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 that many people in Japan obtain each night has declined (NHK Broadcasting Culture Research Institute, 2020), and more than 70% of Japanese men and women 20 years of age and older sleep an average of less than 7 hours. Consequently, more than 30% of Japanese people between the ages of 20 and 59 years old suffer from "daytime drowsiness" at least three times a week (Ministry of Health, Japan, 2019), leading to a decline in productivity. So, there is increasing interest in good sleep. There are the following previous studies on nighttime sleep and athletic performance (Cheri D Mah *et al*., 2011). We measured the shooting accuracy, evels of daytime sleepiness, and Psychomotor Vigilance Task (PVT) when 10 basketball players slept for 10 hours or more and did not. As a result, when sleeping for 10 hours or more, the shooting accuracy was significantly improved and the drowsiness and PVT reaction time were decreased as compared with the short sleep.

It is said that naps are also effective in relieving drowsiness and improving performance. But the effect of the surrounding environment when taking a nap on the quality of the nap (eliminating drowsiness and improving performance) is not clear. In previous studies about nap, it has been described about optical nap length (Hayashi *et al*., 1999, 2003, 2004, 2005), light effect (Hayashi *et al*., 2007), sound effect (Toma *et al*., 2004). However, it is still unknown about effect of a thermal environment on nap quality.

Since the environmental temperature controlled by the air conditioner directly affects the body temperature regulation, it is considered to have a great influence on the "sleep quality" that rests the brain. In addition, air conditioners are becoming widespread all over the world, and more and more homes are installing "one air conditioner in one room". Therefore, in this study, we focus on thermal control during nap using an air conditioner that can be widely applied, and report the results of evaluating the effect of environmental temperature control on the quality of nap (eliminating drowsiness and improving performance).

2. Optimal thermal control for daytime naps

Room temperature inside the nap room is adjusted during the 30-minute nap according to the three stages of "Reclining for nap," "Sleeping," and "Waking from nap." And the environmental temperature at each stage was controlled to ensure a comfortable and moderate sleep depth. Fig 1 show the example of the thermal control for nap.

(1) Reclining for nap...
The warm environment is thought to enhance relaxation before the nap, which accelerate the onset of sleep.

(2) Sleeping...
Assist restful sleep with a Slightly cooler room temperature

(3) Waking from nap...
At higher temperatures, it encourages the body to awaken

And Fig.2 show the typical example of sleep depth by this thermal control (W:wake, R:REM sleep, N1: NREM Sleep Stage 1, N2: NREM Sleep Stage 2, N3: NREM Sleep Stage 3).

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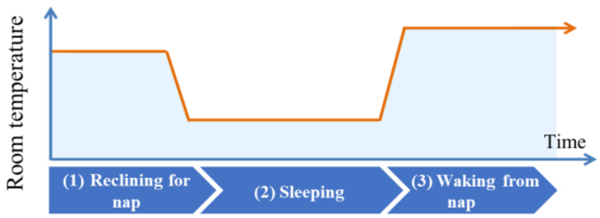

Fig. 1 the thermal control example for nap

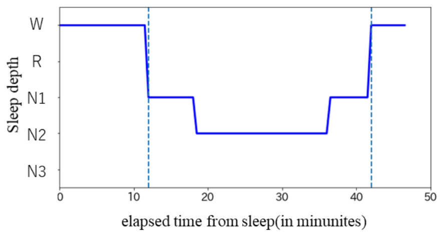

Fig. 2 the typical example of sleep depth

3. Experimental Environment

3.1 nap room

A nap room of H2315 x W (2400 + 385) x D1200 mm (Fig. 3) was created, and a bed was installed in the nap room. During the test, the entrance sliding door was kept closed, and the test was conducted while ensuring sound insulation and light shielding. The humidity inside the experimental nap room remains within a range of 40-60%, and a small space multi-cassette air conditioner "cocotas" manufactured by Daikin Industries was installed to control the temperature of the nap room.

Fig. 3 nap room

3.2 Experimental equipment

Test subjects wear an electroencephalograph G (Sleep Scope, SleepWell Co., Osaka, Japan) (Yoshida *et al*., 2015) and EEG during sleep of the subject was measured.And The room temperature of the nap room was measured using environmental sensor (2JCIE-BU01, OMRON Co., Kyoto, Japan).

4. Method

4.1 Participants and Protocol

The test subjects are 6 males and 5 females in their twenties, and the amount of their clothes was kept constant. From January 2020 to February 2022, 143 tests were conducted. The test subject is given a questionnaire on drowsiness (The Stanford Sleepiness Scale, Table1), and 2 types of productivity measurement tests (PVT-B; Psychomoter Vigilance Task, Fig. 4 and N-Back task, Fig. 5) are conducted. PVT-B objectively assesses fatigue-related changes in alertness nap associated with sleep loss, extended wakefulness, 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.

After that, a 10-minute rest period is provided before the test subject takes a 30-minute nap. After waking, the test subject receives another rest period of 5 minutes and is again given a questionnaire on drowsiness. These productivity measurement tests are administered twice to the test subject after waking at 1-hour and 3-hour intervals.

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

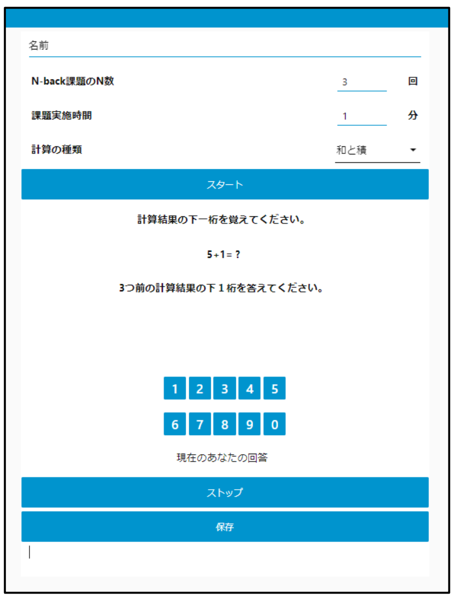

Fig. 5 N-Back Task screen

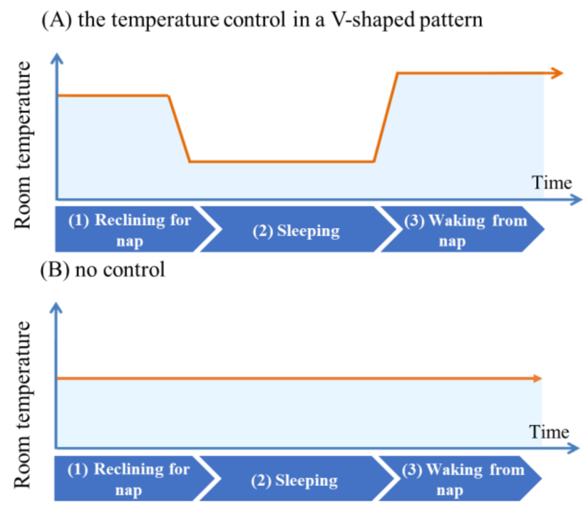

Fig. 6 the thermal control example for nap (A: the temperature control in a V-shaped pattern, B:no thermal control)

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.

4.2 Room temperature conditions

Room temperature inside the nap room is adjusted during the 30-minute nap according to the three stages of “Reclining for nap,” “Sleeping,” and “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. At the time of nap, the following two room temperature environments were applied.

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.

5. Results

5.1 (1) Reclining for nap

Fig. 7 shows the results of sleep onset latency at 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 ℃ or less), neutral (26 ℃), or high (27℃). 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℃).

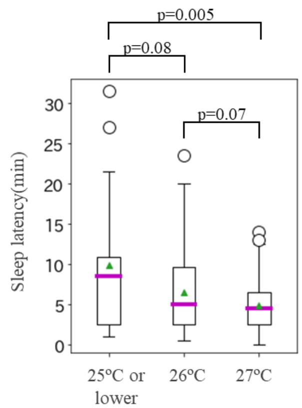

Fig. 7 Sleep onset latency (minutes) and room temperature (°C) before sleep onset

5.1 (2) Sleeping

Daytime naps are said to be "optimal for 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". The experiment was conducted. It was confirmed that test subjects reached and maintained N2 10 minutes after the onset of sleep at a room temperature of 26°C, compared to no change in room temperature (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.

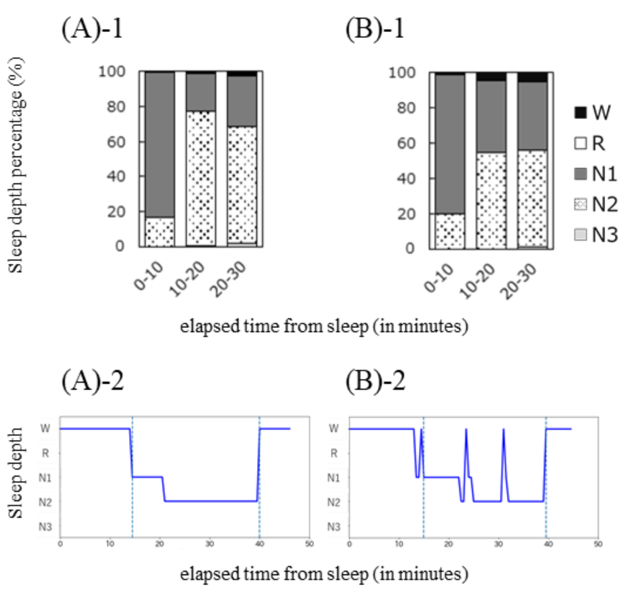

Fig. 8 Sleep depth percentage (%) and elapsed time from sleep (in minutes) (A-1: control A, B-1: control B) Sleep depth and elapsed time from sleep (in minutes) (A-2: control A, B-2: Control B)

5.1 (3) Waking from nap

Contrary to the sleeping conditions during sleep, we hypothesized that "a high room temperature has the effect of promoting awakening" and verified that raising the room temperature immediately before waking up promotes 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.

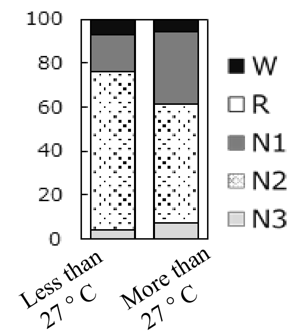

Fig. 9 Sleep depth percentage (%) and room temperature (° C) before waking

5.1 Result: Thermal control method obtained from the demonstration result

From the results of 5.1(1), (2) and (3), the thermal control method shown in Fig. 10 is considered to be optimal for efficient short-time sleep during the day.

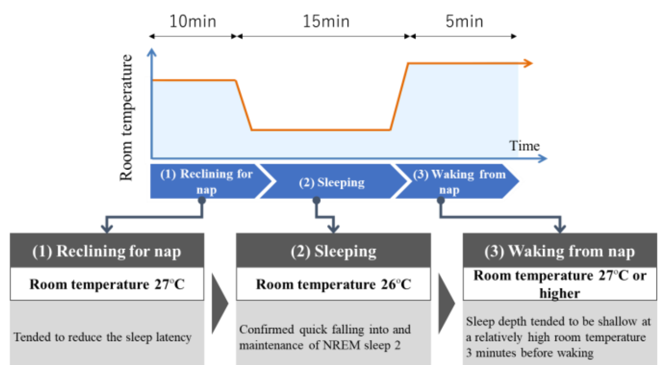

Fig. 10 optimal thermal control

5.2 Performance improvement effect with or without thermal control

This time, we also verified the effect of the application of thermal control on the performance after waking up. As for the verification method, three items of "reaction speed, working memory, and drowsiness" were compared 1 hour after waking up and 3 hours after waking up. 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 rate	Working Memory	Drowsiness
Improvement 1hour after waking	9%	32%	12%
Improvement 3hours after waking	27%	26%	14%

6. Discussions

We introduced a thermal control that allows you to take a nap comfortably and effectively even during the daytime when your arousal level is high. In addition, taking a 30-minute nap during the day using this technology has the effect of reducing drowsiness after waking up and improving reaction speed and working memory compared to taking a nap without thermal control.

In future efforts, we would like to consider customizing the thermal control in consideration of the following two points.

1). Gender difference

2). Circadian rhythm

In fact, the results of this experiment also show the effects of 1). gender differences and 2). circadian rhythms, and we believe that more precise evaluation of these results will enable the realization of individual thermal control methods.

6.1 Gender difference

Regarding 5.1 (1), we received multiple answers such as "it was cold" and "it was hot" in the questionnaire after taking a nap, so we examined how to feel the temperature between men and women. We compared sleep onset latency by gender for the lower room temperature of 25°C. As a result, as shown in Fig.11, no significant difference was observed between men and women. However, 43% of women (3 out of 7 cases) and 23% of men (3 out of 13 cases) answered that they were "cold" by the time they fell asleep. Therefore, it was considered that women tended to feel colder.

On the other hand, when the room temperature was slightly warmer at 27 ° C, a significant difference was found when comparing sleep onset latency by gender (Fig. 12, $p < 0.05$). Furthermore, 2.3% of women (1 out of 43 cases) and 5.1% of men (4 out of 78 cases) answered that they were "hot" by the time they fell asleep. Therefore, it was suggested that men may tend to feel hotter.

6.2 Circadian rhythm

Under the influence of circadian rhythm, it is generally said that it is hard to feel sleepy in the morning and it feels sleepy in the afternoon (Lavie, P *et al*., 1985).

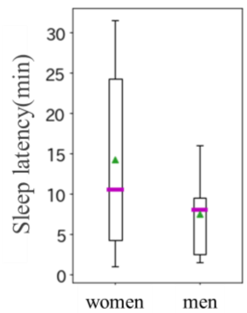

Fig. 11 Sleep onset latency (minutes) for men and women at room temperature of 25° C

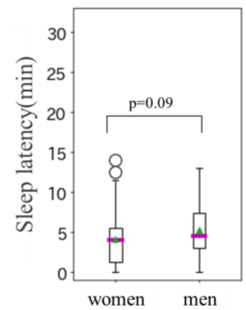

Fig. 12 Sleep onset latency (minutes) for men and women at room temperature of 27 ° C

Fig.13 shows an example of general sleep depth when taking a nap in the morning and taking a nap in the afternoon. As these figures show, drowsiness is less likely to be felt in the morning, resulting in lighter sleep and increased awakening. On the other hand, since it is easy to feel drowsiness in the afternoon, the depth of sleep tends to become deeper as time passes after sleep onset.

Therefore, by applying the result of 5.1(3), in the case of a nap in the morning, we will consider maintaining the room temperature while sleeping without raising it before waking up in order to obtain sufficient N2 time. In the case of a nap in the afternoon, we will consider raising the room temperature before waking up in order to avoid reaching N3.

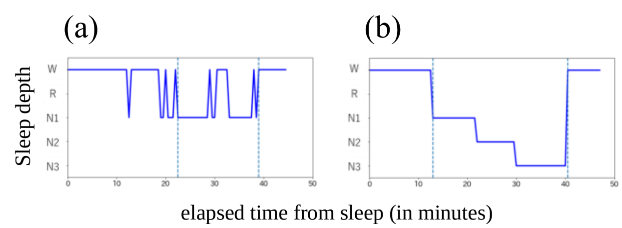

Fig. 13 Sleep depth and elapsed time from sleep (in minutes) (a: in the morning, b: in the afternoon)

7. Conclusion

Thermal control was introduced that enables comfortable and efficient naps even during the day when the degree of alertness is elevated. Additionally, when a 30-minute nap is taken during the day with heat control using this technology, compared to no use of heat control, drowsiness decreases while reaction speed and working memory improve.

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