Thermal environment evaluation considering nap start time

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Abstract

Good health is needed to live a productive and creative life, and restful sleep greatly contributes to maintaining good health. In recent years, some companies have begun allowing time for sleep during work hours as "power naps" to eliminate drowsiness and improve efficiency.

In a study performed last year, we analyzed the effect that 30-minute daytime naps have on improving productivity in subjects by dividing the naps into the three stages of "before falling asleep," "during sleep," and "before waking" and evaluating the role of room temperature at each stage. As reported last year, increasing room temperature significantly shortened sleep laten-cy time for the stage of "before falling asleep," whereas lowering room temperature after falling asleep resulted in subjects reaching Non-REM Sleep Stage 2 faster and maintaining it longer for the stage of "during sleep."

In this study, we evaluate naps taken at times of 10:30, 13:30, and 15:15 and report how the nap start time of day and room temperature for each nap time period affect sleep quality in naps. Although results showed that sleep latency and percentage of mid-awakenings differ depending on the time of day, appropriate room temperature control at all times of the day improves nap quality and the degree of sleepiness after waking.

Keywords

Naps, Room temperature control, Sleep quality, Nap quality, Sleepiness

1. Introduction

- In recent years, sleep time for people in Japan has shown a downward trend (NHK) with more than 70% of Japanese men and women in their twenties or older sleeping less than seven hours per night on average. It is said that more than 30% of the people between ages 20 to 59 experience "daytime drowsiness" three or more times a week, which leads to a decline in productivity [1]. For this reason, interest in sleep quality has increased, and the importance of sleep at night has been shown in examples that include the relationship between sleep time and shooting accuracy (performance) of basketball players and the relationship with PVT test results. Ten men's basketball players at Stanford University were given 10 hours of sleep each night for 40 days, and this resulted in a significant improvement in free throw success rate, sprint numbers, reaction time speed, etc. [2]. Preceding studies in the field of naps have focused on areas relating to environmental evaluations that promote naps including the time for taking a nap [3,4,5,6,7], bright light [8], sound [9], and posture for taking a nap [10]. Furthermore, our research team investigated the effect of environmental temperature on the quality of naps (**Figure 1** [1]) and reported that Non-REM Sleep Stage 2 can be reached and maintained quickly by lowering the room temperature to a neutral temperature after falling asleep. Likewise, raising room temperature above the neutral temperature before waking up results in a shallower sleep depth upon waking. However, investigation is lacking in nap quality by time when the nap is taken or differences due to individual characteristics. Nap quality can be evaluated by the quality of falling asleep and

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waking, amount of sleep time, sleep interruptions, and similar factors. Therefore, in this study, we evaluated the time when a nap was taken and nap quality and also reported the results of analyzing the optimal thermal environment for the time when a nap is taken.

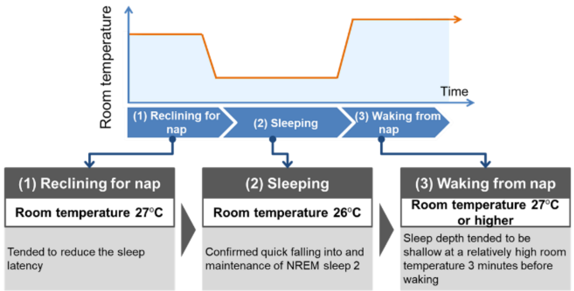


Figure 1: Optimal thermal control during naps

2. Experiment Environment

2.1. Nap room (Figure 2)

A nap room of H2315×W (2400+385) ×D1200mm was created, and a bed was installed inside of it. During the experiment, the entrance sliding door was closed, and sound insulation and light shielding were ensured during testing. Humidity inside the experimental nap room was kept within a range of 40-60%, and Daikin Industries' multi-split cassette air conditioner for small spaces "cocotas" was used to control the temperature of the nap room.

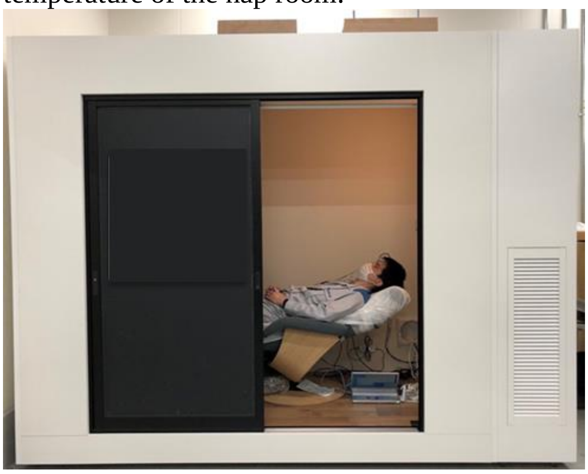


Figure 2: Experiment environment

2.2. Experiment Equipment

EEG measurements during sleep were performed using a SleepWell electroencephalograph (Sleepscope). Also, the room temperature of the nap room was measured using an OMRON environmental sensor (2JCIE-BU01).

3. Experimental Method

3.1. Experimental conditions

A total of 221 cases were conducted from December 2019 to March 2022, targeting seven male employees and five female employees in their 20s who wore a uniform amount of clothing during the experiment. In the experiment, rest periods (10 mins, 5 mins) were set before taking a nap and immediately after waking up; nap duration was 30 minutes; and the nap start time was 10:30, 13:30, or 15:15. In addition, a questionnaire regarding sleepiness (The Stanford Sleepiness Scale, **Table 1**) was conducted before taking a nap as well as 1 hour and 3 hours after waking up.

Table 1

The Stanford Sleepiness Scale

Degree of Sleepiness Scale	Rating
Feeling active, vital, alert, or wide awake	1
Functioning at high levels, but not fully alert	2
Awake, but relaxed; responsive but not fully alert	3
Somewhat foggy, let down	4
Foggy; losing interest in remaining awake; slowed down	5
Sleepy, woozy, fighting sleep; prefer to lie down	6
No longer fighting sleep, sleep onset soon; having dream-like thoughts	7

3.2. Experiment description

Room temperature in the nap room is adjusted during the 30-minute nap as shown in A and B in **Figure 3** according to the three stages of "before falling asleep," "during sleep," and "before waking." Changes in subject's sleep depth and productivity before and after the nap were measured and evaluated according to room temperature, as shown in 4.3. Room temperature environments with the following conditions were applied during the nap.

A: With room temperature control

Temperature is set slightly higher before falling asleep; is lowered after falling asleep; and raised (or kept lower) before waking.

B: Without room temperature control

A neutral temperature or higher than temperature is maintained from before falling asleep to before waking.

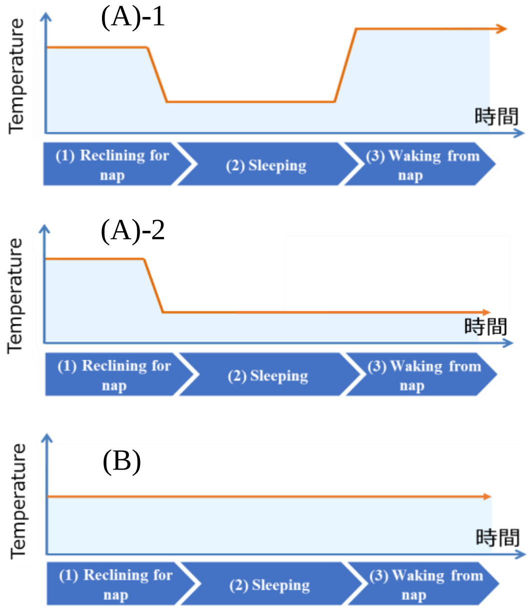


Figure 3: Thermal control during nap
A: With room temperature control (Lower),
B: Without room temperature control (Keep)

4. Evaluation method

Table 2 shows a comparative evaluation performed for three items. In the evaluation of 5.1, ① sleep latency time was evaluated. In the evaluation of 5.2 (1), the length of Non-REM Sleep Stage 2 was evaluated. Generally, in normal sleep, slow wave sleep is reached about 30 minutes after falling asleep [12], and it has been reported that sleep inertia is enhanced when slow wave sleep is included during daytime naps. In addition, since slow wave sleep is non-REM sleep3,4, up to non-REM sleep2 is considered good for napping [13, 14]. In the evaluation of 5.2 (2) and (3), the percentage of sleep awakenings was evaluated. In the evaluation of 5.3(1) and (2) drowsiness was evaluated.

Table 2
Evaluation items and details

Items	contents
① Sleep latency	Time from the start of the test to the determination of sleep onset by the electroencephalograph
② Sleep depth	Changes in sleep depth detected by the electroencephalograph attached to the subject during the period from the start to the end of the test
③ Drowsiness	A Stanford Sleepiness Scale questionnaire was adminis-tered before taking a nap, 1 hour after waking, and 3 hours after waking, and test subjects were asked to re-port their own level of drowsiness on a 7-point scale, and the amount of change from before taking a nap.

5. Experiment Results and Discussion

5.1. Before falling asleep

Figure 4 shows the results of sleep latency time for each room temperature before falling asleep with respect to the start time of taking a nap. In order to create a thermal environment that promotes the rapid onset of sleep at all times of the day, experiments were conducted based on the hypothesis that setting the room temperature slightly warmer before falling asleep “would increase the relaxation effect and make it easier to fall asleep." The average sleep latency time at each start time was 6.7±5.6 mins at 10:30, 6.1±5.3 mins at 13:30, and 4.9±3.8 mins at 15:15 and tended to take longer. In addition, at each start time, the room temperature before falling asleep was set in three ways: low (25°C or less), neutral (26°C), and high (27°C), and the time required to fall asleep in each temperature environment was measured, and we compared the time required to fall asleep in each temperature environment. The Mann–Whitney U test was used as the test method. As a result, it was found that setting the temperature at 10:30 to a relatively high 27°C shortened the sleep latency time significantly. At 13:30, there was no significant difference between 26°C and 27°C, but it was found that latency to fall asleep was significantly shorter at 27°C than at 25°C, which is lower. On the other hand, at 15:15, no reduction in sleep latency time was observed at any room temperature. This is generally said to be due to the influence of the circadian rhythm, and it is thought that it corresponds to the time period when it is easy to feel drowsiness. For this reason, sleep latency time tends to be short, and it is difficult to be affected by the room temperature.

Consequently, setting the room temperature to a relatively high 27°C was found to significantly shorten sleep latency time during time periods when it is difficult to feel drowsiness.

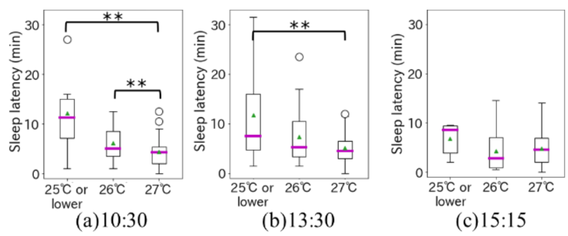


Figure 4: Relationship between room temperature before falling asleep and sleep latency time for each nap start time

5.2. During sleep

(1) Nap start time and length of Non-REM Sleep Stage 2 (N2)

Figure 5 shows the results of calculating the percentage of cases of N2 time in each test by classifying the N2 time during the nap into 0-10 mins, 10-20 mins, and 20-30 mins for each nap start time. Fisher's exact test was used to test the two categories of 20 minutes or more and less than 20 minutes, and it was discovered that there were many cases where the N2 time was significantly longer in the 15:15 test compared to the 10:30 test. Since N2 time occurred in many cases during the time period when people generally feel sleepy during the day, it is thought that the number of cases in which N2 time became longer increased due to the influence of circadian rhythm.

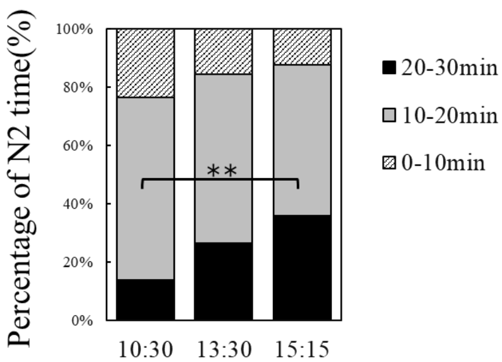


Figure 5: Nap start time and N2 time relation

(2) Nap start time and percentage of mid-awakenings

Our 2022 research shows that lowering room temperature after falling asleep accelerates the onset of N2 and helps maintain N2 time. In this study, we evaluated the mid-onset awakenings, which are thought to affect the quality of sleep (Figure 6). First, we examined cases when the room temperature was not lowered after falling asleep (B: Keep). As a result, in the 10:30 and 13:30 experiments, more than 10% of the subjects woke up during the night, suggesting a greater likelihood to wake up in the middle of the night than in the 15:15 experiment. Next, cases in which room temperature was not lowered after falling asleep were compared with cases in which the room temperature was lowered. The Mann–Whitney U test was used as the test method. It was found that the percentage of midday sleep awakenings decreased at all starting times of 10:30, 13:30, and 15:15. Therefore, lowering the room temperature after falling asleep is an effective way to reduce the percentage of sleep awakenings.

For nighttime sleep, it has been reported that when the environmental temperature inside bedding was kept high during sleep, such as with an electric blanket, sleep interruptions increased, resulting in unstable sleep [15]. It is said that when heat dissipation is hindered, the core body temperature does not drop sufficiently, resulting in poor sleep quality, but the results of this study suggested that lowering the room temperature promoted heat dissipation and stabilized sleep.

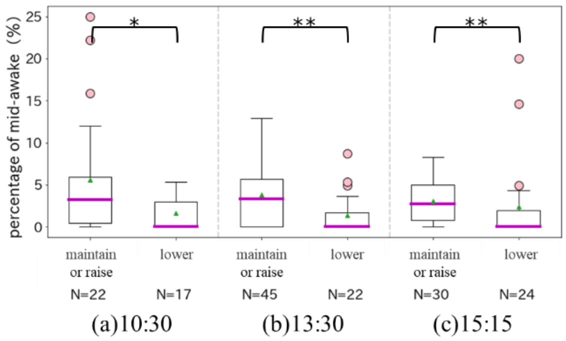


Figure 6: Nap zone and percentage of awakenings

(3) Thermal environment reduces mid-awakenings

Next, we evaluated the extent to which room temperature could be lowered to significantly reduce the percentage of nocturnal awakenings (**Figure 7**). Compared to before falling asleep, cases in which the temperature was lowered by 0.5 to 2°C after falling asleep and cases in which temperature was maintained or increased were compared. The Mann–Whitney U test was used as test method. We found that lowering the temperature by 1°C significantly decreased the percentage of nocturnal awakenings compared to maintaining or increasing temperature and was effective in maintaining stable sleep.

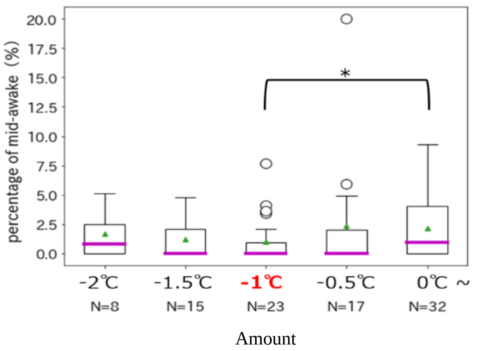


Figure 7: Amount of room temperature change after falling asleep and percentage of awakenings

5.3. Effectiveness after waking

(1) Time of nap start and degree of improvement in sleepiness

For each start time of taking a nap, sleepiness after waking compared to before the nap was evaluated for 1 hour and 3 hours after waking (**Figure 8**). Comparisons were made between cases in which the room temperature was lowered (A-1, A-2: Lower) and maintained (B: Keep) after falling asleep. The Mann-Whitney U test was used. The results showed that lowering the room temperature after falling asleep significantly improved sleepiness at 1 and 3 hours after waking for the 10:30 nap. In the 15:15 nap, room temperature control significantly improved sleepiness only 3 hours after waking. On the other hand, a nap at 13:30 showed no difference due to room temperature control.

The results after 3 hours of waking showed that taking a nap at 10:30 did not worsen sleepiness around 14:00, which is generally considered to be the time when people feel sleepy due to circadian rhythms, but maintained the improvement, suggesting the possibility that taking a nap in the morning is effective.

(2) Thermal environment and drowsiness

Regarding drowsiness after waking up, we reported that our research team found that when the room temperature was lowered after falling asleep and during sleep, drowsiness was more resolved 1 hour and 3 hours after waking up compared to when the room temperature was not lowered [11]. Therefore, we performed a re-analysis to find out how much the room temperature could be significantly improved. As in 5.2 (3), compared with before falling asleep, we compared the cases where the temperature was lowered by 0.5 to 2°C after falling asleep and the cases where it was maintained or raised (**Figure 9**). In the test, Fisher's exact test was used for two classifications for the resolution of drowsiness: no change or worsening. As a result, it was found that lowering the temperature by 0.5 to 1.5°C eliminated drowsiness more effectively than maintaining or increasing the temperature.

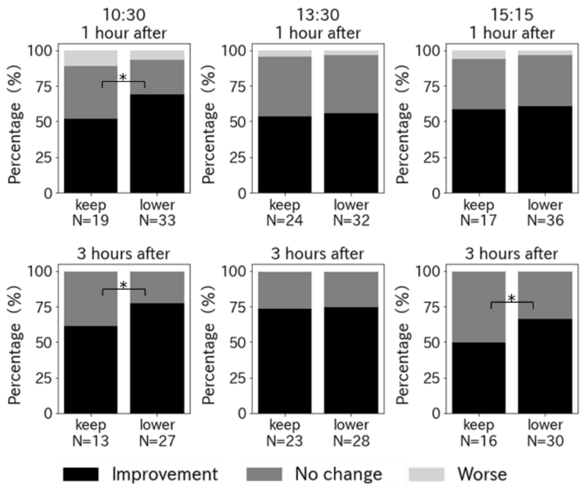
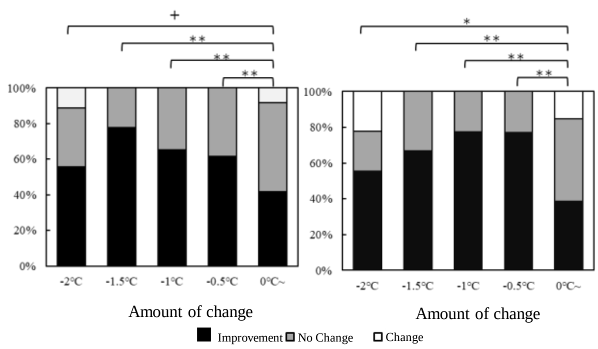


Figure 8: Room temperature control and percentage of reported sleepiness



(a) 1 hour after waking up (b) 3 hours after waking up

Figure 8: Room temperature change after falling asleep and drowsiness after waking

6. Conclusion

Sleep quality in naps and thermal environment were evaluated by nap start time. There was a tendency to take longer to fall asleep for sleep latency time and nap start time in the morning, and the sleep latency time was the shortest around 15:00. This is thought to be the influence of the circadian rhythm, which shortens the sleep latency time during time periods when drowsiness is felt. Additionally, increasing room temperature appears to shorten sleep latency time for time periods when drowsiness is not felt; however, the biological rhythm is thought to have had a more significant effect than room temperature for time periods when drowsiness is felt.

The depth of sleep when asleep is similarly to the above. N2 time tends to be longer during time periods when sleepiness is felt due to the influence of the circadian rhythm, and the depth of sleep is shallow during time periods when sleepiness is not felt. (N2 time is shortened.) As for sleep depth, lowering the room temperature after falling asleep decreases the number of nocturnal awakenings for all time periods, suggesting that sleep is strongly affected by room temperature.

Compared to when the room temperature was maintained or increased, lowering the room temperature by 0.5 to 1.5°C after falling asleep eliminated the sensation of drowsiness felt before the nap for both time periods of 1 hour and 3 hours after waking from the nap.

In addition, we examined the results this time for all subjects, including men and women. However, as evidenced by reports of differences in thermal sensations between men and women [16, 17], it is thought that the optimal temperature varies among individuals. In addition, in this survey, subjects were men and women in their 20s who worked day shifts, and the subjects had similar times for waking and going to sleep. On the other hand, in the case of different lifestyles, such as night owls and early birds, similar results may not be obtained. Therefore, as a future task, it is necessary to pay attention to the characteristics of each individual, and to examine differences in the quality of naps due to individual lifestyle habits and thermal control.

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