A Thermal Environment That Promotes Efficient Napping

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Abstract

People need to maintain good health to live productive and creative lives, and 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 this article, we report on the optimal thermal environment for efficient naps during the daytime when the body is active and the effect that naps have on improving productivity. This study uses questionnaires on drowsiness before and after the test along with the Psychomotor Vigilance Task (PVT) and N-back task to evaluate productivity improvements in test subjects when room temperature is changed for each scene of “reclining for nap,” “sleeping,” and “waking from nap.” Test results show that differences in room temperature can promote the onset of sleep, maintain sleep, and stimulate wakefulness. By optimally controlling these factors, it is possible to take a short high-quality nap to improve productivity. As sleep is said to be related to the function of the autonomic nervous system, it is believed that the thermal environment exerts influence on the autonomic nervous system and affects the quality of sleep, even when sleep duration is short.

1. Introduction

Recently, the amount of sleep Japanese people get has continued to decline, with more than 70% of men and women in their 20s and older averaging less than 7 hours of sleep, and more than 30% of them experiencing "daytime drowsiness" at least 3 times a week (Ministry of Health, Japan 2019), which leads to decreased productivity. For this reason, interest in good sleep is high. In particular, with regard to nighttime sleep, there are studies on the relationship between sleep duration and shooting accuracy in basketball players and PVT test performance. (Cheri D.*et al*., 2011) Nap is also said to be effective in eliminating drowsiness and improving performance, but the effect of the surrounding environment on the quality of nap is not clear. Previous studies in the field of napping have evaluated the optimal nap duration (Hayashi *et al*., 1999, 2003a, 2004, 2005) and the effects of lighting (Hayashi *et al*., 2003b), sound (Yamada *et al*., 2021, Hayashi *et al*., 2003b), and bed (Hayashi *et al*., 2008, Ishihara *et al*., 2015) on nap quality. However, none have investigated the effect of environmental temperature on nap quality.

Since the environmental temperature controlled by the air conditioner acts on the body's thermoregulation, it is thought to have a significant effect on sleep, which allows the brain to rest. Therefore, this study focuses on thermal control during nap using an air conditioner, and reports the results of evaluating the effects of environ-mental temperature control on the quality of nap (eliminating drowsiness and improving performance).

2. Optimal thermal control for daytime naps

As shown in Fig. 1, our proposed control method divides napping into three stages: (1) Reclining for nap, (2) Sleeping and (3) Waking from nap. The environmental temperature in each stage is controlled to provide comfortable sleep and moderate sleep depth.

(1) Reclining for nap

Slightly warmer room temperature before falling asleep enhances relaxation and promotes falling asleep.

(2) Sleeping

Slightly cooler room temperatures keep sleep steady.

(3) Waking from nap

Use a higher room temperature before waking up to promote wakefulness.

Also, a typical graph of sleep depth transition using this control is shown in Fig. 2. (W: wake, R: REM sleep, N1: NREM Sleep Stage 1, N2: NREM Sleep Stage 2, N3: NREM Sleep Stage 3).

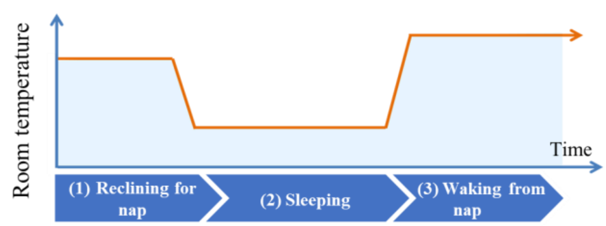

Fig. 1 the thermal control example for nap

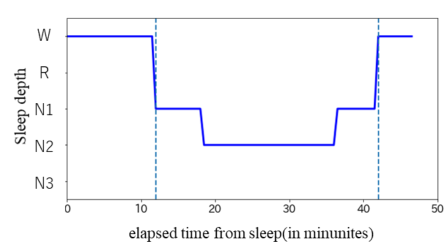

Fig. 2 the typical example of sleep depth

3. Experimental Environment

3.1 nap room

A nap room of H2315 x W (2400+385) x D1200 mm was fabricated and a bed was installed in the nap room. During the test, the door was kept closed to ensure sound and light insulation.

To control the temperature in the booth, a small space multi-cassette air conditioner "cocotas" manufactured by Daikin Industries was installed, and the humidity range was 40% to 60%.

Fig. 3 nap room

3.2 Experimental equipment

Test subjects were fitted with SleepWell's electroencephalograph (Sleepscope) to measure sleep depth. And the room temperature in the nap booth was measured with an environmental sensor (2JCIE-BU01, OMRON Co., Kyoto, Japan).

4. Method

4.1 Participants and Protocol

A total of 143 experimental cases were conducted between January 2020 and February 2022. The experiment was conducted with 6 males and 5 females in their 20s, with a constant amount of clothing. The nap duration was 30 minutes, with rest periods of 10 and 5 minutes before and after the nap, respectively.

To evaluate the effects of the nap, a questionnaire on sleepiness and a performance evaluation test were administered before and after the nap. Specifically, they were administered immediately before, one hour after, and three hours after napping. The Stanford Sleepiness Scale (Table 1) was used as the questionnaire. The performance assessment tests were the PVT-B (Psychomoter Vigilance Task, Fig. 4) and the N-Back task (Fig. 5). PVT-B objectively assesses fatigue-related changes in alertness nap associated with sleep loss, extended wake-fulness, circadian misalignment, and time on task. In this nap test, the reaction speed was measured by clicking a PC mouse in response to a lit signal on the PC monitor in order to evaluate awakening degree. N-Back task is used extensively in literature as a working memory (WM) paradigm. In this nap test, the test subjects have to memorize details to several questions while answering a simple calculation formula to evaluate it. Then, the subject takes a 10-minute rest and a 30-minute nap.

After napping, the subject rest for 5 minutes and complete a questionnaire on sleepiness. The PVT-B and N-Back are administered twice, once 1 hour after waking and again 3 hours after waking.

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

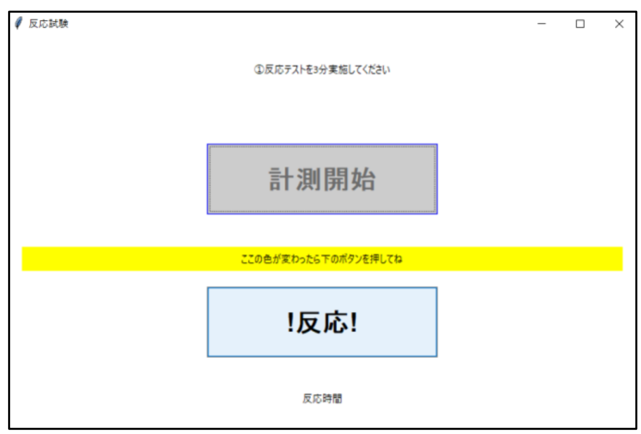

Fig. 4 PVT-B screen

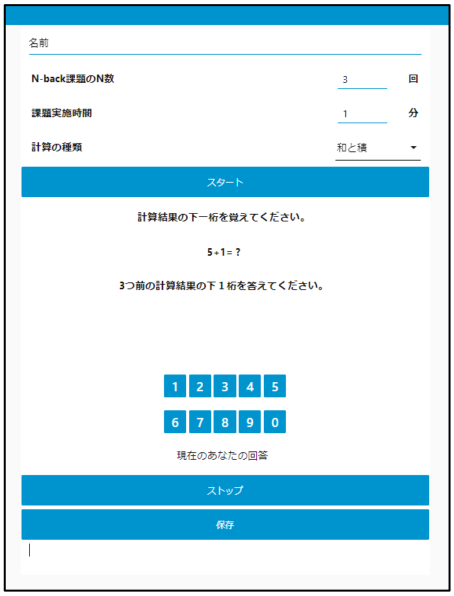

Fig. 5 N-Back Task screen

4.2 Room temperature conditions

Room temperature inside the nap room is adjusted during the 30-minute nap according to the three stages of (1) Reclining for nap, (2) Sleeping, and (3) Waking from nap as shown in Fig.6(A, B). By room temperature, it is measured about "changes in sleep depth" and evaluated about "productivity before and after the nap" as shown in Table2. The following two room temperature conditions were applied for the experiment.

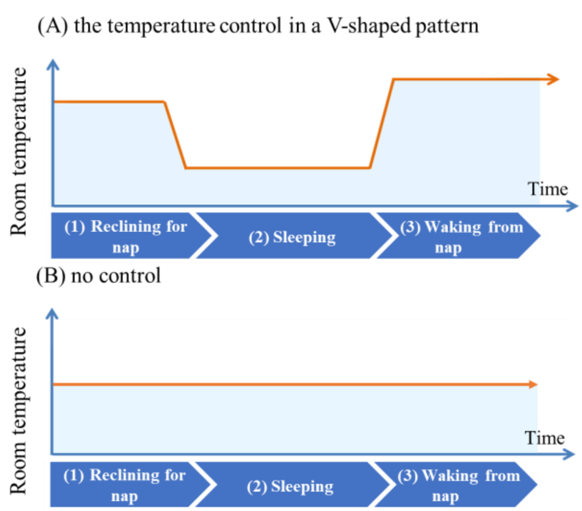

Fig. 6 the thermal control example for nap (A: the temperature control in a V-shaped pattern, B:no thermal control)

A: the temperature control in a V-shaped pattern

- It is kept slightly warm room temperatures before sleep onset, kept lower after sleep onset, and raised before waking.

B: no thermal control

- It is maintained a neutral temperature from before sleep onset to waking up.

4.3 evaluation item

Comparative evaluation of experimental results was conducted for the five items listed in Table 2.

Table 2 Evaluation items and contents

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 Awakening degree	PVT-B is performed before taking a nap, 1 hour after waking up, and 3 hours after waking up, and the amount of change from before taking a nap.
④ working memory (WM)	N-Back task is performed before taking a nap, 1 hour after waking up, and 3 hours after waking up, and the amount of change from before taking a nap.
⑤ 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. Results

5.1 (1) Reclining for nap

Fig. 7 shows the results of sleep onset latency for each room temperature before falling asleep. In order to realize a thermal environment that encourages rapid sleep onset, we hypothesized that by setting the room temperature before falling asleep to a warmer temperature, the relaxing effect would be enhanced and it would be easier to fall asleep. Room temperature before the onset of sleep is set at one of three settings: low (25 ° C or less), neutral (26 ° C), or high (27° C). The time required before the onset of sleep at each temperature environment is evaluated.

As expected, A tendency was seen in which sleep onset latency shortened when the room temperature was kept slightly warm (27° C).

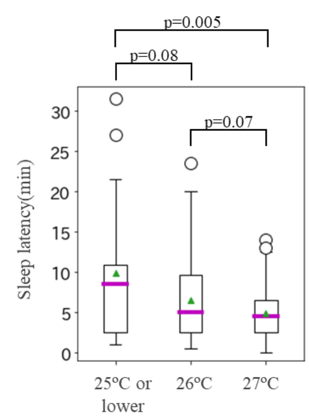

Fig. 7 Sleep onset latency (minutes) and room temperature (°C) before sleep onset

5.1 (2) Sleeping

Daytime naps are said to be "optimal at NREM Sleep Stage 2 (N2)", which does not increase sleep inertia after waking up (Stampi C. *et al.*, 1990). Therefore, with the aim of realizing a "thermal environment that can maintain N2" during sleep, the hypothesis that "a slightly cooler temperature is comfortable and does not interfere with sleep", that is, "a thermal environment that can maintain sleep".

In the experiment, differences in sleep stage transitions were compared between cases in which the room temperature was not changed from the temperature before falling asleep and cases in which the temperature was reduced by 1 ° C from the temperature before falling asleep.

As a result, it was confirmed that test subjects reached and maintained N2 (non-REM sleep stage 2) 10 minutes after the onset of sleep in the case where the room temperature was lowered to 26 ° C from the time of falling asleep, compared to the case where the room temperature was not changed. (Fig.8 (A)-1, (B)-1. Fig. 8 (A) -2 and (B) -2 show examples of sleep depth when the test was performed with control A or B.)

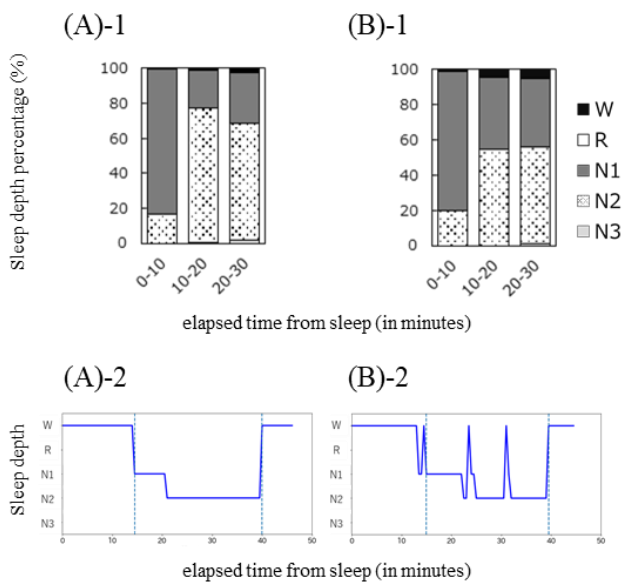

Fig. 8 Sleep depth percentage (%) and elapsed time from sleep (in minutes) (A-1: control A, B-1: control B) Sleep depth and elapsed time from sleep (in minutes) (A-2: control A, B-2: Control B)

5.1 (3) Waking from nap

We hypothesized that high room temperatures, as opposed to during sleep, would promote arousal. Based on this hypothesis, we tested whether raising the room temperature just before waking could promote awakening with less drowsiness. We compared the difference in sleep depth between the case where the room temperature was not changed during sleep and the case where the room temperature was raised to 27 ° C or higher 3 minutes before the wake-up time.

As a result, as shown in Fig. 9, when the room temperature 3 minutes before waking up was 27 ° C or higher, the sleep depth tended to be shallower.

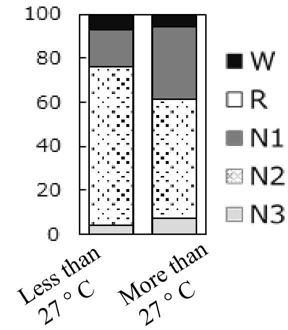

Fig. 9 Sleep depth percentage (%) and room temperature (° C) before waking

5.1 Result: Thermal control methods obtained from experimental results

Based on the experimental results, we believe that the thermal control method shown in Fig. 10 is optimal for efficient daytime napping.

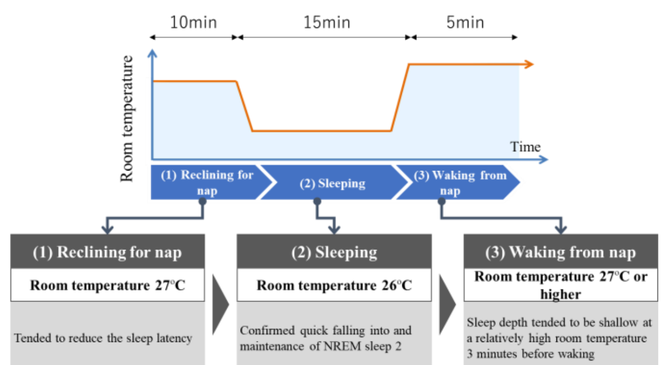

Fig. 10 optimal thermal control

5.2 Performance improvement effect with or without thermal control

This study also examined the effect of the application of thermal control on performance after waking. The effects of thermal control were examined by comparing three items: "reaction speed, working memory, and sleepiness" at 1 and 3 hours after waking. As a result, in about 50 cases tested with thermal control, which provides the best sleep condition, performance was improved compared to the case without thermal control. The results are shown in the Table 3.

Table 3 Improvement in reaction speed, working memory, and drowsiness by thermal control compared to cases without thermal control

	Reaction speed	Working Memory	Drowsiness
Improvement 1hour after waking	9%	32%	12%
Improvement 3hours after waking	27%	26%	14%

6. Discussions

In this study, we proposed a thermal control system that allows for comfortable and effective napping even during daytime hours when arousal intensifies. In other words, the proposed thermal-controlled nap is effective in reducing post-awake drowsiness and improving reaction time and working memory as well. In future efforts, we would like to consider customizing the thermal control method, taking the following two points into consideration.

1). Gender difference

2). Circadian rhythm

Some of the results of this experiment were considered to be influenced by (1) gender differences and (2) circadian rhythms. More detailed evaluation of these results is expected to lead to the realization of individualized thermal control methods.

6.1 Gender difference

We examined how males and females feel about temperature when napping. When a lower temperature setting of 25° C was used before falling asleep, a comparison of males and females showed a trend toward longer latency to fall asleep in females, although the difference was not statistically significant (Fig.11). In addition, 43% of females (3 out of 7 cases) and 23% of males (3 out of 13 cases) answered that they were "cold" by the time they fell asleep. Therefore, it was considered that females tended to feel colder than males.

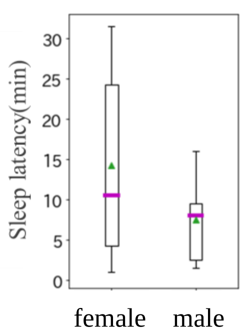

Fig. 11 Sleep onset latency (minutes) for male and female at room temperature of 25° C

6.2 Circadian rhythm

Generally speaking, humans are influenced by circadian rhythms, being more active and less sleepy in the morning and feeling sleepy in the afternoon (Lavie P. *et al*., 1985). An example of a typical sleep depth transition graph for morning and afternoon naps is shown in Fig. 12. As these figures show, sleep is shallow in the morning and the frequency of awakenings increases. Afternoon naps, on the other hand, tend to deepen the depth of sleep as time passes from the onset of sleep. Therefore, based on the results of this 5.1 (3), we will examine the possibility of maintaining the sleep state by continuing the low room temperature during sleep in the morning.

The thermal control method proposed in this study (raising the room temperature before waking) is considered effective in the afternoon to avoid reaching sleep depth 3. Therefore, the effectiveness of different thermal control methods at different times of the day will be investigated in the future.

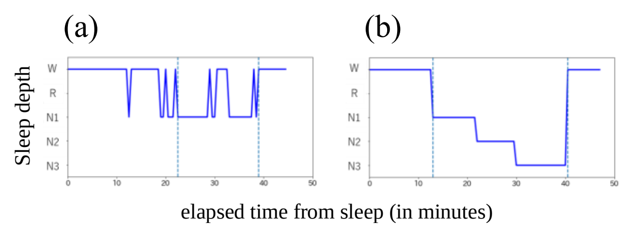

Fig. 12 Sleep depth and elapsed time from sleep (in minutes) (a: in the morning, b: in the afternoon)

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