Efficiency	58	0.03	(-0.235, 0.281)	$p = 0.85$
Sleep Latency	58	-0.05	(-0.303, 0.213)	$p = 0.72$
SS1	57	0.04	(-0.225, 0.295)	$p = 0.78$
SS2	57	-0.06	(-0.315, 0.204)	$p = 0.66$

Note: *significancy at $p < 0.05$. Abbreviation: SS1-2, sleep sensation factor 1-2.

Table 4-12. Correlation between thermal sensation and sleep quality of IDN group

Variable		N	Correlation	95% CI	Sig.
TS1					
	Duration	58	-0.06	(-0.311, 0.204)	$p = 0.67$
	Sleep Minutes	58	0.08	(-0.178, 0.335)	$p = 0.53$
	Sleep Rate*	58	0.28	(0.023, 0.501)	$p < 0.05$
	Sleep Efficiency*	58	0.37	(0.119, 0.571)	$p < 0.01$
	Sleep Latency	58	-0.12	(-0.369, 0.140)	$p = 0.36$
	SS1	57	0.17	(-0.095, 0.412)	$p = 0.21$
	SS2	57	-0.15	(-0.397, 0.113)	$p = 0.26$
TS2					
	Duration	58	0.01	(-0.245, 0.271)	$p = 0.92$
	Sleep Minutes	58	0.05	(-0.208, 0.307)	$p = 0.69$
	Sleep Rate	58	0.07	(-0.193, 0.321)	$p = 0.61$
	Sleep Efficiency	58	0.04	(-0.223, 0.293)	$p = 0.78$
	Sleep Latency	58	-0.03	(-0.286, 0.230)	$p = 0.82$
	SS1	57	-0.05	(-0.309, 0.211)	$p = 0.70$
	SS2	57	0.04	(-0.219, 0.301)	$p = 0.75$
TS3					
	Duration*	58	0.31	(0.051, 0.523)	$p < 0.05$
	Sleep Minutes*	58	0.30	(0.044, 0.517)	$p < 0.05$
	Sleep Rate	58	0.11	(-0.157, 0.354)	$p = 0.43$
	Sleep Efficiency	58	0.06	(-0.202, 0.313)	$p = 0.66$
	Sleep Latency	58	-0.05	(-0.300, 0.216)	$p = 0.74$
	SS1	57	-0.01	(-0.272, 0.249)	$p = 0.93$
	SS2	57	-0.05	(-0.305, 0.215)	$p = 0.72$

Note: *significancy at $p < 0.05$. Abbreviation: TS1-3, thermal sensation factor 1-3; SS1-2, sleep sensation factor 1-2.

b. Correlation between thermal comfort and sleep quality in JPN group.

In the JPN group, the analysis was the same as in the IDN group above. The current sub chapter performed an analysis of the correlation between thermal environment and sleep quality. Table 4-13 shows the correlation coefficient and significance value. The T_a showed a significant correlation with sleep rate (weak negative correlation), sleep latency (weak positive correlation), and SS1 (weak negative correlation). Moreover, RH showed a significant correlation between SS1 (weak negative correlation) and SS2 (weak positive correlation).

Table 4-13. Correlation between thermal environment and sleep quality of JPN group

Variable	N	Correlation	95% CI	Sig.
T_a				
Duration	56	0.09	(-0.175, 0.347)	$p = 0.50$
Sleep Minutes	56	-0.10	(-0.353, 0.168)	$p = 0.47$
Sleep Rate*	56	-0.26	(-0.486, 0.007)	$p < 0.05$
Sleep Efficiency	56	-0.24	(-0.470, 0.028)	$p = 0.08$
Sleep Latency*	56	0.38	(0.129, 0.584)	$p < 0.00$
SS1*	56	-0.30	(-0.518, -0.035)	$p < 0.03$
SS2	56	-0.07	(-0.326, 0.197)	$p = 0.61$
RH				
Duration	56	0.16	(-0.105, 0.408)	$p = 0.23$
Sleep Minutes	56	0.22	(-0.043, 0.459)	$p = 0.10$
Sleep rate	56	0.09	(-0.176, 0.346)	$p = 0.50$
Sleep Efficiency	56	0.00	(-0.261, 0.264)	$p = 0.99$
Sleep Latency	56	0.01	(-0.256, 0.270)	$p = 0.96$
SS1*	56	-0.36	(-0.568, -0.106)	$p < 0.01$
SS2*	56	0.26	(-0.003, 0.489)	$p < 0.05$

Note: *significancy at $p < 0.05$. Abbreviation: T_a, air temperature; RH, relative humidity; SS1-2, sleep sensation factor 1-2.

Moreover, the correlation analysis between thermal sensation and sleep quality and sensation found that TS1 did not correlate with sleep quality and sleep sensation. TS2 showed a weak negative correlation with sleep rate and efficiency and a moderate negative correlation with SS1. In analysis between TS3 and sleep quality, there was weak negative correlation with sleep latency. The results were summarized in Table 4-14.

Table 4-14. Correlation between thermal sensation and sleep quality of JPN group

Variable	N	Correlation	95% CI	Sig.
TS1				
Duration	56	0.04	(-0.226, 0.299)	$p = 0.78$
Sleep Minutes	56	0.06	(-0.208, 0.316)	$p = 0.67$
Sleep Rate	56	0.01	(-0.256, 0.270)	$p = 0.96$
Sleep Efficiency	56	0.11	(-0.160, 0.360)	$p = 0.43$
Sleep Latency	56	0.02	(-0.245, 0.281)	$p = 0.89$
SS1	56	-0.11	(-0.361, 0.159)	$p = 0.43$
SS2	56	-0.15	(-0.398, 0.116)	$p = 0.27$

Table 4-14. Correlation between thermal sensation and sleep quality of JPN group (continued)

Variable	N	Correlation	95% CI	Sig.
TS2				
Duration	56	0.12	(-0.151, 0.368)	$p = 0.39$
Sleep Minutes	56	-0.11	(-0.363, 0.157)	$p = 0.42$
Sleep Rate*	56	-0.29	(-0.513, -0.028)	$p < 0.05$
Sleep Efficiency*	56	-0.32	(-0.535, -0.059)	$p < 0.05$
Sleep Latency	56	0.26	(-0.006, 0.487)	$p = 0.06$
SS1*	56	-0.40	(-0.599, -0.152)	$p < 0.01$
SS2	56	0.18	(-0.083, 0.426)	$p = 0.17$
TS3				
Duration	56	-0.13	(-0.382, 0.135)	$p = 0.33$
Sleep Minutes	56	-0.08	(-0.335, 0.187)	$p = 0.56$
Sleep Rate	56	0.08	(-0.184, 0.338)	$p = 0.54$
Sleep Efficiency	56	-0.03	(-0.289, 0.237)	$p = 0.84$
Sleep Latency*	56	-0.26	(-0.489, 0.004)	$p < 0.05$
SS1	56	0.15	(-0.121, 0.394)	$p = 0.28$
SS2	56	-0.11	(-0.359, 0.162)	$p = 0.44$

Note: *significancy at $p < 0.05$. Abbreviation: TS1-3, thermal sensation factor 1-3; SS1-2, sleep sensation factor 1-2.

4.2 Effect of thermal comfort on brain response

4.2.1 Data preparation

The current section aimed to investigate the effect of thermal comfort on brain response. Objective and subjective parameters were administrated across two studies (summer and winter study: sub chapter 3.2, page 42). In the first step, the data set in the current study was prepared with the same steps. The data are combination variables in the current investigation, i.e., thermal environment, skin temperature, thermal sensation, brain response, reaction time, and Uchida-Kraepelin test.

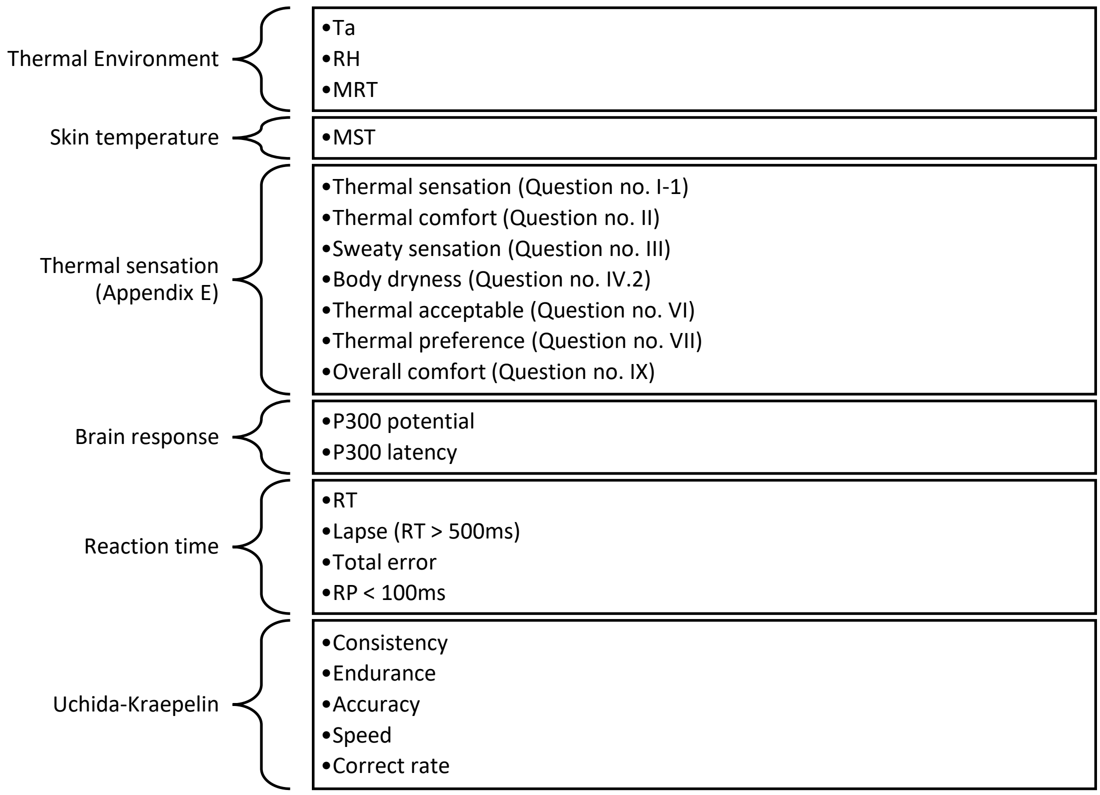


Figure 4-10. Data set list and reference of question number in the brain response experiment

4.2.2 Principal component analysis

The thermal sensation of experimental room performed the same methodology. The correlation matrix was applied to calculate the correlation of variables. The following Table 4-16 and chart Figure 4-11 discuss eigenvalues, which indicate the quality of a projection from an N-dimensional starting table (N=7 in this case) to a smaller number of dimensions. This research shows that the first eigenvalue is 3.328 and accounts for 48% (round up of 47.543 %) of the overall variability. It indicates that if the data plot on a single axis, it will show 48% of the total variability. In the current investigation, the cumulative variability of two components (with eigenvalues greater than 1) accounts for 77% (round up of 77.414 %) of overall variability (cumulative of F1 and F2).

Table 4-15. Correlation matrix of thermal sensation variables in the brain response experiment

Variables	TSV	TC	Sweaty	Body	Acceptable	Preference	Overall Comfort
TSV	**1**	-0.085	**0.614**	**0.474**	-0.008	**-0.535**	-0.091
TC	-0.085	**1**	**-0.421**	**-0.184**	**0.823**	0.094	**0.911**
Sweaty	**0.614**	**-0.421**	**1**	**0.579**	**-0.353**	**-0.571**	**-0.410**
Body	**0.474**	**-0.184**	**0.579**	**1**	**-0.130**	**-0.482**	**-0.169**
Acceptable	-0.008	**0.823**	**-0.353**	**-0.130**	**1**	0.051	**0.815**
Preference	**-0.535**	0.094	**-0.571**	**-0.482**	0.051	**1**	0.121
Overall Comfort	-0.091	**0.911**	**-0.410**	**-0.169**	**0.815**	0.121	**1**

Note: Values in bold are different from 0 with a significance level alpha = 0.05

Table 4-16. Eigenvalues of thermal sensation variables in the brain response experiment

	F1	F2	F3	F4	F5	F6	F7
Eigenvalue	**3.328**	**2.091**	0.535	0.472	0.281	0.206	0.087
Variability (%)	47.543	29.871	7.643	6.737	4.016	2.941	1.248
Cumulative %	47.543	77.414	85.057	91.794	95.811	98.752	100.000

Note: Values in bold are eigenvalues higher than 1. Abbreviation: F1-7, factor 1-7.

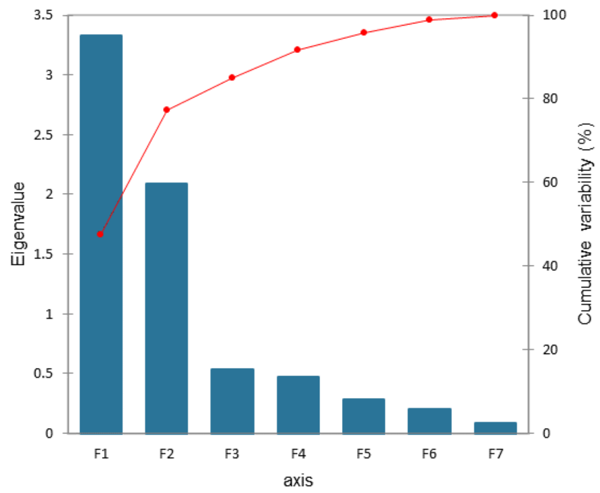


Figure 4-11. Eigenvalue scree plot of thermal sensation variables in the brain response experiment

In the correlation circle of this analysis (Figure 4-12), the first two components account for 77.414 % of the data's initial variability. The number of components has been reduced to five because the other three components are adversely connected with other variables (thermal preference, acceptable, thermal comfort, and overall comfort). The PCA biplot was implemented to represent the experimental room thermal sensation survey and parameters into new space (two factorial axes F1 and F2) for all group (Figure 4-4) and for each group (Appendix K).

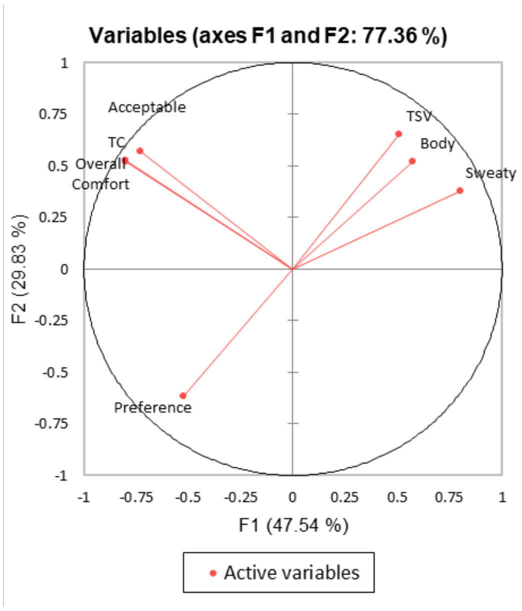


Figure 4-12. Correlation circle (on axes F1 and F2) of thermal sensation variables in the brain response experiment

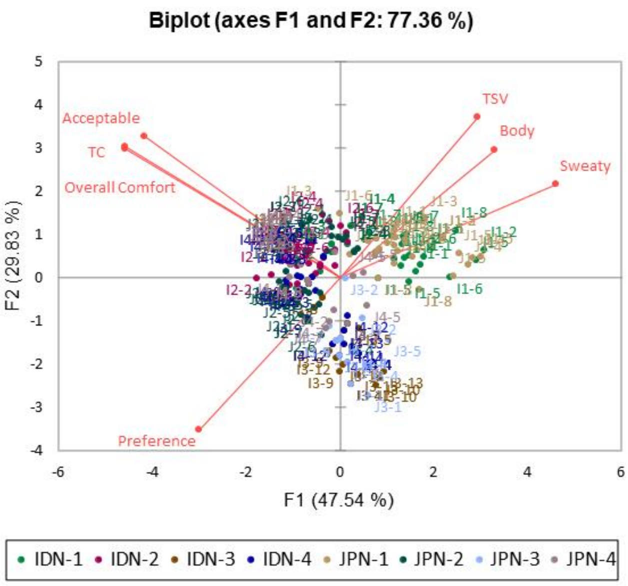


Figure 4-13. Experimental room thermal sensation biplot of participants in the correlation circle

In this investigation, the horizontal axis is linked with thermal comfort, and the vertical axis with thermal sensation. The horizontal axis (F1) consisted of four variables i.e., thermal comfort, sweaty sensation, acceptable, and overall comfort. Two other variables were found in the vertical axis (F2) viz., thermal sensation and preference. One variable (body dryness) was F3.

Table 4-17. Squared cosines of thermal sensation variables in the brain response experiment

	F1	F2	F3	F4	F5	F6	F7
TSV	0.263	**0.423**	0.093	0.170	0.048	0.003	0.000
TC	**0.643**	0.279	0.000	0.000	0.004	0.028	0.046
Sweaty	**0.645**	0.143	0.002	0.010	0.198	0.001	0.000
Body	0.331	0.268	**0.388**	0.000	0.013	0.000	0.000
Acceptable	**0.534**	0.325	0.000	0.001	0.000	0.140	0.000
Preference	0.274	**0.379**	0.049	0.289	0.008	0.000	0.000
Overall Comfort	**0.639**	0.273	0.003	0.000	0.010	0.034	0.041

Note: Values in bold are different from 0 with a significance level alpha = 0.05

According to squared cosines of thermal sensation variables in the brain response experiment, four variables in the F1 (horizontal axis) represented the new thermal sensation TE1, two variables in the F2 (vertical axis) represented TE2, and one variable in the F3 represented the TE3.

The following analysis process is clustering using AHC. The results, shown in Figure 4-14 (more details in Appendix P), indicated that two clusters were formed. Table 4-18 shows that cluster one is more homogeneous than cluster two (confirmed by within-class variance). The cluster one is dominated by Indonesian and Japanese in hot condition. The cluster two is dominated by Indonesian and Japanese in cooling, cold, and heating condition. The cluster one clearly indicated that thermal sensation between Indonesian and Japan during hot condition was close.

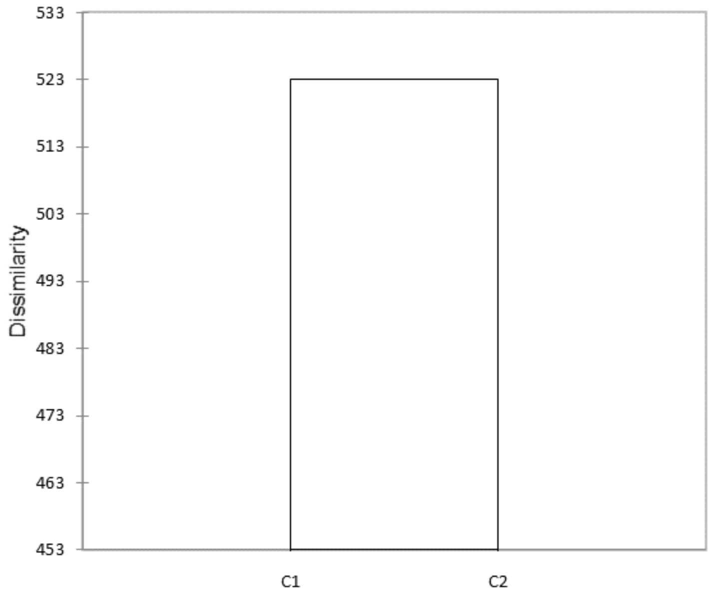


Figure 4-14. Dendrogram of experimental room thermal sensation factors

Table 4-18. Results by class of experimental room thermal sensation factors

Class	1	2
Objects	43	186
Sum of weights	43	186
Within-class variance	3.068	4.778
Minimum distance to centroid	0.257	0.743
Average distance to centroid	1.592	2.058
Maximum distance to centroid	2.847	4.254
Indonesian-hot	8%	6%
Indonesian-cooling	0%	14%
Indonesian-cold	0%	9%
Indonesian-heating	0%	15%
Japanese-hot	10%	3%
Japanese-cooling	0%	14%
Japanese-cold	0%	7%
Japanese-heating	0%	13%

4.2.3 Distribution of all variables

To investigate the correlation between thermal comfort and brain response, the current sub chapter performed a similar statistical method (Pearson correlation method). It started with summary of descriptive statistic for all variables. Table 4-19 summarizes the descriptive of thermal environment, mean skin temperature, and thermal sensation.

Table 4-19. Summary of descriptive statistic of thermal environment, mean skin temperature, and thermal sensation

Variable	Mean	SD	Minimum	Q1	Median	Q3	Maximum
Ta	23.9	5.9	10.8	21.1	23.5	29.1	34.3
RH	51	15	21	39	50	63	82
MRT	24.6	6.0	11.6	21.9	24.3	29.5	34.3
MST	32.6	1.8	27.2	31.8	32.7	34.0	35.2
TE1	0.1	1.9	-3.2	-1.3	-0.3	1.1	5.6
TE2	0.0	1.4	-4.0	-0.5	0.6	1.1	2.3
TE3	0.0	0.7	-2.0	-0.4	0.0	0.5	1.6

Abbreviations: T_a, air temperature; RH, relative humidity; MRT, mean radiant temperature; MST, mean skin temperature; TE1-3, thermal sensation in experimental study

Table 4-20, Table 4-21, and Table 4-22 summarize the descriptive of P300, PVT, Uchida-Kraepelin test, respectively.

Table 4-20. Summary of descriptive statistic of P300 potential and latency

Variable	Mean	SD	Minimum	Q1	Median	Q3	Maximum
Potential	25.28	7.31	13.56	19.54	23.52	29.27	48.86
Latency	0.37	0.04	0.25	0.34	0.36	0.40	0.47

Table 4-21. Summary of descriptive statistic of PVT

Variable	Mean	SD	Minimum	Q1	Median	Q3	Maximum
RT	253.36	34.52	192.29	228.24	247.31	271.95	377.12
Sleep vote	6.71	2.27	1.00	5.75	7.00	8.00	10.00
RT > 500ms	0.98	1.60	0.00	0.00	0.00	1.00	11.00
Total Errors	1.30	1.78	0.00	0.00	1.00	2.00	11.00
RT < 100ms	0.09	0.31	0.00	0.00	0.00	0.00	2.00

Table 4-22. Summary of descriptive statistic of Uchida-Kraepelin test

Variable	Mean	SD	Minimum	Q1	Median	Q3	Maximum
Consistency	0.82	0.12	0.41	0.75	0.85	0.91	1.00
Endurance	3.71	7.31	-17.84	-0.95	3.45	7.38	27.05
Accuracy	0.86	1.86	0.00	0.17	0.33	0.87	15.23
Speed	63.40	19.74	25.13	44.57	65.33	77.33	113.93
Correct Rate	98.68	2.70	79.23	98.37	99.46	99.77	100.00

4.2.4 Correlation between thermal comfort and brain response

a. Correlation between thermal comfort and brain response in IDN group

Table 4-23 summarizes Pearson correlation analysis between thermal environment and P300 in the IDN group. The correlation analysis found following results: correlation between T_a and P300 potential was weak negative correlation, correlation between RH and P300 latency was weak positive correlation, and correlation between MRT and P300 potential was weak negative correlation (all $p < 0.05$).

Table 4-23. Summary of correlation analysis between thermal environment and P300 of IDN group

Variable		N	Correlation	95% CI	Sig.
Ta					
	Potential*	59	-0.25	(-0.477, 0.005)	$p < 0.05$
	Latency	59	0.18	(-0.082, 0.415)	$p = 0.18$
RH					
	Potential	59	-0.19	(-0.422, 0.074)	$p = 0.16$
	Latency*	59	0.35	(0.103, 0.556)	$p < 0.01$
MRT					
	Potential*	56	-0.26	(-0.493, -0.002)	$p < 0.05$
	Latency	56	0.19	(-0.080, 0.429)	$p = 0.17$

Note: *significancy at $p < 0.05$. Abbreviation: T_a, air temperature; RH, relative humidity; MRT, mean radian temperature.

Moreover, in the IDN group, the MST did not correlate with P300 potential and latency (all $p > 0.05$, Table 4-24). Then, the correlation between simplified thermal sensation (TE1, TE2, TE3) and P300 were analyzed. As seen in Table 4-25, only TE2 had a correlation with P300 latency (weak positive).

Table 4-24. Summary of correlation analysis between MST and P300 of IDN group

Variable		N	Correlation	95% CI	Sig.
MST					
	Potential	59	-0.24	(-0.469, 0.015)	$p = 0.06$
	Latency	59	0.15	(-0.108, 0.393)	$p = 0.25$

Abbreviation: MST, mean skin temperature.

Table 4-25. Summary of correlation analysis between thermal sensation and P300 of IDN group

Variable		N	Correlation	95% CI	Sig.
TE1					
	Potential	118	-0.17	(-0.338, 0.014)	p = 0.07
	Latency	118	0.01	(-0.169, 0.193)	p = 0.90
TE2					
	Potential	118	0.05	(-0.224, 0.136)	p = 0.63
	Latency*	118	0.18	(-0.002, 0.348)	p < 0.05
TE3					
	Potential	118	0.05	(-0.133, 0.228)	p = 0.60
	Latency	118	0.10	(-0.078, 0.279)	p = 0.26

Note: *significancy at $p < 0.05$. Abbreviation: TE1-3, thermal sensation factor 1-3.

The psychomotor vigilance task investigation (PVT) performed similar analysis. Table 4-26 shows the summary of Pearson correlation analysis between thermal environment and parameter of PVT (reaction time, sleep vote, number of reaction time more than 500 ms, total errors, and number reaction time less than 100 ms). A weak positive correlation between Ta and sleep vote ($p < 0.05$) was found. Mean radiant temperature (Table 4-26) and mean skin temperature (Table 4-27) had a weak positive correlation with sleep vote (all $p < 0.05$). It indicates that the air temperature of the experimental room influenced sleep vote during the experiment in the IDN group.

Table 4-26. Summary of correlation analysis between thermal environment and PVT of IDN group

Variable		N	Correlation	95% CI	Sig.
Ta					
	Reaction Time	59	-0.05	(-0.298, 0.213)	p = 0.73
	Sleep vote*	59	0.26	(-0.000, 0.481)	p < 0.05
	Lapses (RT > 500ms)	59	0.06	(-0.203, 0.308)	p = 0.67
	Total Errors	59	0.03	(-0.229, 0.282)	p = 0.83
	RT < 100 ms	59	-0.18	(-0.418, 0.078)	p = 0.17
RH					
	Reaction Time	59	-0.09	(-0.338, 0.171)	p = 0.50
	Sleep vote	59	0.10	(-0.162, 0.346)	p = 0.46
	Lapses (RT > 500ms)	59	0.08	(-0.178, 0.331)	p = 0.54
	Total Errors	59	-0.04	(-0.295, 0.216)	p = 0.75
	RT < 100 ms	59	-0.10	(-0.351, 0.156)	p = 0.43

Note: *significancy at $p < 0.05$. Abbreviation: Ta, air temperature; RH, relative humidity.

Table 4-26. Summary of correlation analysis between thermal environment and PVT of IDN group (continued)

Variable	N	Correlation	95% CI	Sig.
MRT				
Reaction Time	56	-0.04	(-0.302, 0.223)	$p = 0.76$
Sleep vote*	56	0.28	(0.018, 0.505)	$p < 0.05$
Lapses (RT > 500ms)	56	0.08	(-0.185, 0.337)	$p = 0.55$
Total Errors	56	0.03	(-0.237, 0.288)	$p = 0.84$
RT < 100ms	56	-0.19	(-0.435, 0.072)	$p = 0.15$

Note: *significancy at $p < 0.05$. Abbreviation: MRT, mean radiant temperature.

Table 4-27. Summary of correlation analysis between MST and PVT of IDN group

Variable	N	Correlation	95% CI	Sig.
MST				
Reaction Time	59	-0.02	(-0.273, 0.239)	$p = 0.89$
Sleep vote*	59	0.34	(0.092, 0.549)	$p < 0.01$
Lapses (RT > 500ms)	59	0.11	(-0.151, 0.355)	$p = 0.41$
Total Errors	59	0.07	(-0.185, 0.324)	$p = 0.58$
RT < 100ms	59	-0.08	(-0.331, 0.178)	$p = 0.54$

Note: *significancy at $p < 0.05$. Abbreviation: MST, mean skin temperature.

Furthermore, the effect of simplified thermal sensation on PVT was analyzed. The simplified thermal sensation was obtained from PCA (sub chapter 4.3.2). In the current investigation, TE3 had a weak positive correlation with the reaction time (Table 4-28).

Table 4-28. Summary of correlation analysis between thermal sensation and PVT of IDN group

Variable	N	Correlation	95% CI	Sig.
TE1				
Reaction Time	118	0.04	(-0.143, 0.218)	$p = 0.68$
Sleep vote	118	0.09	(-0.092, 0.266)	$p = 0.33$
Lapses (RT > 500ms)	118	0.04	(-0.142, 0.219)	$p = 0.67$
Total Errors	118	-0.04	(-0.215, 0.146)	$p = 0.70$
RT < 100 ms	118	0.01	(-0.167, 0.195)	$p = 0.88$
TE2				
Reaction Time	118	-0.11	(-0.288, 0.069)	$p = 0.22$
Sleep vote	118	0.00	(-0.181, 0.180)	$p = 0.99$
Lapses (RT > 500ms)	118	0.04	(-0.144, 0.217)	$p = 0.68$
Total Errors	118	0.10	(-0.084, 0.275)	$p = 0.29$
RT < 100 ms	118	-0.11	(-0.283, 0.074)	$p = 0.24$

Note: *significancy at $p < 0.05$. Abbreviation: TE1-2, thermal sensation factor 1-2.

Table 4-28. Summary of correlation analysis between thermal sensation and PVT of IDN group (continued)

Variable	N	Correlation	95% CI	Sig.
TE3				
Reaction Time*	118	0.20	(0.022, 0.369)	$p < 0.05$
Sleep vote	118	0.08	(-0.100, 0.259)	$p = 0.38$
Lapses (RT > 500ms)	118	0.03	(-0.148, 0.213)	$p = 0.72$
Total Errors	118	0.06	(-0.127, 0.233)	$p = 0.56$
RT < 100 ms	118	-0.01	(-0.194, 0.167)	$p = 0.88$

Note: *significancy at $p < 0.05$. Abbreviation: TE3, thermal sensation factor 3.

The current sub chapter also analyzed the correlation between thermal environment, mean skin temperature (MST), thermal sensation, and Uchida-Kraepelin (U-K) test parameter (consistency, endurance, accuracy, speed, and correct rate). Current investigation did not show any correlation between thermal environment (Table 4-29), MST (Table 4-30), thermal sensation (Table 4-31), and U-K test (all $p > 0.05$).

Table 4-29. Summary of correlation analysis between thermal environment and U-K test of IDN group

Variable	N	Correlation	95% CI	Sig.
Ta				
Consistency	59	-0.17	(-0.411, 0.087)	$p = 0.19$
Endurance	59	0.01	(-0.244, 0.268)	$p = 0.92$
Accuracy	59	0.03	(-0.232, 0.280)	$p = 0.85$
Speed	59	0.11	(-0.150, 0.356)	$p = 0.41$
Correct Rate	59	0.01	(-0.243, 0.270)	$p = 0.91$
RH				
Consistency	59	-0.13	(-0.372, 0.133)	$p = 0.34$
Endurance	59	0.04	(-0.218, 0.293)	$p = 0.76$
Accuracy	59	-0.22	(-0.452, 0.037)	$p = 0.09$
Speed	59	0.05	(-0.207, 0.304)	$p = 0.70$
Correct Rate	59	0.23	(-0.025, 0.461)	$p = 0.08$
MRT				
Consistency	56	-0.17	(-0.411, 0.101)	$p = 0.22$
Endurance	56	0.01	(-0.249, 0.276)	$p = 0.92$
Accuracy	56	0.04	(-0.228, 0.297)	$p = 0.79$
Speed	56	0.15	(-0.121, 0.394)	$p = 0.28$
Correct Rate	56	0.01	(-0.255, 0.271)	$p = 0.95$

Abbreviation: Ta, air temperature; RH, relative humidity; MRT, mean radiant temperature.

Table 4-30. Summary of correlation analysis between MST and U-K test of IDN group

Variable	N	Correlation	95% CI	Sig.
MST				
Consistency	59	-0.16	(-0.396, 0.104)	$p = 0.24$
Endurance	59	-0.03	(-0.284, 0.227)	$p = 0.82$
Accuracy	59	-0.04	(-0.294, 0.217)	$p = 0.76$
Speed	59	0.11	(-0.156, 0.351)	$p = 0.43$
Correct Rate	59	0.07	(-0.191, 0.319)	$p = 0.61$

Abbreviation: MST, mean skin temperature.

Table 4-31. Summary of correlation analysis between thermal sensation and U-K test of IDN group

Variable	N	Correlation	95% CI	Sig.
TE1				
Consistency	59	-0.07	(-0.319, 0.191)	$p = 0.61$
Endurance	59	0.02	(-0.240, 0.272)	$p = 0.90$
Accuracy	59	-0.03	(-0.286, 0.225)	$p = 0.81$
Speed	59	-0.12	(-0.362, 0.144)	$p = 0.38$
Correct Rate	59	0.02	(-0.233, 0.279)	$p = 0.86$
TE2				
Consistency	59	-0.18	(-0.418, 0.078)	$p = 0.17$
Endurance	59	-0.08	(-0.331, 0.178)	$p = 0.54$
Accuracy	59	0.10	(-0.165, 0.343)	$p = 0.47$
Speed	59	0.16	(-0.102, 0.398)	$p = 0.23$
Correct Rate	59	-0.05	(-0.298, 0.213)	$p = 0.73$
TE3				
Consistency	59	-0.06	(-0.310, 0.200)	$p = 0.66$
Endurance	59	-0.21	(-0.438, 0.054)	$p = 0.12$
Accuracy	59	-0.01	(-0.267, 0.245)	$p = 0.93$
Speed	59	0.05	(-0.211, 0.300)	$p = 0.72$
Correct Rate	59	0.02	(-0.235, 0.277)	$p = 0.87$

Abbreviation: TE1-3, thermal sensation factor 1-3.

b. Correlation between thermal comfort and brain response in JPN group

Table 4-32 summarizes Pearson correlation analysis between thermal environment and P300 of the JPN group. Correlation between T_a and P300 potential was moderate positive. T_a and P300 latency had a weak positive correlation. MRT and P300 potential exhibited a weak positive correlation. MRT and P300 latency had a weak negative correlation (all $p < 0.05$).

Moreover, mean skin temperature of JPN group showed a significant correlation with P300 (moderate positive correlation with P300 potential, weak negative correlation with P300 latency, Table 4-33).

Table 4-32. Summary of correlation analysis between thermal environment and P300 of JPN group

Variable	N	Correlation	95% CI	Sig.
Ta				
Potential*	54	0.40	(0.142, 0.599)	$p < 0.01$
Latency*	54	-0.30	(-0.523, -0.032)	$p < 0.05$
RH				
Potential	54	0.23	(-0.043, 0.467)	$p = 0.10$
Latency	54	-0.06	(-0.321, 0.213)	$p = 0.68$
MRT				
Potential*	51	0.37	(0.100, 0.582)	$p < 0.01$
Latency*	51	-0.32	(-0.548, -0.049)	$p < 0.05$

Note: *significancy at $p < 0.05$. Abbreviation: Ta, air temperature; RH, relative humidity; MRT, mean radian temperature.

Table 4-33. Summary of correlation analysis between MST and P300 of JPN group

Variable	N	Correlation	95% CI	Sig.
MST				
Potential*	54	0.40	(0.144, 0.601)	$p < 0.01$
Latency*	54	-0.37	(-0.580, -0.113)	$p < 0.01$

Note: *significancy at $p < 0.05$. Abbreviation: MST, mean skin temperature.

The correlations between simplified thermal sensation (TE1, TE2, TE3) and P300 were also analyzed. As seen in Table 4-34, correlation between TE1 and P300 potential was weakly positive, correlation between TE2 and P300 potential was weakly positive, correlation between TE2 and P300 latency was weak negative, and correlation between TE3 and P300 latency was weak positive.

Meanwhile, Table 4-35 shows the summary of Pearson correlation analysis between thermal environment and parameter of PVT (reaction time, sleep vote, number of reaction time more than 500 ms, total errors, and number reaction time less than 100 ms). The thermal environment of the JPN group did not correlate with any PVT parameter (all $p > 0.05$).

Table 4-34. Summary of correlation analysis between thermal sensation and P300 of JPN group

Variable		N	Correlation	95% CI	Sig.
TE1					
	Potential*	107	0.23	(0.039, 0.400)	$p < 0.05$
	Latency	107	0.06	(-0.132, 0.247)	$p < 0.54$
TE2					
	Potential*	107	0.20	(0.014, 0.379)	$p < 0.05$
	Latency*	107	-0.35	(-0.508, -0.173)	$p < 0.01$
TE3					
	Potential	107	0.02	(-0.168, 0.211)	$p = 0.82$
	Latency*	107	0.27	(0.087, 0.440)	$p < 0.01$

Note: *significancy at $p < 0.05$. Abbreviation: TE1-3, thermal sensation factor 1-3.

Table 4-35. Summary of correlation analysis between thermal environment and PVT of JPN group

Variable		N	Correlation	95% CI	Sig.
Ta					
	Reaction Time	56	0.15	(-0.119, 0.396)	$p = 0.27$
	Sleep vote	56	0.07	(-0.193, 0.330)	$p = 0.59$
	Lapses (RT > 500ms)	56	0.15	(-0.113, 0.401)	$p = 0.26$
	Total Errors	56	0.09	(-0.182, 0.341)	$p = 0.53$
	RT < 100 ms	56	0.02	(-0.241, 0.285)	$p = 0.86$
RH					
	Reaction Time	56	-0.01	(-0.268, 0.258)	$p = 0.97$
	Sleep vote	56	-0.10	(-0.349, 0.173)	$p = 0.49$
	Lapses (RT > 500ms)	56	-0.08	(-0.333, 0.190)	$p = 0.58$
	Total Errors	56	0.10	(-0.164, 0.356)	$p = 0.45$
	RT < 100 ms	56	0.10	(-0.168, 0.353)	$p = 0.47$
MRT					
	Reaction Time	53	0.14	(-0.133, 0.397)	$p = 0.31$
	Sleep vote	53	0.06	(-0.218, 0.321)	$p = 0.69$
	Lapses (RT > 500ms)	53	0.16	(-0.114, 0.413)	$p = 0.25$
	Total Errors	53	0.07	(-0.207, 0.331)	$p = 0.63$
	RT < 100 ms	53	0.04	(-0.231, 0.309)	$p = 0.77$

Abbreviation: Ta, air temperature; RH, relative humidity; MRT, mean radian temperature.

The mean skin temperature of the JPN group also did not correlate with the PVT parameters (all $p > 0.05$, Table 4-36).

Table 4-36. Summary of correlation analysis between MST and PVT of JPN group

Variable		N	Correlation	95% CI	Sig.
MST					
	Reaction Time	56	0.13	(-0.141, 0.377)	*p* = 0.35
	Sleep vote	56	0.23	(-0.039, 0.461)	*p* = 0.09
	Lapses (RT > 500ms)	56	0.19	(-0.073, 0.435)	*p* = 0.15
	Total Errors	56	0.12	(-0.150, 0.369)	*p* = 0.39
	RT < 100 ms	56	0.11	(-0.154, 0.365)	*p* = 0.41

Abbreviation: MST, mean skin temperature.

Furthermore, simplified thermal sensation's effect on PVT in the JPN group was analyzed. Similar to the correlation between mean skin temperature and PVT, the simplified thermal sensation did not correlate with the PVT parameters (all $p > 0.05$, Table 4-37).

Table 4-37. Summary of correlation analysis between thermal sensation and PVT of JPN group

Variable		N	Correlation	95% CI	Sig.
TE1					
	Reaction Time	111	0.12	(-0.071, 0.297)	*p* = 0.22
	Sleep vote	111	0.12	(-0.071, 0.297)	*p* = 0.22
	Lapses (RT > 500ms)	111	0.00	(-0.185, 0.188)	*p* = 0.99
	Total Errors	111	0.07	(-0.116, 0.255)	*p* = 0.46
	RT < 100 ms	111	-0.07	(-0.253, 0.118)	*p* = 0.47
TE2					
	Reaction Time	111	0.07	(-0.122, 0.249)	*p* = 0.49
	Sleep vote	111	-0.09	(-0.273, 0.096)	*p* = 0.34
	Lapses (RT > 500ms)	111	0.13	(-0.062, 0.305)	*p* = 0.19
	Total Errors	111	-0.07	(-0.252, 0.119)	*p* = 0.47
	RT < 100 ms	111	-0.10	(-0.285, 0.084)	*p* = 0.28
TE3					
	Reaction Time	111	-0.05	(-0.237, 0.134)	*p* = 0.58
	Sleep vote	111	-0.08	(-0.262, 0.108)	*p* = 0.41
	Lapses (RT > 500ms)	111	-0.16	(-0.335, 0.029)	*p* = 0.10
	Total Errors	111	-0.01	(-0.197, 0.176)	*p* = 0.91
	RT < 100 ms	111	-0.03	(-0.211, 0.161)	*p* = 0.79

Abbreviation: TE1-3, thermal sensation factor 1-3.

The correlations between thermal environment, mean skin temperature, thermal sensation, and Uchida-Kraepelin (U-K) test parameter (consistency, endurance, accuracy, speed, and correct rate) in the JPN group were then analyzed. There was no correlation between thermal environment and UK-test (Table 4-38), and mean skin temperature and U-K test (Table 4-30, Table 4-39, all $p > 0.05$).

Table 4-38. Summary of correlation analysis between thermal environment and U-K test of JPN group

Variable	N	Correlation	95% CI	Sig.
Ta				
Consistency	56	-0.06	(-0.317, 0.207)	$p = 0.67$
Endurance	56	-0.15	(-0.398, 0.116)	$p = 0.27$
Accuracy	56	0.11	(-0.156, 0.363)	$p = 0.42$
Speed	56	0.15	(-0.118, 0.397)	$p = 0.27$
Correct Rate	56	-0.10	(-0.352, 0.169)	$p = 0.47$
RH				
Consistency	56	-0.01	(-0.269, 0.257)	$p = 0.96$
Endurance	56	-0.05	(-0.308, 0.217)	$p = 0.72$
Accuracy	56	-0.07	(-0.327, 0.197)	$p = 0.61$
Speed	56	-0.07	(-0.329, 0.194)	$p = 0.60$
Correct Rate	56	0.08	(-0.187, 0.336)	$p = 0.56$
MRT				
Consistency	53	-0.04	(-0.304, 0.235)	$p = 0.79$
Endurance	53	-0.18	(-0.426, 0.099)	$p = 0.21$
Accuracy	53	0.07	(-0.204, 0.334)	$p = 0.62$
Speed	53	0.17	(-0.105, 0.421)	$p = 0.22$
Correct Rate	53	-0.06	(-0.328, 0.210)	$p = 0.65$

Abbreviation: Ta, air temperature; RH, relative humidity; MRT, mean radian temperature.

Table 4-39. Summary of correlation analysis between MST and U-K test of JPN group

Variable	N	Correlation	95% CI	Sig.
MST				
Consistency	56	-0.04	(-0.300, 0.225)	$p = 0.77$
Endurance	56	-0.16	(-0.408, 0.105)	$p = 0.23$
Accuracy	56	-0.12	(-0.370, 0.149)	$p = 0.38$
Speed	56	0.14	(-0.129, 0.387)	$p = 0.31$
Correct Rate	56	0.12	(-0.144, 0.374)	$p = 0.36$

Abbreviation: MST, mean skin temperature.

However, in the thermal sensation of JPN group, TE3 showed a weak positive correlation with accuracy and a weak negative correlation with speed and correct rate (all $p < 0.05$).

Table 4-40. Summary of correlation analysis between thermal sensation and U-K test of JPN group

Variable	N	Correlation	95% CI	Sig.
TE1				
Consistency	56	-0.14	(-0.391, 0.125)	*p* = 0.29
Endurance	56	0.14	(-0.125, 0.390)	*p* = 0.30
Accuracy	56	0.15	(-0.116, 0.399)	*p* = 0.26
Speed	56	-0.01	(-0.275, 0.251)	*p* = 0.93
Correct Rate	56	-0.15	(-0.393, 0.122)	*p* = 0.28
TE2				
Consistency	56	0.02	(-0.241, 0.285)	*p* = 0.86
Endurance	56	-0.23	(-0.468, 0.031)	*p* = 0.08
Accuracy	56	0.15	(-0.117, 0.397)	*p* = 0.27
Speed	56	-0.01	(-0.276, 0.249)	*p* = 0.92
Correct Rate	56	-0.16	(-0.405, 0.108)	*p* = 0.24
TE3				
Consistency	56	-0.09	(-0.347, 0.175)	*p* = 0.50
Endurance	56	0.15	(-0.122, 0.394)	*p* = 0.28
Accuracy*	56	0.34	(0.082, 0.552)	*p* < 0.01
Speed*	56	-0.36	(-0.566, -0.103)	*p* < 0.01
Correct Rate*	56	-0.34	(-0.551, -0.081)	*p* < 0.01

Note: *significancy at $p < 0.05$. Abbreviation: TE1-3, thermal sensation factor 1-3.

4.3 Effect of sleep quality on brain response

4.3.1 Data preparation

The current section aimed to investigate the effect of sleep quality on brain response. Objective and subjective were administrated across two studies (summer and winter study: sub chapter 3.1, page 31; sub chapter 3.2, page 42). In the first step, the data set in the current study was prepared. The data are combination variables in the current investigation, i.e., sleep quality, sleep sensation, brain response, reaction time, and Uchida-Kraepelin test (Figure 4-15).

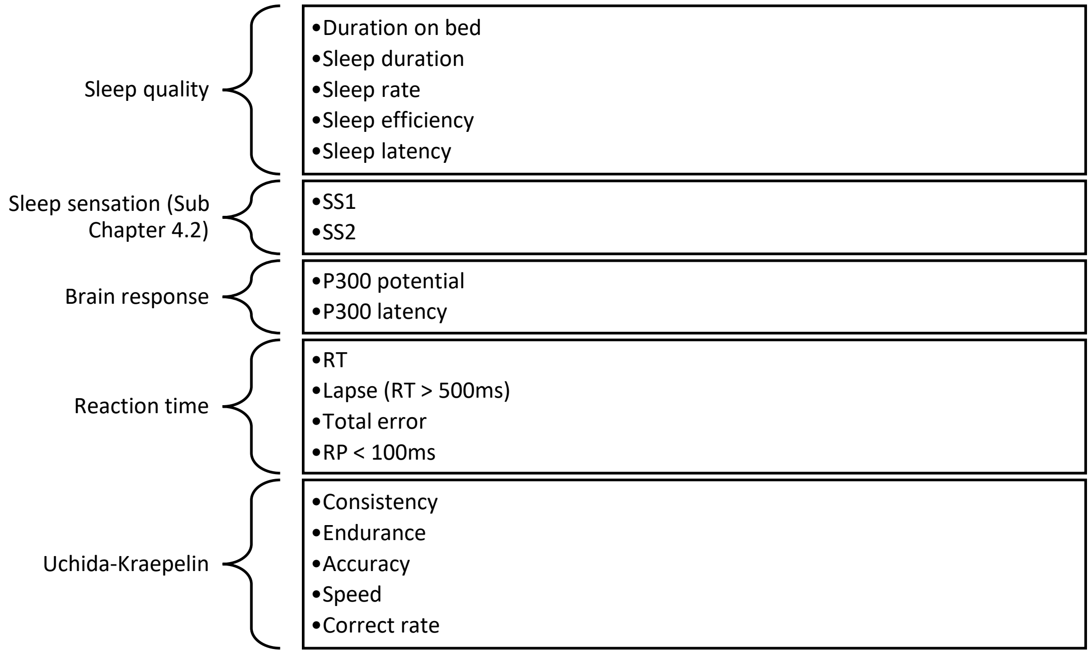


Figure 4-15. Data set list of sleep quality, sleep sensation, and brain response

4.3.2 Correlation between sleep quality on next-day brain response

In the current investigation, two separate investigations on the correlation of sleep quality and brain response, and simplified sleep sensation (investigation on page 77) and brain response were conducted in a similar analysis method as previous investigations (effect of thermal comfort on sleep quality on page 81; effect of thermal comfort on brain response on page 92). Figure 4-16 presents the first investigation conceptual model. In the first investigation, three correlation analyses with sleep quality as a continuous predictor were performed. In the second investigation, as seen in Figure 4-18, three correlation analyses with the simplified sleep sensation were also performed. The significant correlation was presented in the scatterplots and the linear regression trendline at the end of each investigation.

a. Correlation between sleep quality and brain response

As seen in Figure 4-16, the investigation consisted of three correlation approaches. In the first correlation, correlation analysis of sleep quality (duration on bed, sleep minute, sleep rate, sleep efficiency, and sleep latency) and P300 (potential and latency) was performed.

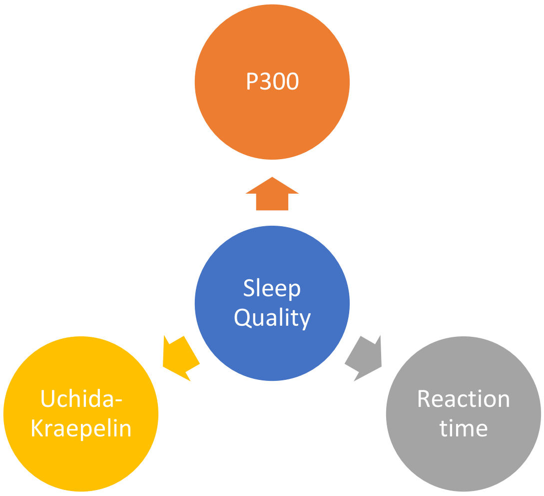


Figure 4-16. Conceptual model of correlation between sleep quality and brain response

Table 4-41. Summary of correlation between sleep quality and P300

Variable	N	Correlation	95% CI	Sig.
Duration				
Potential	113	0.08	(-0.107, 0.261)	$p = 0.40$
Latency*	113	-0.29	(-0.447, -0.106)	$p < 0.01$
Sleep minute				
Potential	113	0.09	(-0.096, 0.270)	$p = 0.34$
Latency*	113	-0.32	(-0.479, -0.147)	$p < 0.01$
Sleep rate				
Potential	113	0.04	(-0.142, 0.226)	$p = 0.65$
Latency*	113	-0.19	(-0.360, -0.003)	$p < 0.05$
Sleep efficiency				
Potential	113	0.07	(-0.116, 0.252)	$p = 0.46$
Latency	113	-0.11	(-0.284, 0.081)	$p = 0.27$
Sleep latency				
Potential	113	0.10	(-0.091, 0.275)	$p = 0.32$
Latency	113	0.08	(-0.111, 0.256)	$p = 0.43$

Note: *significancy at $p < 0.05$.

Table 4-41 shows Pearson correlation analysis between sleep quality and P300. Weak negative correlations between duration on bed and latency, between sleep minute and latency, and between sleep rate and latency (all $p < 0.05$) were observed.

The same continuous predictor (sleep quality) and PVT as a response in the second correlation were performed. The results show that sleep quality did not correlate with any parameter of PVT (reaction time, sleep vote, RT more than 500 ms, number of total errors, and RT < 100 ms, all $p > 0.05$).

Table 4-42. Summary of correlation between sleep quality and PVT

Variable	N	Correlation	95% CI	Sig.
Duration				
Reaction Time	114	-0.04	(-0.220, 0.147)	$p = 0.69$
Sleep vote	114	0.11	(-0.076, 0.288)	$p = 0.25$
Lapses (RT > 500 ms)	114	-0.04	(-0.219, 0.148)	$p = 0.70$
Total Errors	114	-0.03	(-0.214, 0.153)	$p = 0.74$
RT < 100 ms	114	0.02	(-0.169, 0.199)	$p = 0.87$
Sleep minute				
Reaction Time	114	-0.09	(-0.268, 0.097)	$p = 0.35$
Sleep vote	114	0.05	(-0.139, 0.228)	$p = 0.62$
Lapses (RT > 500 ms)	114	-0.09	(-0.271, 0.094)	$p = 0.33$
Total Errors	114	0.05	(-0.138, 0.229)	$p = 0.62$
RT < 100 ms	114	0.06	(-0.121, 0.245)	$p = 0.50$
Sleep rate				
Reaction Time	114	-0.08	(-0.260, 0.105)	$p = 0.40$
Sleep vote	114	-0.07	(-0.249, 0.117)	$p = 0.47$
Lapses (RT > 500 ms)	114	-0.10	(-0.281, 0.083)	$p = 0.28$
Total Errors	114	0.10	(-0.087, 0.277)	$p = 0.30$
RT < 100 ms	114	0.10	(-0.082, 0.282)	$p = 0.27$
Sleep efficiency				
Reaction Time	114	-0.02	(-0.201, 0.167)	$p = 0.85$
Sleep vote	114	-0.02	(-0.205, 0.163)	$p = 0.82$
Lapses (RT > 500 ms)	114	-0.03	(-0.215, 0.152)	$p = 0.73$
Total Errors	114	0.07	(-0.112, 0.254)	$p = 0.44$
RT < 100 ms	114	0.10	(-0.087, 0.277)	$p = 0.30$
Sleep latency				
Reaction Time	114	0.11	(-0.077, 0.286)	$p = 0.25$
Sleep vote	114	0.09	(-0.097, 0.268)	$p = 0.35$
Lapses (RT > 500 ms)	114	0.15	(-0.031, 0.329)	$p = 0.10$
Total Errors	114	-0.04	(-0.221, 0.146)	$p = 0.68$
RT < 100 ms	114	-0.03	(-0.210, 0.157)	$p = 0.77$

Abbreviation: RT, reaction time.

Similarly, in the third correlation, sleep quality as a continuous predictor and Uchida-Kraepelin (U-K) test as a response was performed. A weak positive correlation between sleep minute and speed in completing U-K test was found.

Table 4-43. Summary of correlation between sleep quality and U-K test

Variable	N	Correlation	95% CI	Sig.
Duration				
Consistency	114	0.00	(-0.181, 0.187)	$p = 0.97$
Endurance	114	0.13	(-0.053, 0.309)	$p = 0.16$
Accuracy	114	-0.15	(-0.322, 0.039)	$p = 0.12$
Speed	114	0.17	(-0.018, 0.340)	$p = 0.08$
Correct Rate	114	0.15	(-0.034, 0.325)	$p = 0.11$
Sleep minute				
Consistency	114	-0.01	(-0.194, 0.174)	$p = 0.91$
Endurance	114	0.07	(-0.118, 0.249)	$p = 0.47$
Accuracy	114	-0.11	(-0.286, 0.078)	$p = 0.25$
Speed*	114	0.20	(0.015, 0.369)	$p < 0.05$
Correct Rate	114	0.12	(-0.061, 0.301)	$p = 0.19$
Sleep rate				
Consistency	114	-0.02	(-0.206, 0.162)	$p = 0.81$
Endurance	114	-0.07	(-0.254, 0.112)	$p = 0.44$
Accuracy	114	0.03	(-0.155, 0.213)	$p = 0.75$
Speed	114	0.14	(-0.048, 0.313)	$p = 0.15$
Correct Rate	114	0.00	(-0.185, 0.183)	$p = 0.99$
Sleep efficiency				
Consistency	114	-0.10	(-0.283, 0.081)	$p = 0.27$
Endurance	114	-0.01	(-0.194, 0.174)	$p = 0.91$
Accuracy	114	-0.04	(-0.221, 0.147)	$p = 0.69$
Speed	114	0.06	(-0.130, 0.237)	$p = 0.56$
Correct Rate	114	0.08	(-0.105, 0.260)	$p = 0.40$
Sleep latency				
Consistency	114	-0.10	(-0.280, 0.084)	$p = 0.28$
Endurance	114	0.14	(-0.048, 0.313)	$p = 0.15$
Accuracy	114	-0.09	(-0.267, 0.098)	$p = 0.36$
Speed	114	-0.14	(-0.316, 0.044)	$p = 0.14$
Correct Rate	114	0.08	(-0.101, 0.264)	$p = 0.37$

Note: *significancy at $p < 0.05$.

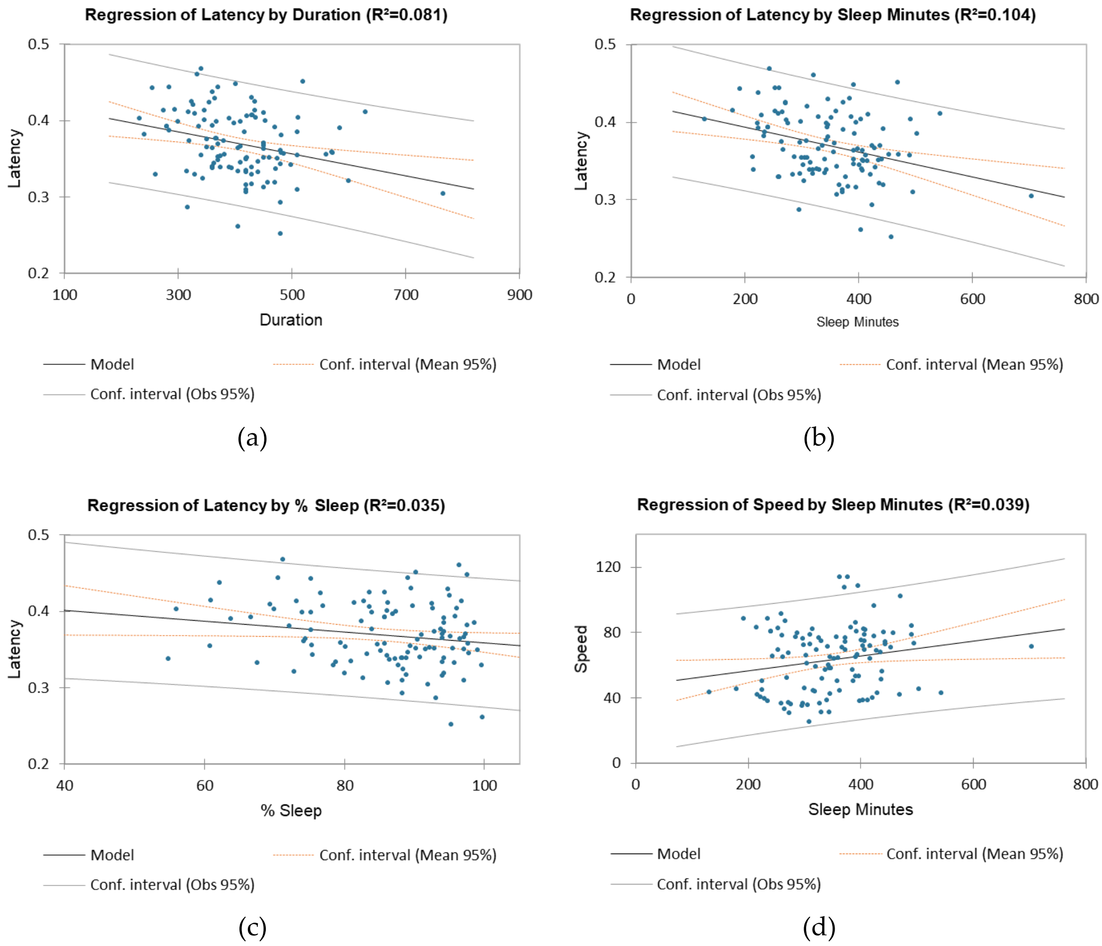


Figure 4-17. Scatterplots and the linear regression trendline of significant correlation of (a) duration on bed and P300 latency, (b) sleep minutes and P300 latency, (c) sleep rate and P300 latency, and (d) sleep minutes and U-K test speed

b. Correlation between sleep sensation and brain response

As seen in Figure 4-18, the investigation consisted of three correlation approach. First, correlation analysis of simplified sleep sensation (SS1 and SS2) and P300 (potential and latency) was performed.

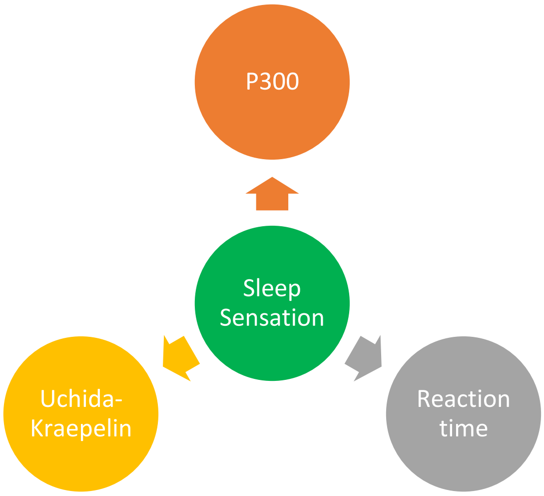


Figure 4-18. Conceptual model of correlation between sleep sensation and brain response

Table 4-44 shows Pearson correlation analysis between sleep sensation and P300. Weak positive correlation between SS1 and latency; and weak negative correlation between SS2 and potential (all $p < 0.05$) were observed.

Table 4-44. Summary of correlation between sleep sensation and P300

Variable		N	Correlation	95% CI	Sig.
SS1					
	Potential	112	-0.10	(-0.282, 0.085)	$p = 0.29$
	Latency*	112	0.26	(0.079, 0.426)	$p < 0.01$
SS2					
	Potential*	112	-0.19	(-0.364, -0.006)	$p < 0.05$
	Latency	112	0.14	(-0.044, 0.320)	$p = 0.13$

Note: *significancy at $p < 0.05$. Abbreviation: SS1-2, sleep sensation in factor 1-2.

In the second correlation, the same continuous predictor (sleep sensation) and PVT as a response was conducted. The results show that SS1 moderately negative correlated with sleep vote ($p < 0.05$).

Table 4-45. Summary of correlation between sleep sensation and PVT

Variable		N	Correlation	95% CI	Sig.
SS1					
	Reaction Time	113	0.10	(-0.087, 0.279)	$p = 0.29$
	Sleep vote*	113	-0.44	(-0.575, -0.275)	$p < 0.01$
	Lapses (RT > 500ms)	113	-0.01	(-0.197, 0.172)	$p = 0.89$
	Total Errors	113	0.10	(-0.083, 0.282)	$p = 0.28$
	RT < 100 ms	113	0.02	(-0.170, 0.200)	$p = 0.87$
SS2					
	Reaction Time	113	-0.06	(-0.243, 0.125)	$p = 0.52$
	Sleep vote	113	-0.10	(-0.277, 0.089)	$p = 0.31$
	Lapses (RT > 500ms)	113	-0.12	(-0.302, 0.062)	$p = 0.19$
	Total Errors	113	-0.02	(-0.205, 0.164)	$p = 0.83$
	RT < 100 ms	113	0.04	(-0.147, 0.222)	$p = 0.68$

Note: *significancy at $p < 0.05$. Abbreviation: SS1-2, sleep sensation in factor 1-2.

Similarly, in the third correlation, sleep sensation as a continuous predictor and Uchida-Kraepelin (U-K) test as a response was performed. There were a weak negative correlation between SS1 and endurance of U-K test; moderate negative correlation between SS1 and speed; weak positive correlation between SS2 and consistency; weak positive correlation between SS2 and accuracy, and weak negative correlation between SS2 and correct rate.

Table 4-46. Summary of correlation between sleep sensation and U-K test

Variable		N	Correlation	95% CI	*p*-value
SS1					
	Consistency	113	-0.02	(-0.202, 0.168)	$p = 0.85$
	Endurance*	113	-0.31	(-0.464, -0.128)	$p < 0.01$
	Accuracy	113	0.16	(-0.024, 0.336)	$p = 0.09$
	Speed*	113	-0.46	(-0.595, -0.302)	$p < 0.01$
	Correct Rate	113	-0.18	(-0.349, 0.009)	$p = 0.06$
SS2					
	Consistency*	113	0.22	(0.038, 0.390)	$p < 0.05$
	Endurance	113	0.12	(-0.065, 0.300)	$p = 0.20$
	Accuracy*	113	0.20	(0.012, 0.368)	$p < 0.05$
	Speed	113	-0.02	(-0.201, 0.168)	$p = 0.86$
	Correct Rate*	113	-0.22	(-0.385, -0.032)	$p < 0.05$

Note: *significancy at $p < 0.05$. Abbreviation: SS1-2, sleep sensation in factor 1-2.

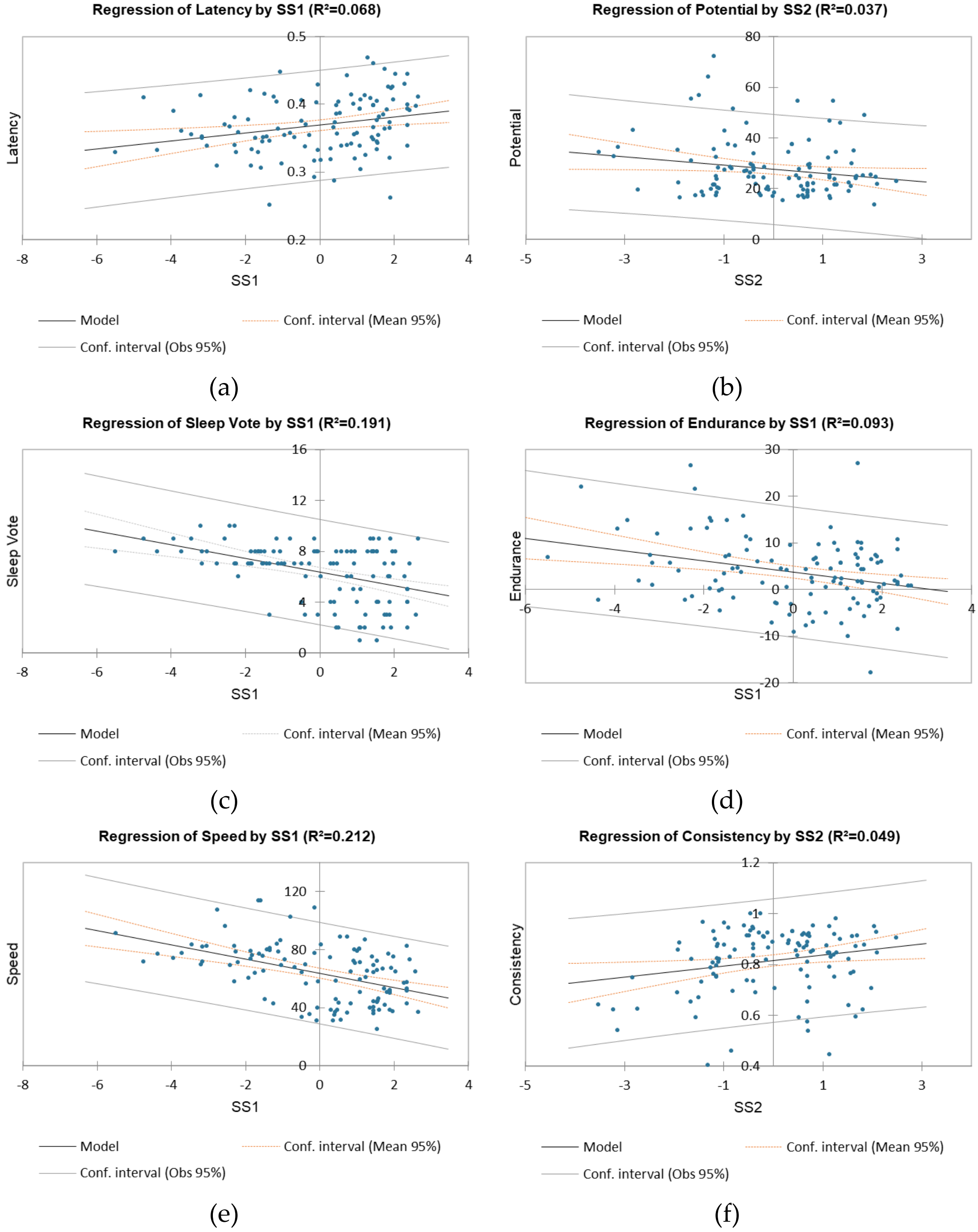
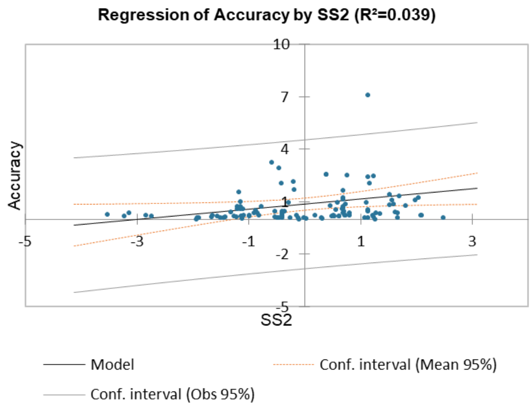
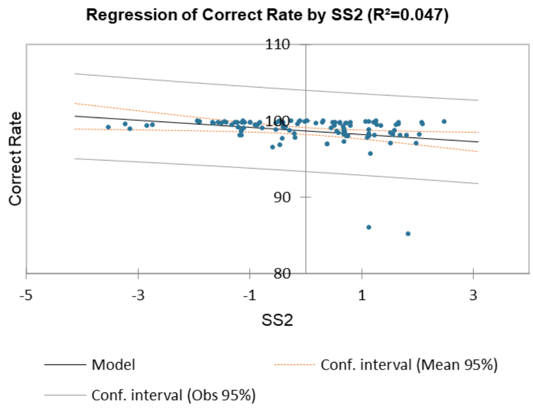


Figure 4-19. Scatterplots and the linear regression trendline of significant correlation of (a) SS1 and P300 latency, (b) SS2 and P300 potential, (c) SS1 and sleep vote of PVT, (d) SS1 and endurance, (e) SS1 and speed, (f) SS2 and consistency, (g) SS2 and accuracy, and (h) SS2 and correct rate of U-K test



(g)



(h)

Figure 4-19. Scatterplots and the linear regression trendline of significant correlation of (a) SS1 and P300 latency, (b) SS2 and P300 potential, (c) SS1 and sleep vote of PVT, (d) SS1 and endurance, (e) SS1 and speed, (f) SS2 and consistency, (g) SS2 and accuracy, and (h) SS2 and correct rate of U-K test (continued)

4.4 Summary

Three main investigations of effect of thermal comfort on sleep quality and brain response were presented. The objectives of current study were 1) to simplify the sensation variables in the sleep survey and brain response experiment, 2) to investigate the correlation between simplified sensation variables and sleep quality, and brain response, and 3) to investigate the correlation between sleep quality and brain response.

Principal component analysis showed that the overall variability cumulative of the new variables are not less than 50%: eight variables of thermal sensation questionnaire in sleep survey can be simplified with two new variables (TS1 and TS2, 59% of overall variability), seven variables of sleep sensation questionnaire in sleep survey can be simplified with two new variables (SS1 and SS2, 72% of overall variability), and seven variables of thermal sensation questionnaire in brain response experiment can be simplified with two new variables (TE1 and TE2, 77% of overall variability). Moreover, in the agglomerative hierarchical clustering, the thermal sensation in sleep survey (bedroom thermal sensation) grouped into four clusters. Three of four cluster indicated the close of thermal sensation between Indonesian and Japan during summer and winter. Moreover, in the sleep sensation in sleep survey (sleep sensation), the cluster is grouped into two clusters. Each cluster is dominated by different nationality. In the thermal sensation in brain response experiment (experimental room thermal sensation), the cluster is grouped into two clusters that one cluster is dominated by thermal sensation in hot condition from both nationalities.

Although the cluster indicated the close of bedroom thermal sensation, the Pearson correlation analysis reported the different effects of thermal sensation on sleep survey among groups. TS1 was associated with sleep rate and latency in the Indonesian group. Furthermore, TS2 was not associated with any measure of sleep quality. TS1 was not associated with any sleep quality variables in the Japanese group. Additionally, TS2 was found to be associated with sleep rate, sleep efficiency, and SS1.

Moreover, correlation analysis revealed a different effect of thermal sensation on brain response across groups. TE1 was not correlated with any brain response variable in the Indonesian group. Additionally, TE2 was associated with P300 latency. TE1 was associated with P300 potential in the Japanese group, whereas TE2 was associated with P300 potential and latency.

To find out the effect of sleep quality on the next-day brain response, the correlation analysis between sleep quality (objective and sensation) and next-day brain response of all participants was analyzed. The duration on bed, sleep minute, and sleep rate were correlated with P300 latency. In the sleep sensation, SS1 was correlated with P300 latency, sleep vote, endurance, and speed of U-K test. Furthermore, SS2 was correlated with P300 potential, consistency, accuracy, and correct rate of U-K test. A higher sensitivity of Japanese group can be seen by examining the relationship between the two thermal sensations (TE1 and TE2).

It concludes that each nationality (Japanese or Indonesian) has its own adaptive thermal responses. Due to differences in thermal response, the thermal sensation also differed between both nationalities. In both seasons, Japanese group demonstrated a greater sensitivity to their indoor environment than Indonesian group.

Chapter 5 Concluding Remarks

Conclusions

This chapter presents main findings, the overall conclusions. The conclusion organizes summary of the two chapter above (Chapter 3 and Chapter 4) in line to objectives of this study. For a better understanding of the conclusions, a schematic conclusion is illustrated in Figure 5-1.

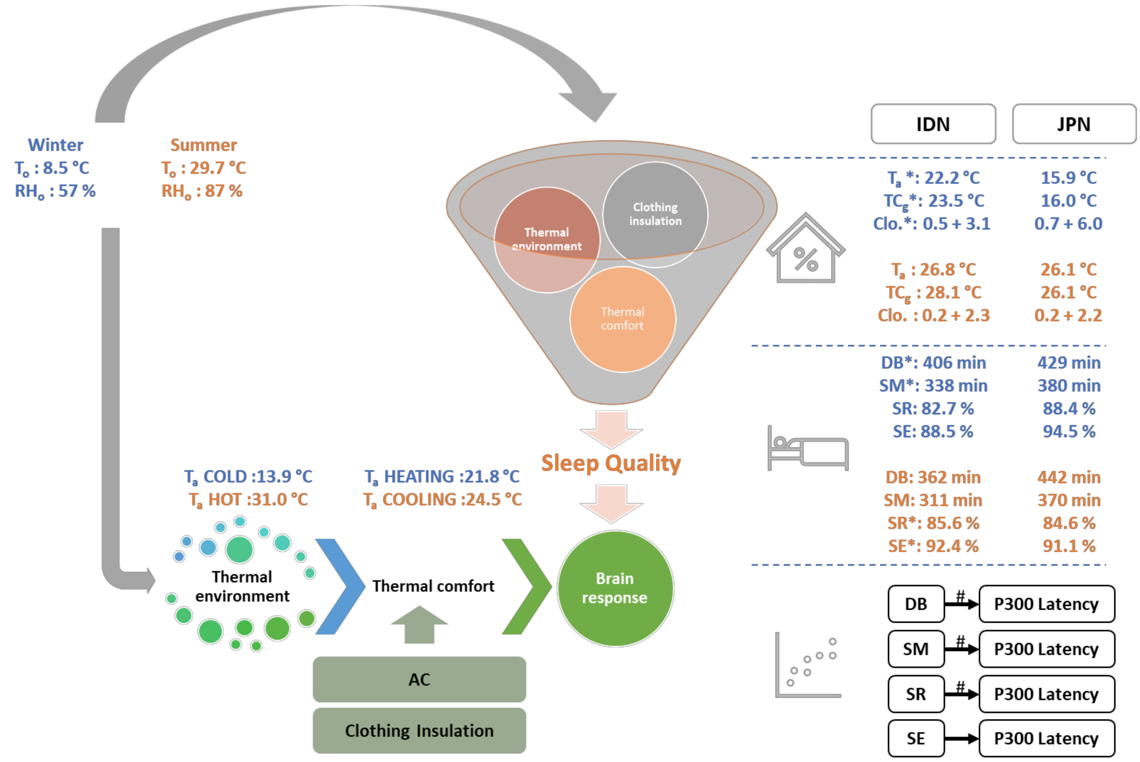


Figure 5-1. Schematic of conclusions. Note: *significantly different at $p < 0.05$; #significantly correlated at $p < 0.05$. Abbreviation: IDN, Indonesian; JPN, Japanese; DB, duration on bed; SM, sleep minutes; SR, sleep rate; SE, sleep efficiency

In the Chapter 3, the results and discussion of investigation on sleep quality and brain response of Indonesian and Japanese group in summer and winter season were presented. In the summer sleep survey, the average bedroom temperature and relative humidity of Indonesian and Japanese groups were comparable during the summer. The current study also discovered that Indonesian group had a higher comfort temperature than Japanese group and previous studies conducted in Japan. The Griffiths' method predicted the summer means of comfort temperature for Indonesian and Japanese were 28.1 °C and 26.1 °C. Moreover, Indonesian group's bedtime (duration on bed) and sleep minute were comparable to those of Japanese students during the summer. However, the sleep rate of Indonesian group was lower than that of Japanese group. In the winter sleep survey, the bedroom temperature of Indonesian group was significantly warmer than Japanese group. In winter, majority of Indonesian group prefer "warm" in contrast to the preference of Japanese who mostly prefer "neutral". According to the thermal comfort survey, Indonesian had lower value than Japanese in winter. Moreover, there was a significant difference in the wake-up time of Japanese group in the sleep quality study. Actigraphy measurements also indicated that the Indonesian group' waking time coincided with sunrise. Japanese group, on the other hand, awoke later than Indonesian group. In the comfort temperature, the Griffiths' method indicated that the winter means of comfort temperature for Indonesian and Japanese were 23.5 °C and 16.0 °C.

Still in the same chapter, in the brain response experiment, the current study showed that there were no differences in P300 potential and latency of participants (Indonesian and Japanese group) between cooling and hot conditions. Moreover, after performing U-K test during comfort condition (cooling during summer), the RT and number of lapse (RT > 500ms) of Indonesian group showed delayed and increased significantly, respectively. Moreover, in the brain response experiment, the current study showed no differences in P300 potential, P300 latency, and RT of Indonesian and Japanese participants between cold and heating conditions in the winter. After performing the U–K test at heating condition, the RT of Indonesian group showed a significant delay.

To sum up conclusion from Chapter 3, a thermal comfort survey and sleep quality of Indonesian and Japanese group of Toyohashi city (Chubu area of Japan) was conducted during summer and winter. Indonesian group' duration on bed and sleep minutes were shorter than Japanese group. Indonesian group woke up to follow the sunrise time. Although Indonesian group had shorter sleep minutes, the sleep rate was not different from Japanese group, and sleep sensation was better than Japanese group. The result showed that culture or religion has a significant contribution to encourage the sleep duration of Indonesian participants. The seasonal effect was found in the bedroom temperature and relative humidity. Indonesian group' average bedroom temperature was significantly higher in the winter than Japanese group' bedroom temperature. Moreover, indoor relative humidity of Indonesian group was significantly lower than Japanese group. Even though different, both of relative humidity in ASHRAE recommendation (30-60%). The significant difference in indoor air temperature and relative humidity between Indonesian and Japanese group caused by the difference of adaptation action during winter. Indonesian group set higher air temperature and wore clothing with lower clothing insulation than Japanese group. Each season's mean comfort temperature calculated using the Griffiths' method was 28.1 °C for Indonesian and 26.1 °C for Japanese in summer. In the winter, the comfort temperature was 23.5 °C for Indonesian and 16.0 °C for Japanese. The comfort temperature of Indonesian group is surprisingly high.

An investigation on P300 and reaction time of Indonesian and Japanese group was conducted in natural (hot in summer and cold in winter) and comfort condition (cooling and heating). In conclusion, the temperature under contrasting conditions (hot, cooling, cold, and heating) did not have an effect or influence P300 potential and latency in Indonesian and Japanese group because the ambient temperature was not severe in the present study. Moreover, the Uchida Kraepelin test in the present study did not require greater attention. However, in the comfort condition (cooling and heating), its effect on reaction time was more pronounced than in the natural condition, particularly in the Indonesian group. With a shorter sleep duration during summer, P300 potential of Indonesian group was lower in hot condition (summer), and P300 latency of Indonesian group was longer in hot and cooling condition (summer) than Japanese group. Moreover, in everyday life during winter, Indonesian group might experience more discomfort due to cold air. Consequently, Indonesian group began to relax in heating condition, promoting a delayed reaction time and a lower correct rate in the Uchida Kraepelin is lower. Moreover, it is possible that energy consumption will increase in order to cope with a higher neutral temperature of the Indonesian group during winter. According to the findings presented here, brain response (P300) is related to cognitive response (Uchida Kraepelin test and reaction time of PVT). Additionally, skin temperature and thermal sensation influence the cognitive response. P300, on the other hand, is influenced by previous night's sleep, fatigue, and physical condition (present environment).

In Chapter 4, principal component analysis, agglomerative hierarchical clustering, and Pearson correlation analysis of the effect of thermal comfort on sleep quality, brain response of Indonesian and Japanese group, and the effect of sleep quality on brain response were performed. Principal component analysis showed following results: eight variables of thermal sensation questionnaire in sleep survey can be simplified with two new variables (TS1 and TS2), seven variables of sleep sensation questionnaire in sleep survey can be simplified with two new variables (SS1 and SS2), and seven variables of thermal sensation questionnaire in brain response experiment can be simplified with two new variables (TE1 and TE2).

Pearson correlation analysis reported different correlation among groups. In sleep quality of Indonesian group, TS1 was correlated with sleep rate and sleep latency and TS2 was correlated with sleep rate, sleep efficiency and SS1. In brain response of Indonesian group, TE2 was correlated P300 latency. Moreover, In Japanese group, TE1 was correlated with P300 potential and TE2 was correlated P300 potential and latency. In the correlation analysis between sleep quality sensation and brain response, duration on bed, sleep minute, and sleep rate were correlated with P300 latency. In the sleep sensation, SS1 was correlated with P300 latency, sleep vote, endurance, and speed of U-K test, SS2 was correlated with P300 potential, consistency, accuracy, and correct rate of U-K test.

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Appendix

Appendix A. Thermal sensation questionnaire in the sleep survey

Thermal Sensation questionnaire

date and time: / :

This questionnaire refers to your present sensation or feeling.

Please try and answer every questions.

Name: Age: Yrs. Sex: Male / Female

1. Thermal sensation: How do you feel right now? (circle each chosen word)

Very cold	Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot	Very hot

2. Humidity sensation: How do you feel right now? (circle a chosen word)

Extremely humid	Humid	Slightly humid	Neutral	Slightly dry	Dry	Extremely dry

3. Airflow sensation: How do you feel right now? (circle a chosen word)

Not feel	Feel slightly	Feel	Feel too much

4. Sweating sensation: How do you feel right now? (circle a chosen word)

Not feel	Feel slightly	Feel	Feel too much

5. Thermal Comfort sensation: How do you feel right now? (circle each chosen word)

Very uncomfortable	Uncomfortable	Slightly uncomfortable	Neutral	Slightly comfortable	Comfortable	Very comfortable

6. How do you judge this indoor environment on a personal level? (circle a chosen word)

Acceptable	Unacceptable

7. How would you prefer to be now? (circle a chosen word)

Warmer	No change	Cooler

8. How satisfied are you with this environment in the bedroom? (circle a chosen word)

Unsatisfied	Slightly unsatisfied	Neutral	Slightly satisfied	satisfied

Appendix B. Physical condition questionnaire in the sleep survey

Physical Condition questionnaire

date and time: ________ / ________ : ________

This questionnaire refers to your Today's conditions.

Please try and answer every questions.

Name: ____________________ Age: ____ Yrs. Sex: Male / Female

1. What time did you wake up this morning? ____ : ____

2. Did you take a daytime nap today? YES / NO

3. What time did you have a dinner? ____ : ____

4. What time did you take a bath or shower? shower / bath ____ : ____

5. Did you engage in an intense physical activity or work today? YES / NO

6. How is your current physical condition compared to your usual condition?

Excellent	Good	As usual	Not Good	Bad

7. How is your current sleepiness in comparison to your normal condition?

Very Sleepy	Slightly sleepy	As usual	Clear-Headed	Completely Clear-Headed

8. How is your mental feeling in comparison to your usual condition?

Excellent	Good	As usual	Not Good	Bad

9. Are you more anxious or less anxious today compared to usual?

More	A little more	As usual	A little less	Less

10. What kind of clothes did you wear when you sleep?

1. Material : Cotton / Nylon / Silk / Others ( )

2. Sleeves: Short / Long **3. Pants:** Short / Long / Skirt & Dress

11. What kind of Comforter (ex: Blankets) did you use when you sleep?

1. Material : Cotton / Nylon / Silk / Others ( )

2. Thickness: Very Thick / Thick / Thin / Very Thin

12. What kind of air conditioning did you use when you sleep? Air Conditioner/ Fan/ Window Opened/ Nothing

Appendix C. St. Mary's Hospital sleep sensation questionnaire for last night in the sleep survey

Sleep questionnaire date and time: / :

This questionnaire refers to your last night's sleep.
Please try and answer every questions.

Name: Age: Yrs. Sex: Male / Female

At what time did you:

1. Settle down for the night? :

2. Fall asleep last night? :

3. Finally wake this morning? :

4. Get up this morning? :

5. Was your sleep: (circle a chosen word)

Very light	Light	Fairly light	Light average	Deep average	Fairly deep	Deep	Very deep

6. How many times did you wake up? (circle a chosen word)

Not at all	Once	Twice	Three times	Four times	Five times	Six times	More than six times

7. How well did you sleep last night? (circle a chosen word)

Very badly	Badly	Fairly badly	Fairly well	Well	Very well

If not well, what was the trouble? (e.g., restless, etc.)

1 ____________________

2 ____________________

3 ____________________

8. How clear-headed did you feel after getting up this morning? (circle a chosen word)

Still very drowsy indeed	Still moderately drowsy	Still slightly drowsy	Fairly clear-headed	Alert	Very alert

9. How satisfied were you with last night's sleep? (circle a chosen word)

Very unsatisfied	Moderately unsatisfied	Slightly unsatisfied	Fairly satisfied	Completely satisfied

10. Were you troubles by waking early and being unable to get off to sleep again?

NO / YES

11. How much difficulty did you have in getting off to sleep last night? (circle a chosen word)

None or very little	Some	A lot	Extreme difficulty

12. How long did it take you to fall asleep last night? :

Appendix D. Thermal sensation questionnaire in brain response experiment

Name :________________________
Sex : Male/ Female
Age :______ years old
Date :________________________

Condition : Hot / Cooling / Cold / Heating
Room : A / B

Ⅰ Thermal Sensation

	Very Cold	Cold	Cool	Slightly Cool	Neither	Slightly Warm	Warm	Hot	Very Hot
Whole Body									
Head									
Upper Body									
Hand									
Lower Body									
Foot									
	−4	−3	−2	−1	0	1	2	3	4

Ⅱ Thermal Comfort

Very Uncomfortable	Uncomfortable	Slightly Uncomfortable	Slightly Comfortable	Comfortable	Very Comfortable
−3	−2	−1	1	2	3

Ⅲ Sweaty

Not Sweaty	Slightly Sweaty	Sweaty	Quite Sweaty	Very Sweaty
0	1	2	3	4

Ⅳ Dryness

	Dry	Slightly Dry	Neither	Slightly Wet	Wet
Room					
Body					
Eye					
	−2	−1	0	1	2

Ⅴ Exercise intensity

1 Not Tired
2 Very Easy
3
4 Quite Easy
5
6 Easy
7
8 Slightly Hard
9
10 Hard
11
12 Quite Hard
13
14 Very Hard
15 Exhaustion

Ⅵ Thermal Acceptable

Unacceptable	Slightly Unacceptable	Slightly Acceptable	Acceptable
1	2	3	4

Ⅶ Thermal Preference

Cooler	Neither	Warmer
−1	0	1

Ⅷ Clothing

	Want to decrease… Quite	Slightly	Neither	Want to increase… Slightly	Quite
Whole Body					
Upper Body					
Lower Body					
	−2	−1	0	1	2

Ⅸ Overall Comfort

Very Uncomfortable	Uncomfortable	Slightly Uncomfortable	Neither	Slightly Comfortable	Comfortable	Very Comfortable
−3	−2	−1	0	1	2	3

Appendix E. Swedish Occupational Fatigue Inventory (SOFI) questionnaire in brain response experiment

Swedish Occupational Fatigue Inventory (SOFI) Questionnaire

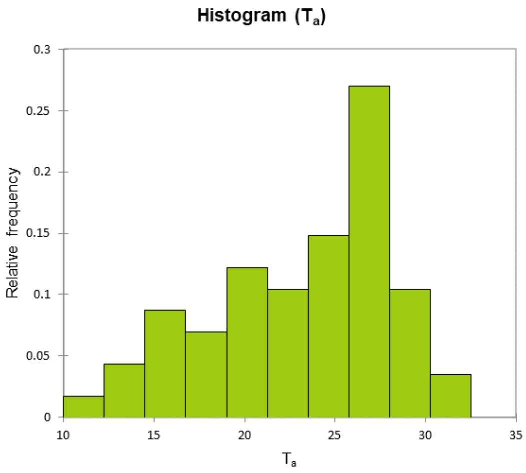
A. Identity

Name	:_________________________	Condition	: Hot / Cooling / Cold / Heating
Sex	: Male/ Female	Room	: A / B
Age	:______ years old		
Date	:_________________________		

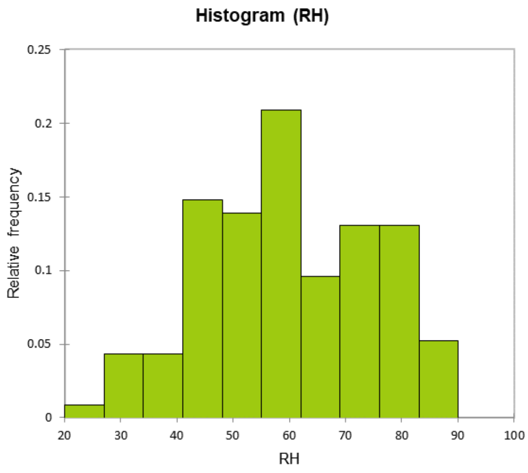
B. Fatigue Indicators

No	Indicators	Not at All 0	1	2	3	4	5	6	7	8	9	Extremely 10
	Lack of Energy											
1	Overworked	0	1	2	3	4	5	6	7	8	9	10
2	Spent	0	1	2	3	4	5	6	7	8	9	10
3	Drained	0	1	2	3	4	5	6	7	8	9	10
4	Worn Out	0	1	2	3	4	5	6	7	8	9	10
5	Exhausted	0	1	2	3	4	5	6	7	8	9	10
	Physical Exertion											
1	Breathing Heavily	0	1	2	3	4	5	6	7	8	9	10
2	Out of Breath	0	1	2	3	4	5	6	7	8	9	10
3	Taste of Blood	0	1	2	3	4	5	6	7	8	9	10
4	Sweaty	0	1	2	3	4	5	6	7	8	9	10
5	Palpitations	0	1	2	3	4	5	6	7	8	9	10
	Physical Discomfort											
1	Aching	0	1	2	3	4	5	6	7	8	9	10
2	Hurting	0	1	2	3	4	5	6	7	8	9	10
3	Stiff Joints	0	1	2	3	4	5	6	7	8	9	10
4	Numbness	0	1	2	3	4	5	6	7	8	9	10
5	Tense Muscles	0	1	2	3	4	5	6	7	8	9	10
	Lack of Motivation											
1	Uninterested	0	1	2	3	4	5	6	7	8	9	10
2	Passive	0	1	2	3	4	5	6	7	8	9	10
3	Indifferent	0	1	2	3	4	5	6	7	8	9	10
4	Lack of Initiative	0	1	2	3	4	5	6	7	8	9	10
5	Listless	0	1	2	3	4	5	6	7	8	9	10
	Sleepiness											
1	Sleepy	0	1	2	3	4	5	6	7	8	9	10
2	Yawns	0	1	2	3	4	5	6	7	8	9	10
3	Drowsy	0	1	2	3	4	5	6	7	8	9	10
4	Fall Asleep	0	1	2	3	4	5	6	7	8	9	10
5	Lazy	0	1	2	3	4	5	6	7	8	9	10

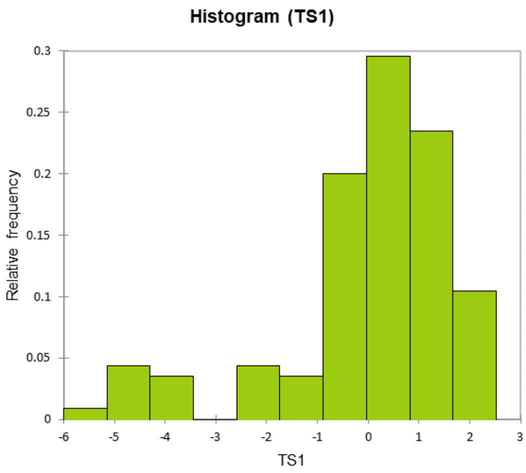
Appendix F. Histogram of (a) Ta, (b) RH, (c) TS1, (d) TS2, and (e) TS3 in the effect of thermal comfort on sleep quality study



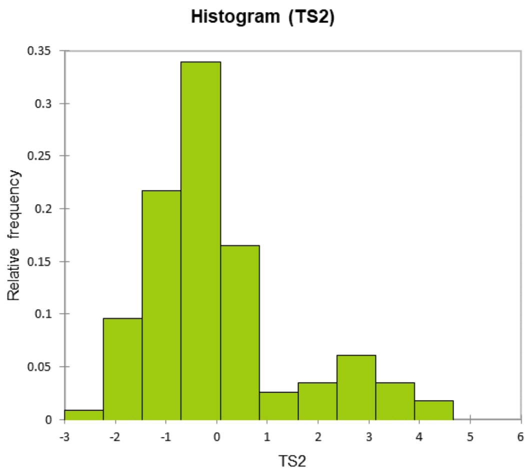
(a)



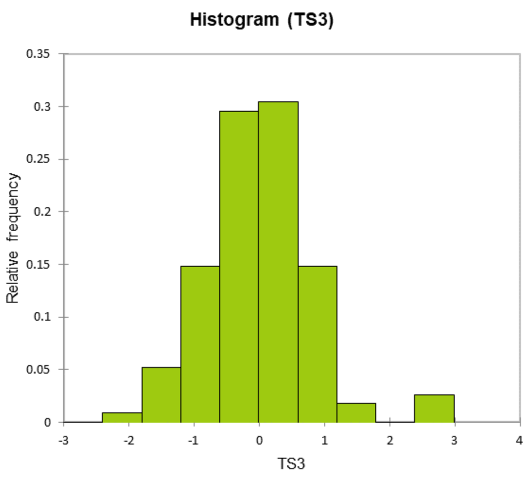
(b)



(c)

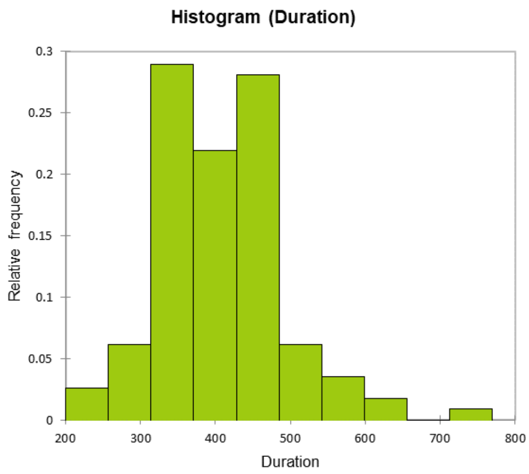


(d)

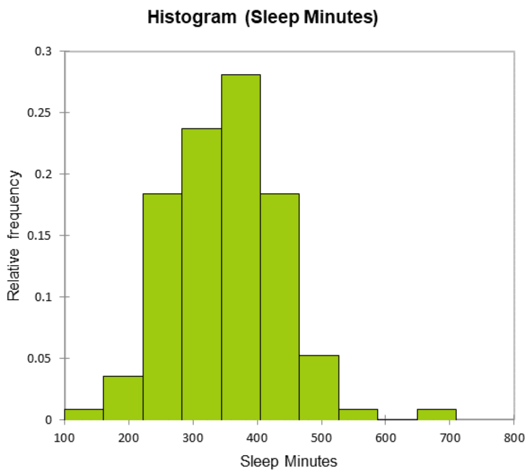


(e)

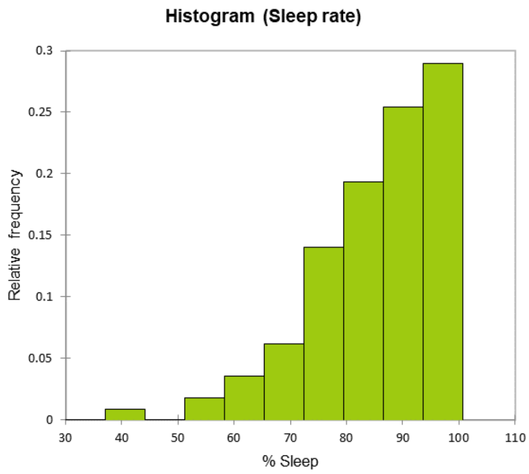
Appendix G. Histogram of (a) duration, (b) sleep minutes, (c) sleep rate, (d) sleep efficiency, (e) sleep latency, (f) SS1, and (g) SS2 in the effect of thermal comfort on sleep quality



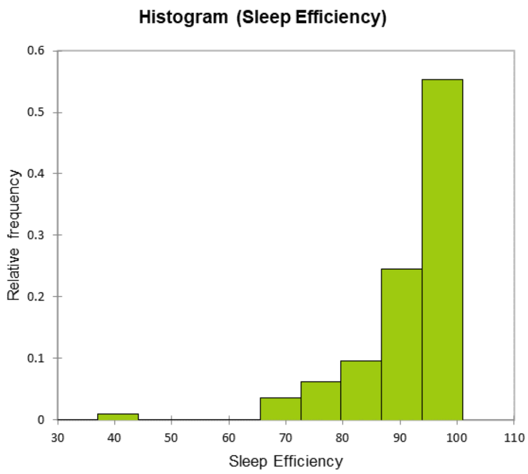
(a)



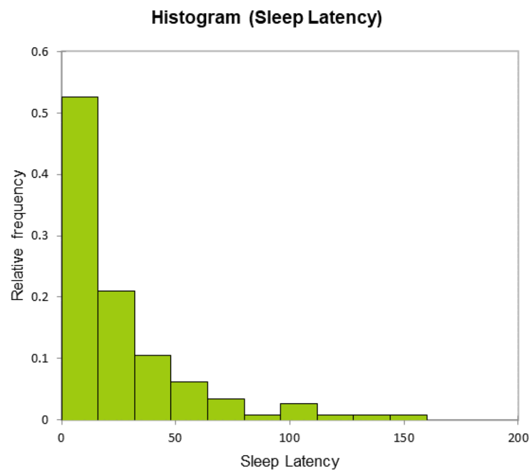
(b)



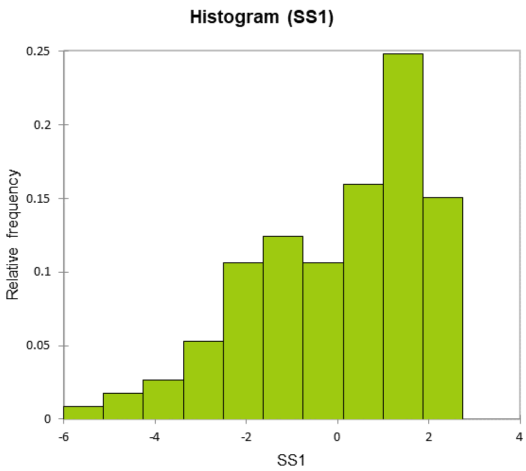
(c)



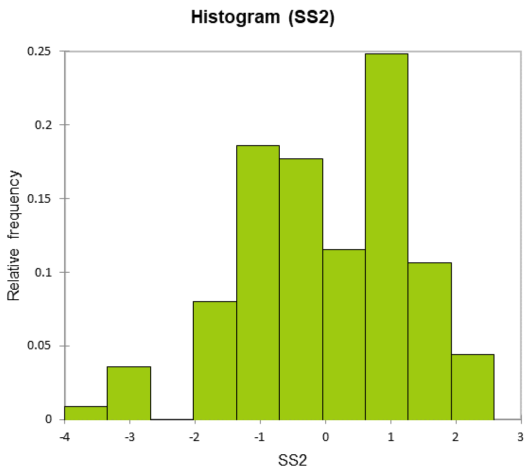
(d)


Histogram (Sleep Latency)
Relative frequency
Sleep Latency
0
0.1
0.2
0.3
0.4
0.5
0.6
0
50
100
150
200

(e)

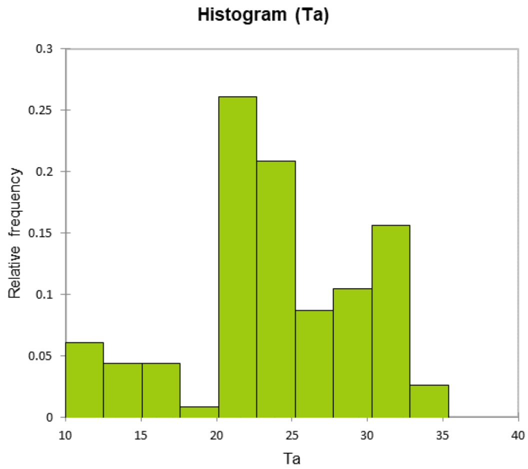

Histogram (SS1)
Relative frequency
SS1
0
0.05
0.1
0.15
0.2
0.25
-6
-4
-2
0
2
4

(f)

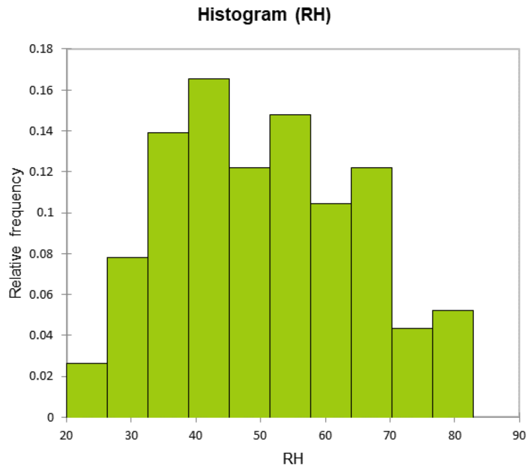

Histogram (SS2)
Relative frequency
SS2
0
0.05
0.1
0.15
0.2
0.25
-4
-3
-2
-1
0
1
2
3

(g)

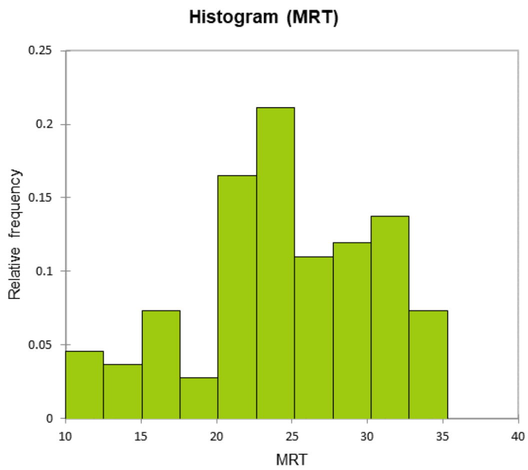
Appendix H. Histogram of (a) Ta, (b) RH, (c) MRT, (d) MST, (e) TE1, (f) TE2, and TE3 in the effect of thermal comfort on brain response study



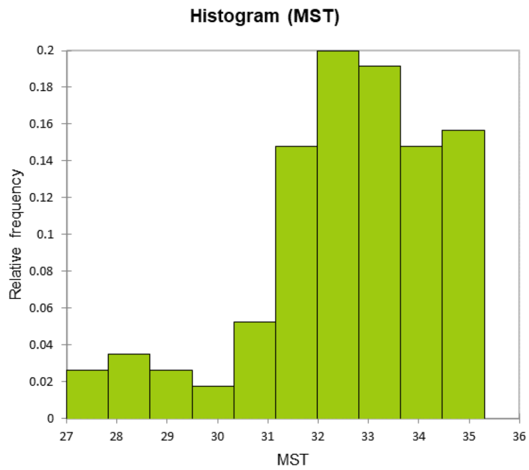
(a)



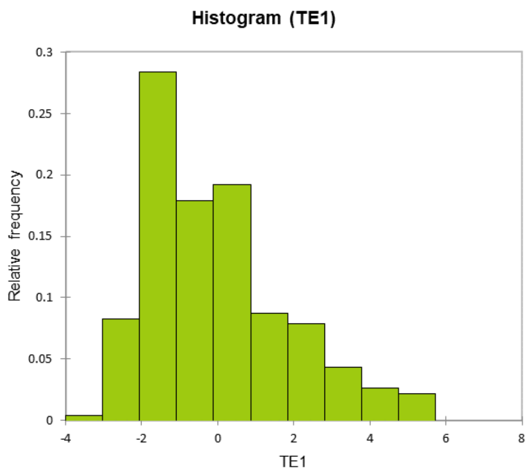
(b)



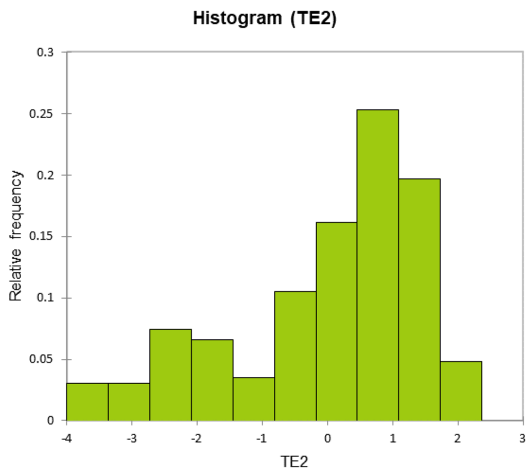
(c)



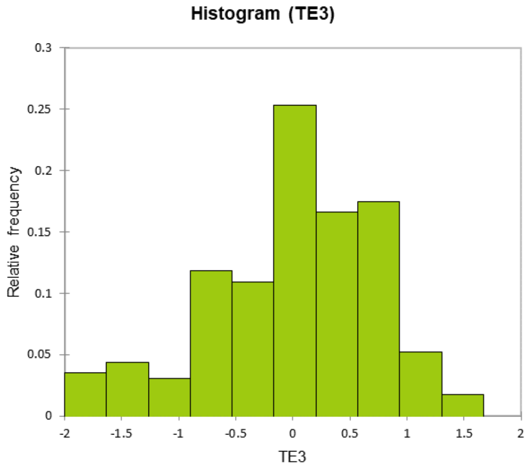
(d)



(e)

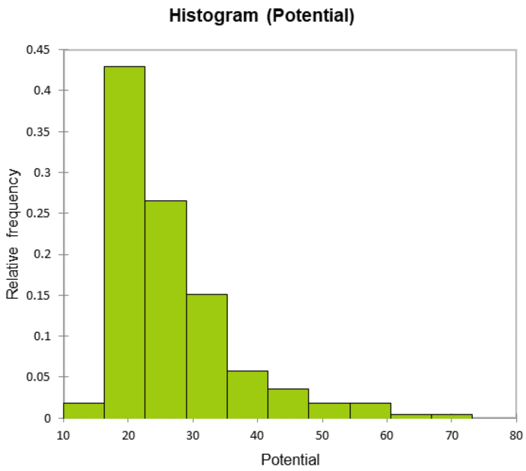


(f)

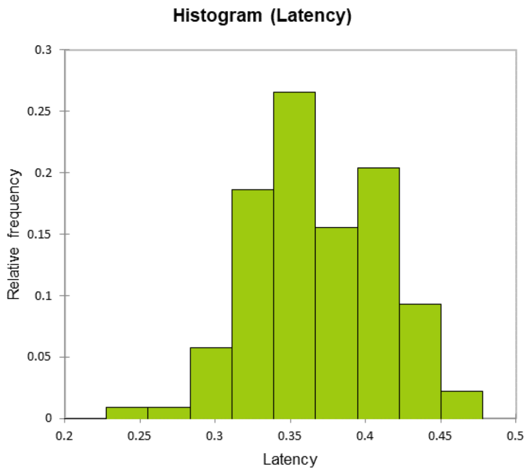

Histogram (TE3)
Relative frequency
0.3
0.25
0.2
0.15
0.1
0.05
0
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
TE3

(g)

Appendix I. Histogram of P300 potential and latency in the effect of thermal comfort on brain response study

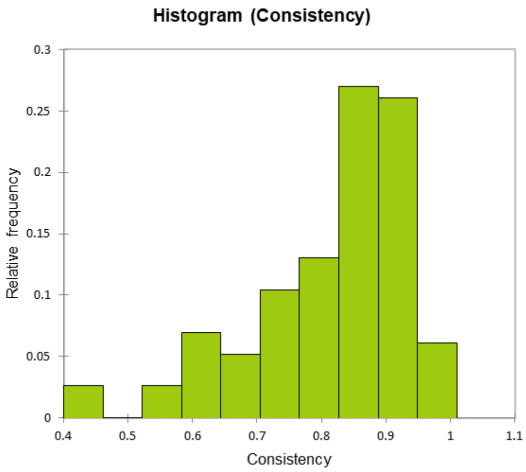


(a)

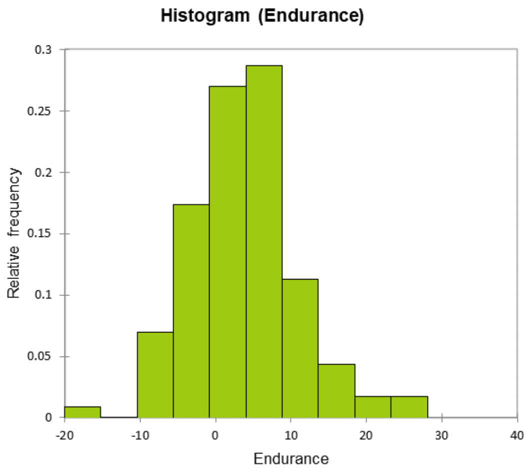


(b)

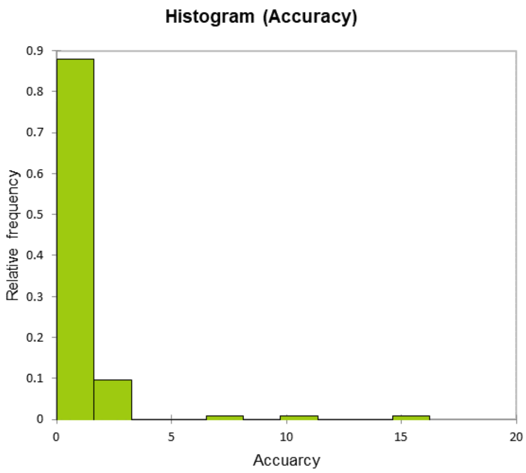
Appendix J. Histogram of Uchida-Kraepelin (a) consistency, (b) endurance, (c) accuracy, (d) speed, and (e) correct rate in the effect of thermal comfort on brain response study



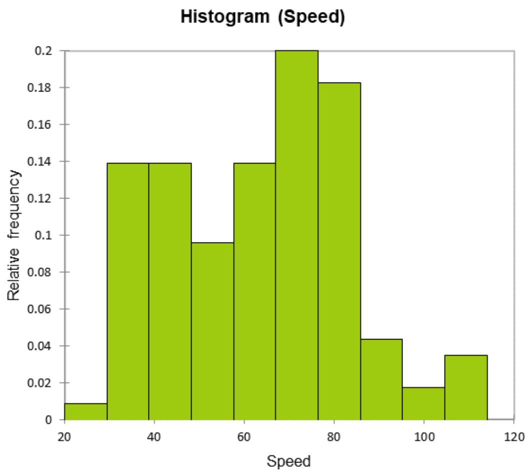
(a)



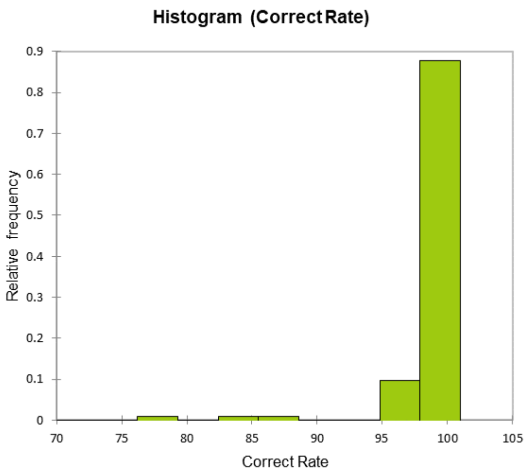
(b)



(c)



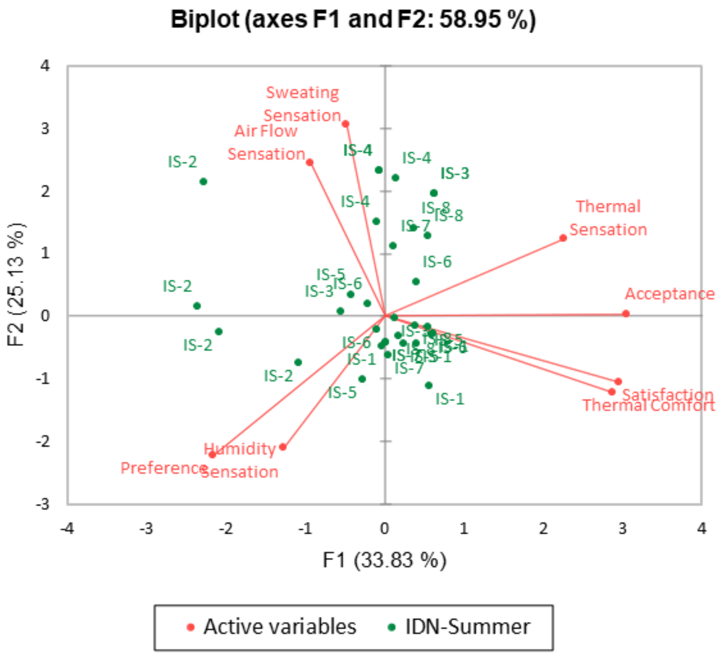
(d)



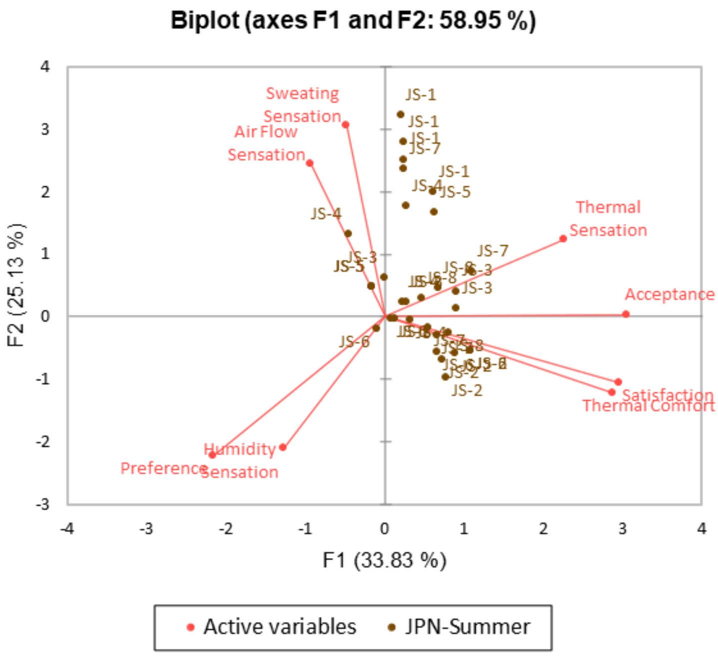
(e)

Appendix K. Bedroom thermal sensation biplot of (a) Indonesian during summer, (b) Japanese during summer, (c) Indonesian during winter, and (d) Japanese during winter in the correlation circle

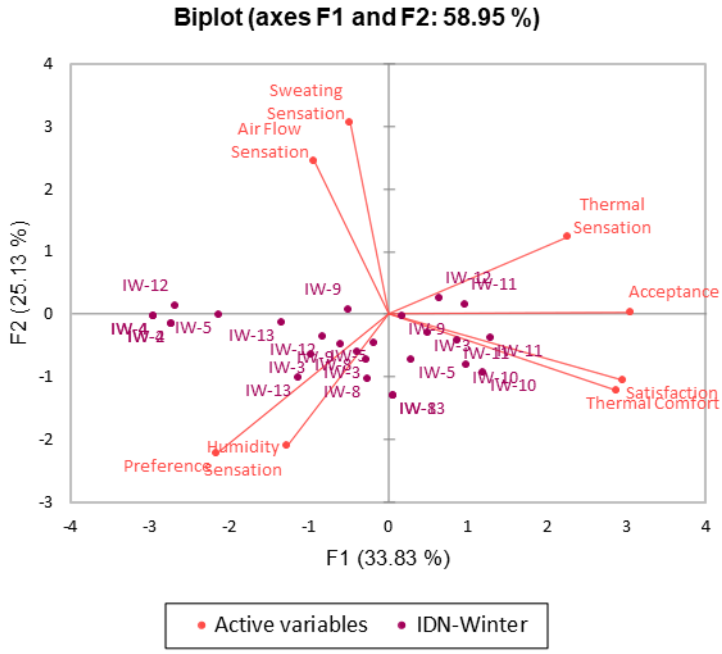
(a)



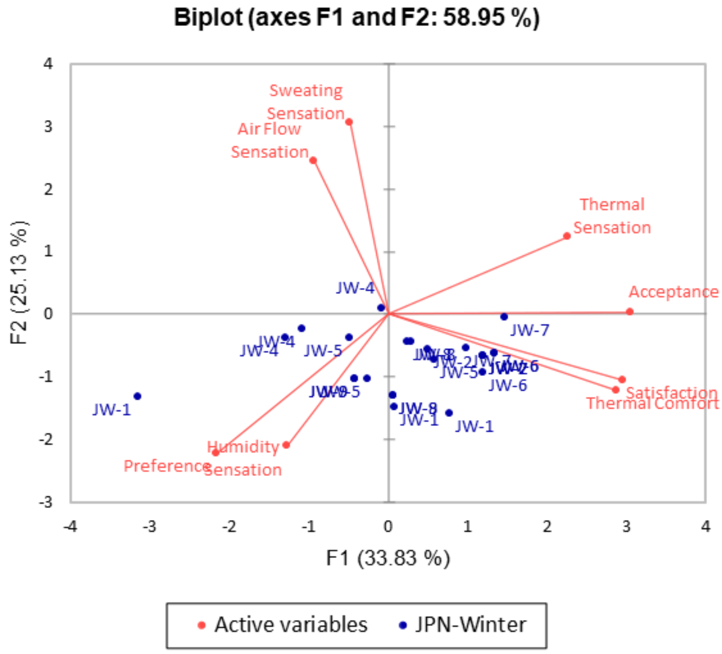
(b)



(c)

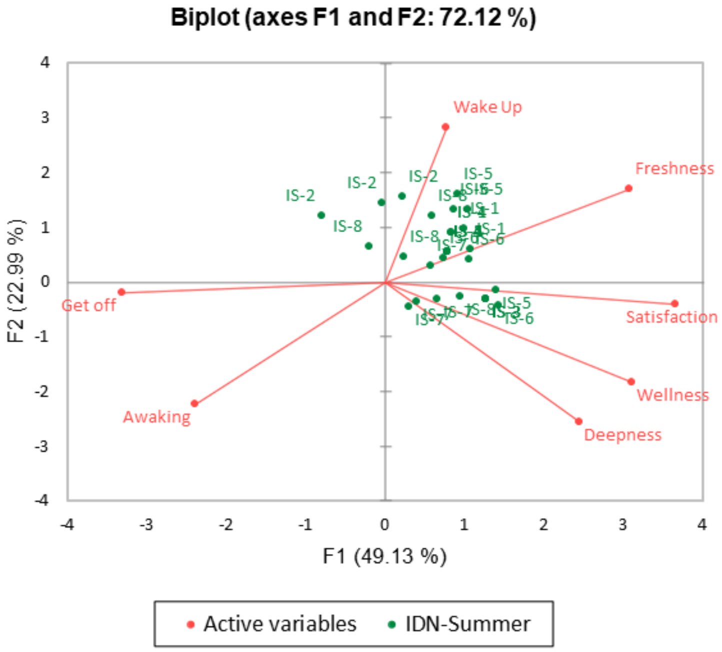


(d)

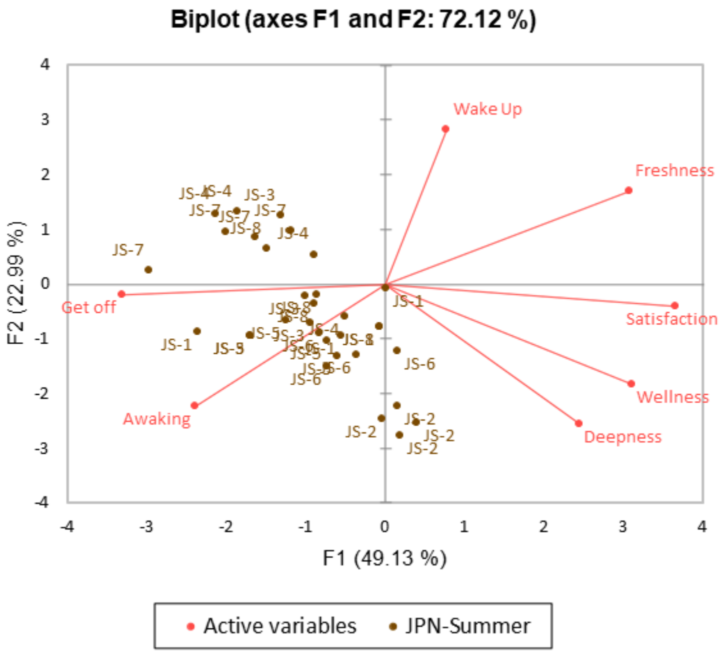


Appendix L. Sleep sensation biplot of (a) Indonesian during summer, (b) Japanese during summer, (c) Indonesian during winter, and (d) Japanese during winter in the correlation circle

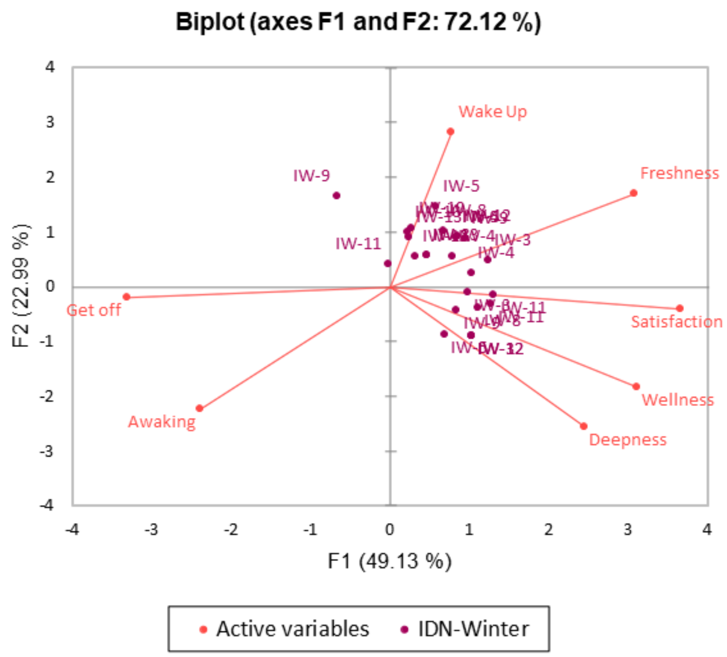
(a)


Biplot (axes F1 and F2: 72.12 %)
4
3
2
1
0
-1
-2
-3
-4
F2 (22.99 %)
-4
-3
-2
-1
0
1
2
3
4
F1 (49.13 %)
Wake Up
Freshness
Satisfaction
Wellness
Deepness
Awaking
Get off
Active variables
IDN-Summer

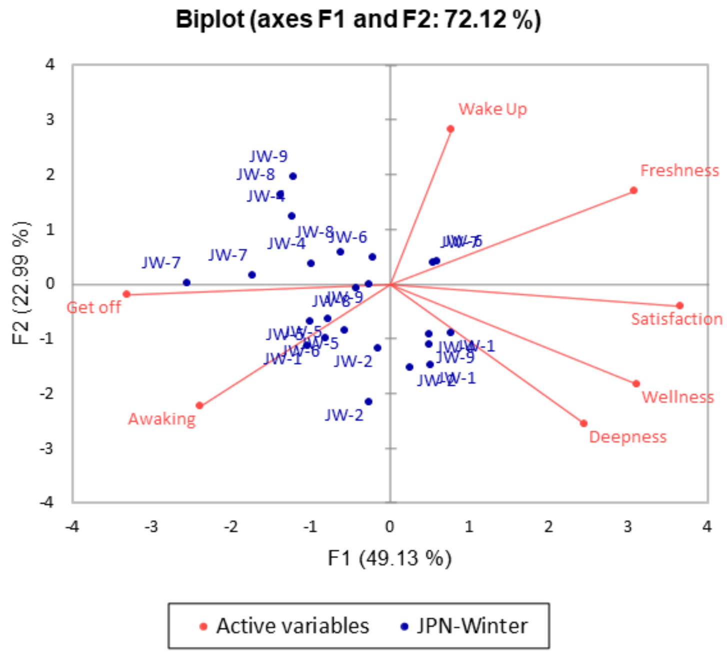
(b)


Biplot (axes F1 and F2: 72.12 %)
4
3
2
1
0
-1
-2
-3
-4
F2 (22.99 %)
-4
-3
-2
-1
0
1
2
3
4
F1 (49.13 %)
Wake Up
Freshness
Satisfaction
Wellness
Deepness
Awaking
Get off
Active variables
JPN-Summer

(c)

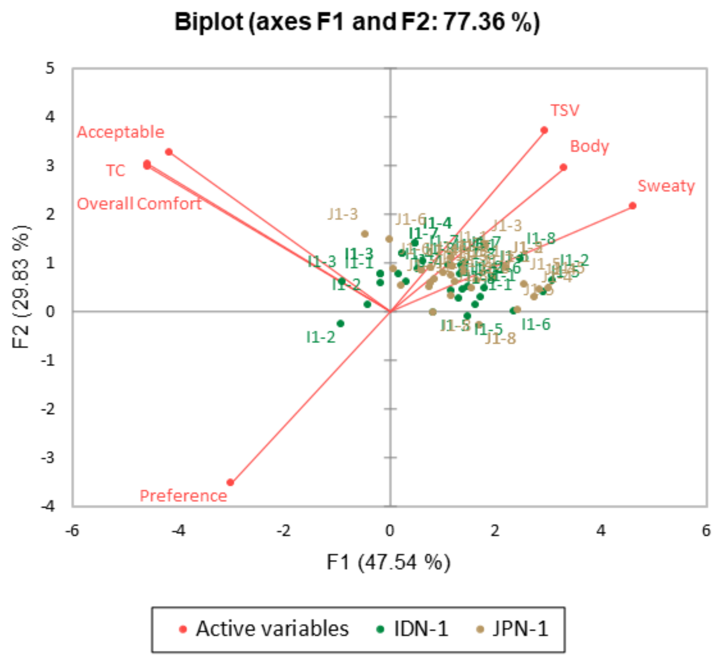

Biplot (axes F1 and F2: 72.12 %)
F2 (22.99 %)
F1 (49.13 %)
Wake Up
Freshness
Satisfaction
Wellness
Deepness
Awaking
Get off
IW-9
IW-11
IW-5
IW-3
IW-4
Active variables
IDN-Winter

(d)

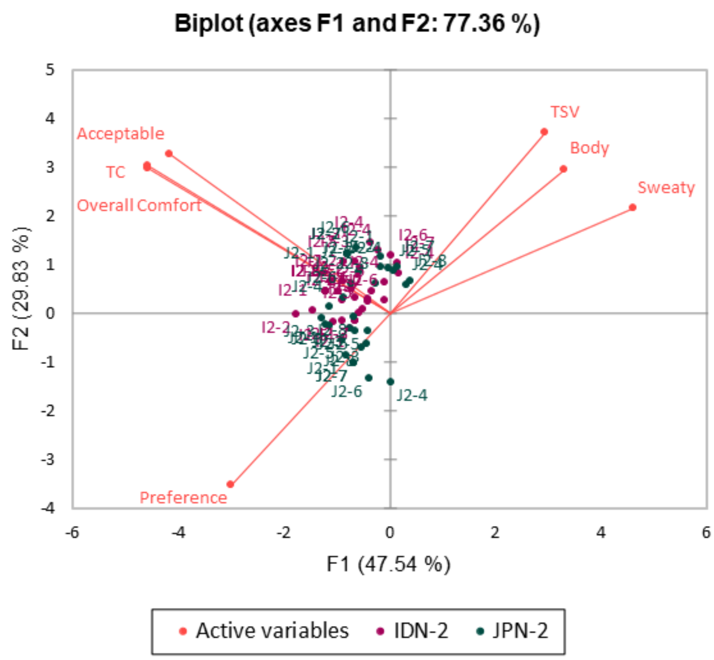

Biplot (axes F1 and F2: 72.12 %)
F2 (22.99 %)
F1 (49.13 %)
Wake Up
Freshness
Satisfaction
Wellness
Deepness
Awaking
Get off
JW-9
JW-8
JW-4
JW-7
JW-7
JW-6
JW-2
JW-2
JW-9
Active variables
JPN-Winter

Appendix M. Experimental room thermal sensation biplot of (a) Indonesian and Japanese hot condition, (b) Indonesian and Japanese cooling condition, (c) Indonesian and Japanese cold condition, and (d) Indonesian and Japanese heating condition.

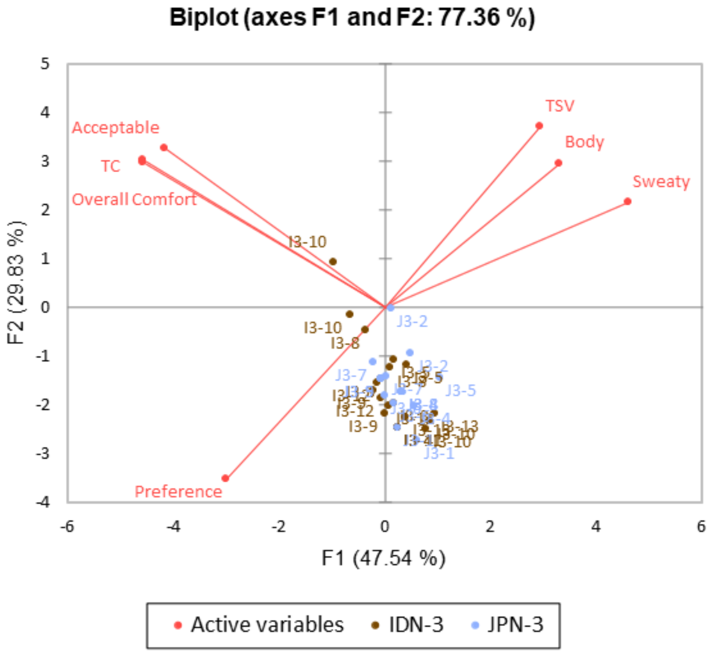
(a)



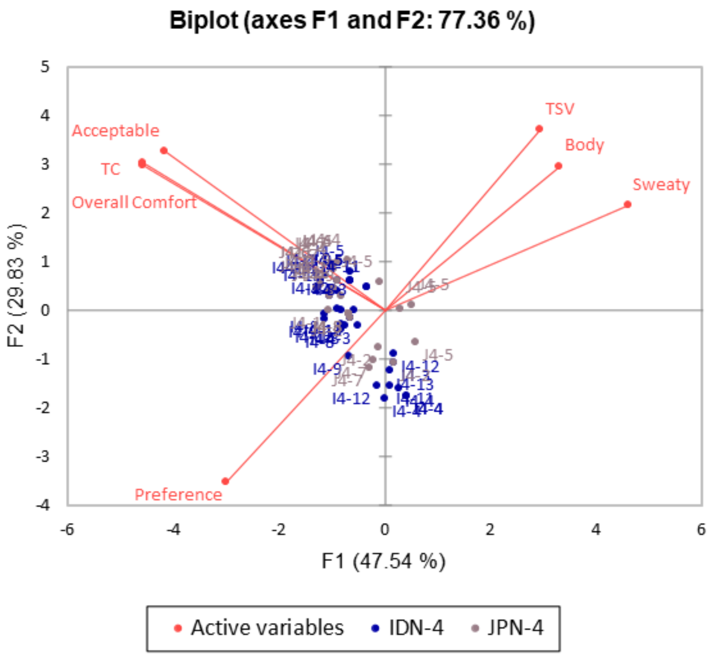
(b)



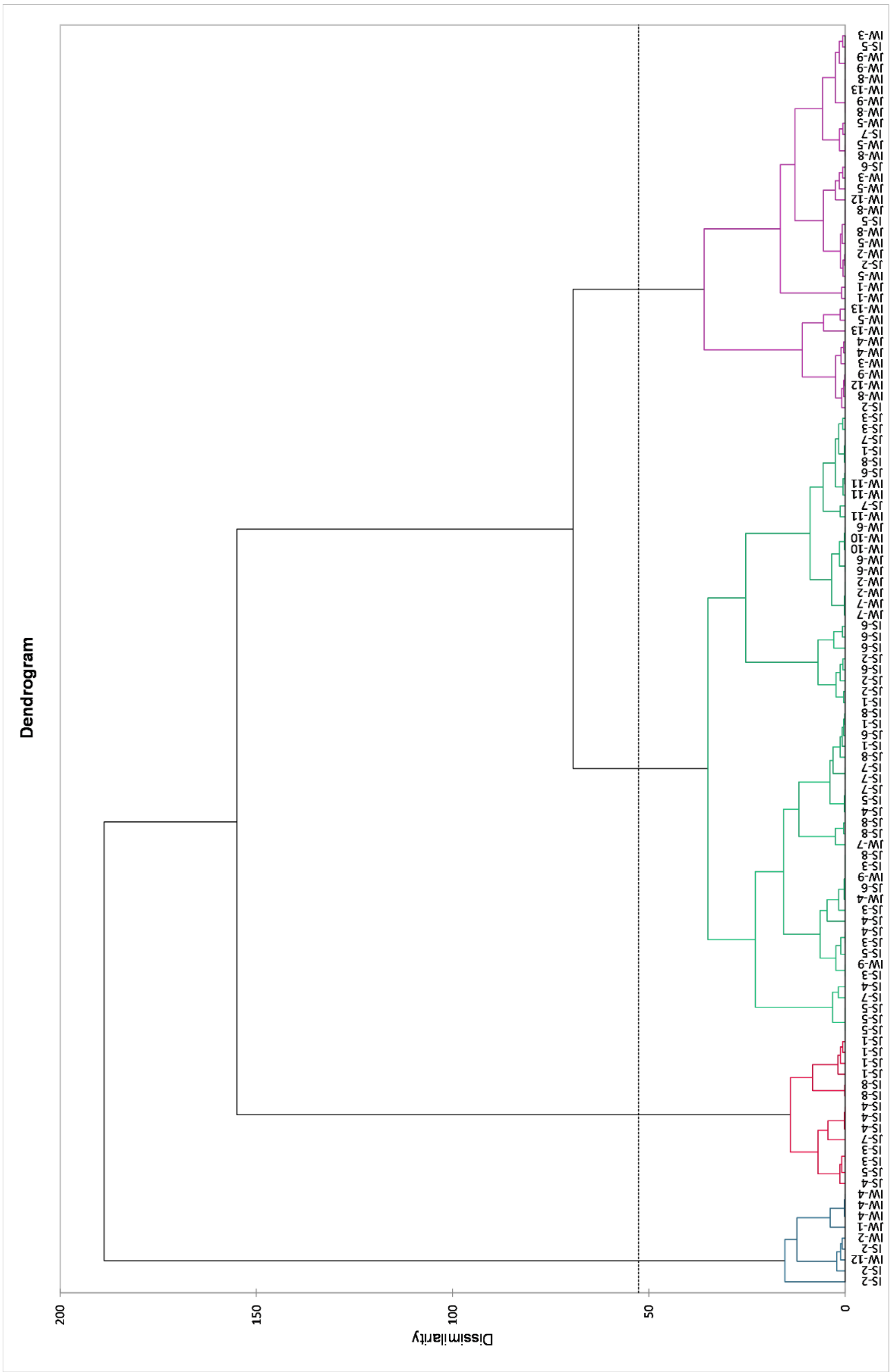
(c)


Biplot (axes F1 and F2: 77.36 %)
F2 (29.83 %)
F1 (47.54 %)
Acceptable
TC
Overall Comfort
TSV
Body
Sweaty
Preference
Active variables
IDN-3
JPN-3

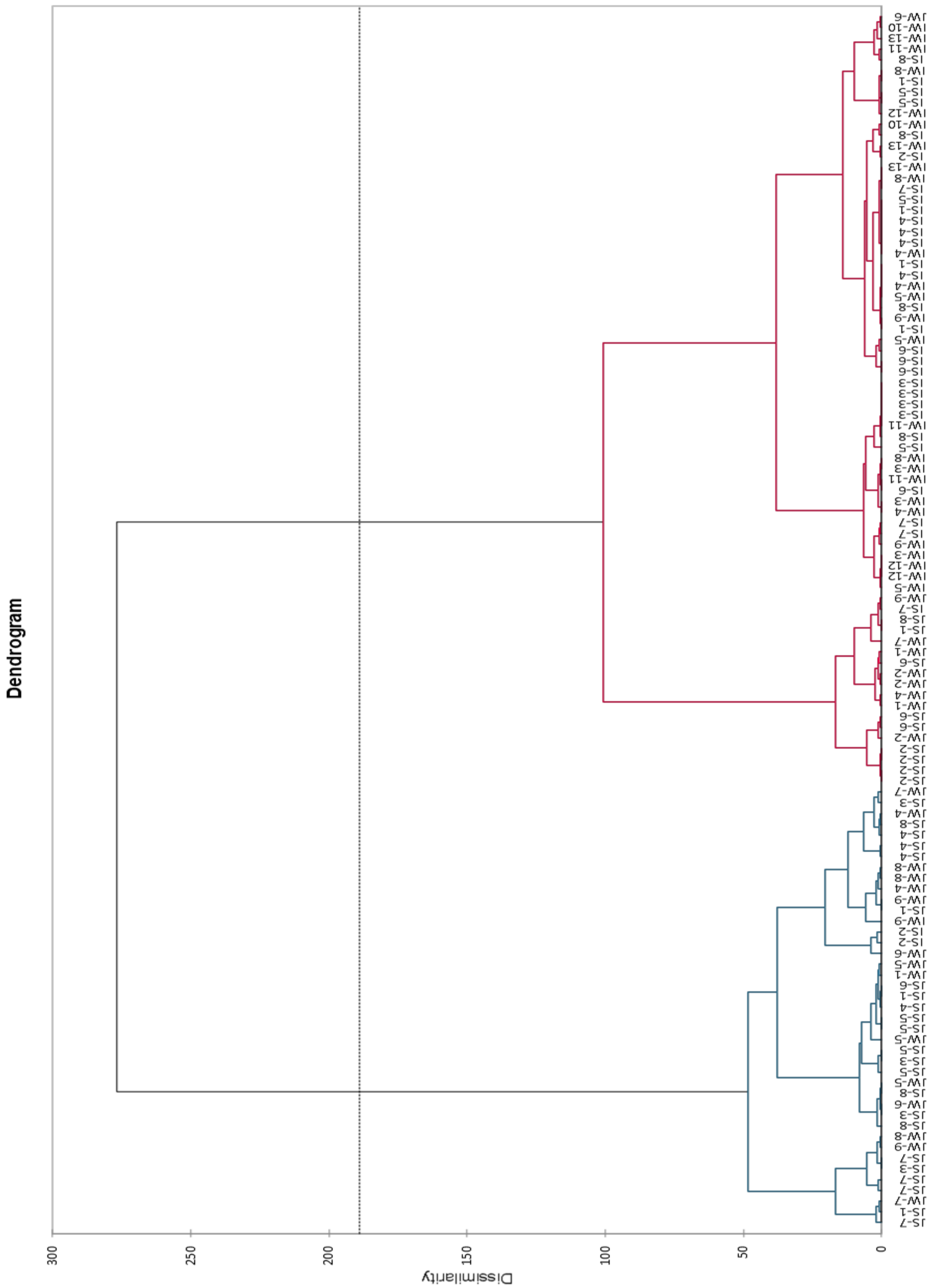
(d)


Biplot (axes F1 and F2: 77.36 %)
F2 (29.83 %)
F1 (47.54 %)
Acceptable
TC
Overall Comfort
TSV
Body
Sweaty
Preference
Active variables
IDN-4
JPN-4

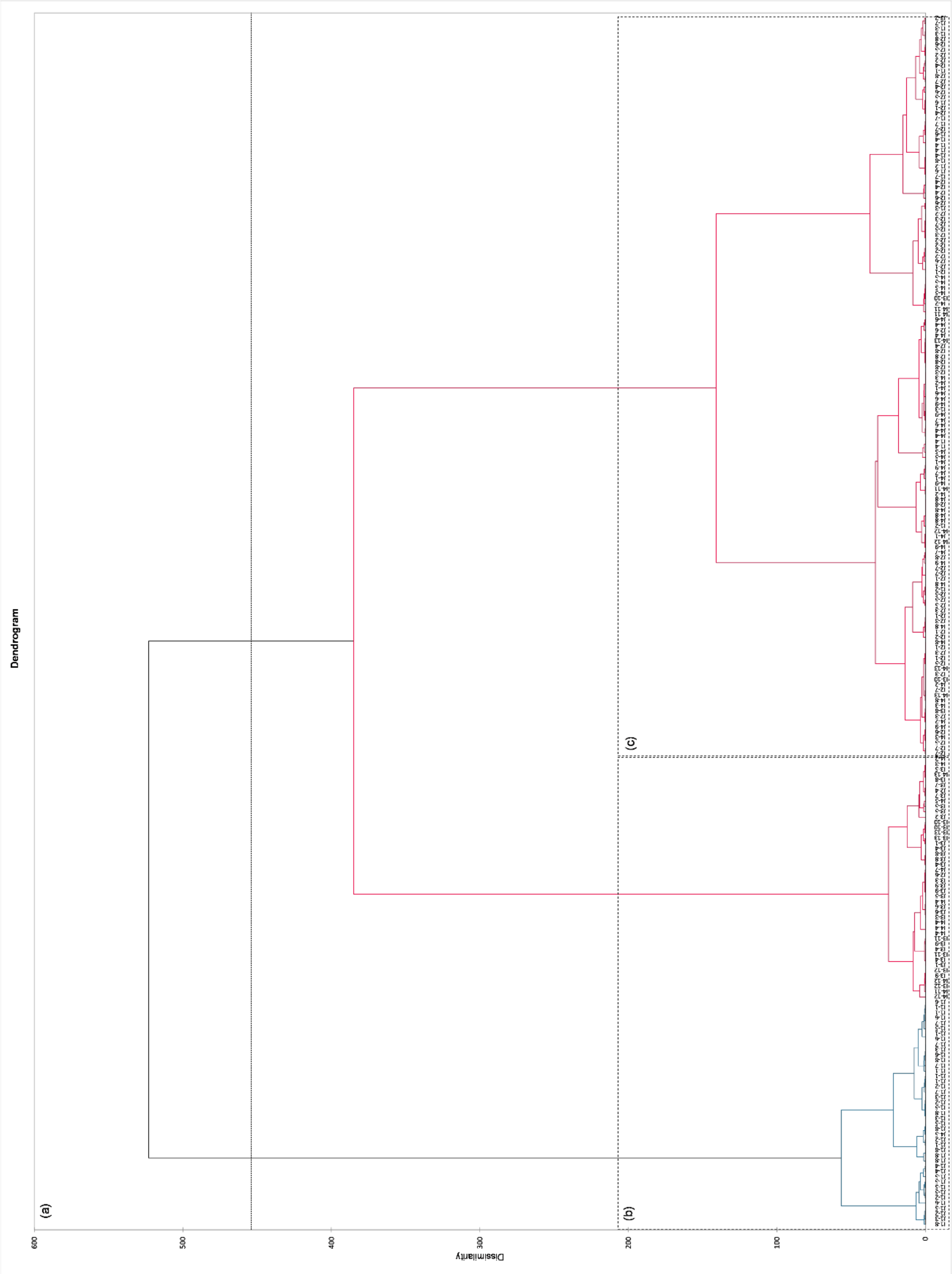
Appendix N. Dendrogram of bedroom thermal sensation factors and label of participants



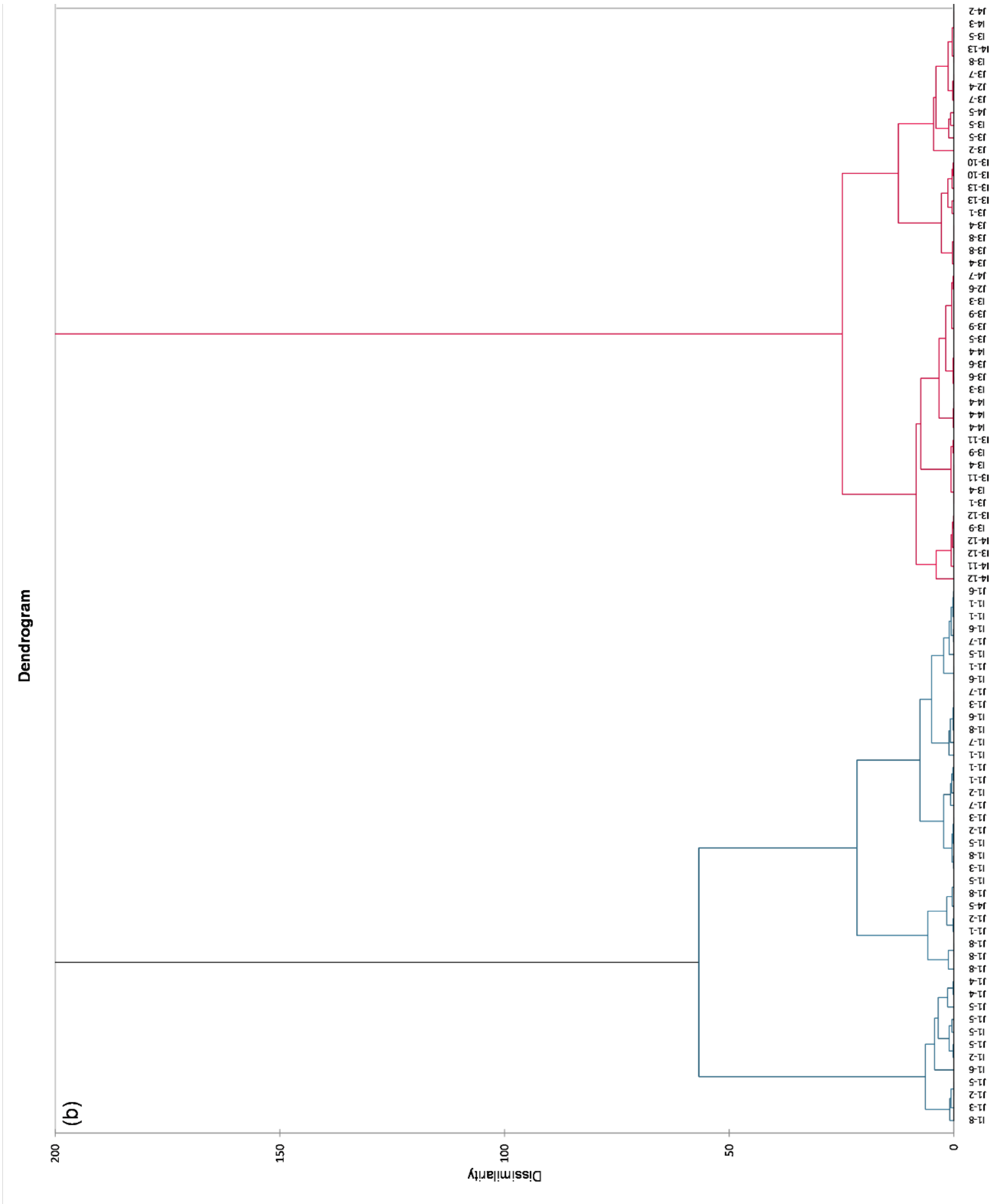
Appendix O. Dendrogram of sleep sensation factors and label of participants

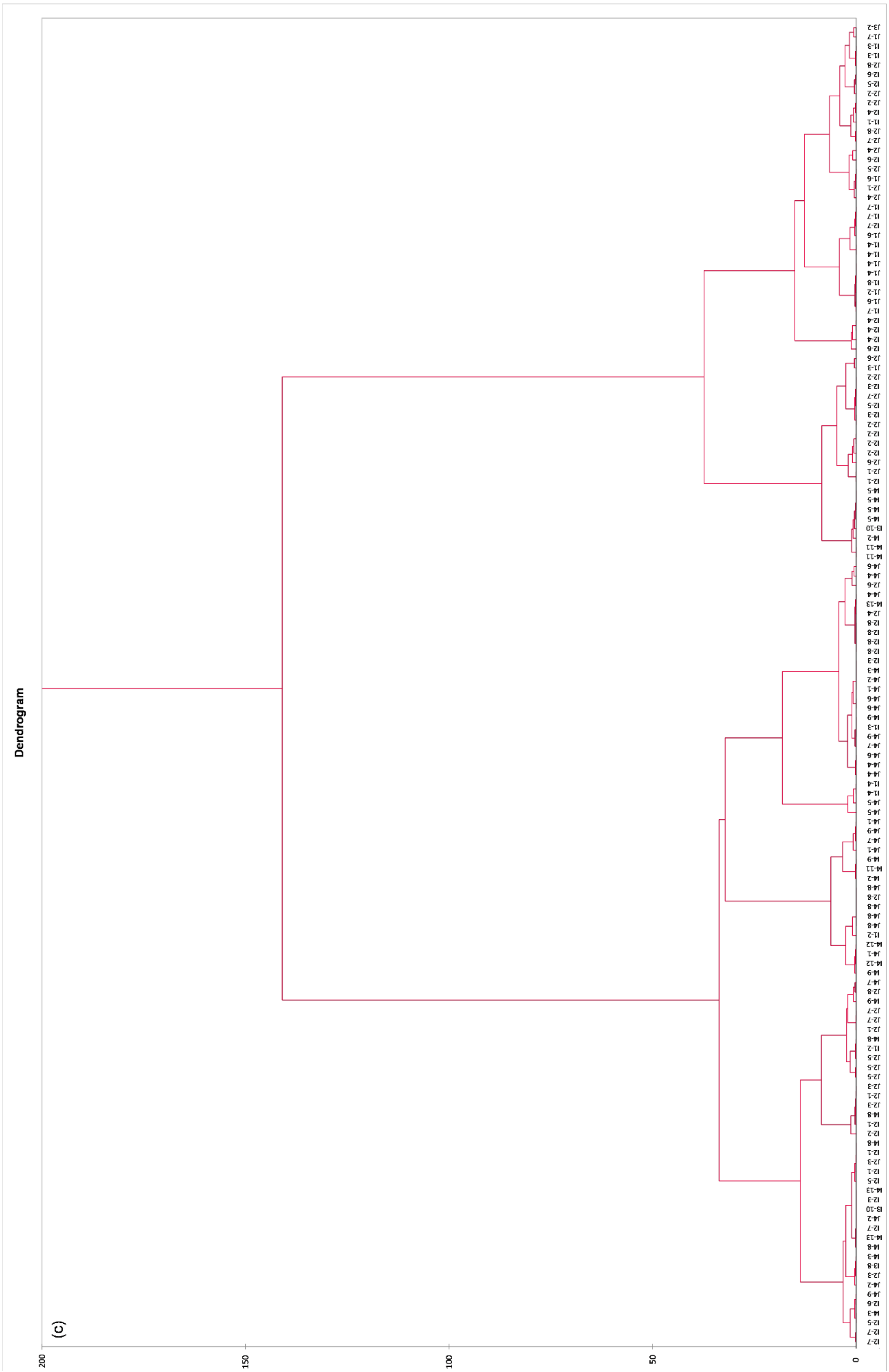


Appendix P. Dendrogram of experimental room thermal sensation factors and label of participants.



Note: a, dendrogram in full display with 600 for maximum dissimilarity; b-c, dendrogram in a part display with 200 for maximum dissimilarity.


Dendrogram
(b)
Dissimilarity
200
150
100
50
0


Dendrogram
(c)
200
150
100
50
0