The Effect of Light Interventions on Nap Quality and Subjective Alertness

Yuhao Wu [1], Yuanli Yang [2], Kai Liu [2], Min Cheng [2], Genxing Ren [1], Nianyu Zou [1], Ling Yu [1], Xiaoyang He [1,a *]

[1] School of Information Science and Engineering, Dalian Polytechnic University, Dalian 116034, Liaoning, China

[2] CQC Standard (Shanghai) Testing Technology Co., Ltd, Shanghai 200233, China

* hexy@dlpu.edu.cn; phone 136 2408 8025

Abstract. The human eyes can perceive light even when napping during the day. In order to further investigate the effects of constant light exposure during napping on nap quality and subjective alertness, seven lighting conditions were designed in this paper, L0 (darkness), L1 (60 lx, 2800 k), L2 (300 lx, 2800 k), L3 (600 lx, 2800 k), L4 (60 lx, 5800 k), L5 (300 lx, 5800 k), L6 (600 lx, 5800 k). 12 participants were invited to perform a 30-minute light intervention nap experiment. Participants' Pittsburgh Sleep Quality Index (PSQI), Electroencephalographic (EEG), Karolinska Sleepiness Scale (KSS), skin temperature, and heart rate data were recorded. The results show that at L2 afternoon nap, θ band share is higher than other lighting conditions. At L6 afternoon nap, the δ band share was the lowest. High illuminance and low CCT significantly affected immediate subjective alertness during nap wakefulness, but reduced afternoon alertness was not related to light during nap. Although post-nap vigilance was lowest in L0 darkness, it rose rapidly to a maximum within 30 min of waking. From 0-25 min of napping, heart rate decreased significantly at L1 vs. L4, and skin temperature increased significantly at L2 vs. L5. None of the seven lighting conditions (L0-L6) inhibited participants' napping to a greater extent, and high illuminance and high colour temperature did not significantly increase the level of nap arousal (25-30 min).

Keywords: Napping, Constant light exposure, Subjective alertness

1. Introduction

Office workers and students who work long hours, often take naps after lunch at workplaces in order to reduce fatigue in the morning or to make up for the lack of sleep [1]. During the daytime, alertness decreases over time, which can lead to a serious decline in work efficiency and accidents, so it is beneficial to demonstrate optimal alertness for daily life [2]. Research has shown that napping is an effective response to interrupt the persistent decline in alertness and performance after lunch[3]. A nap of about 30 minutes can restore some alertness and enhance a range of cognitive performance[4]. But waking up from a nap is often accompanied by sleep inertia. Even though sleep inertia melts away quickly within 30 minutes[5]. Giving light after a nap, or using bright light stimulation during the midday break instead of a nap, can have the effect of reducing sleep inertia and increasing subsequent productivity and alertness[6]. However, few studies have addressed the quality of the nap itself. In reality it is very common to have some level of light during naps, and the effect of light on napping has not been studied enough [7]. Past studies have demonstrated that light triggers non-visual effects (NIF) through intrinsic photosensitive retinal ganglion cells (ipRGCs) in the retina and affects cognitive responses such as subjective vigilance [8]. During homeostatic sleep, light affects the EEG, subjective alertness indicators, skin temperature, heart rate, etc., of nappers, and it is important to promote healthy lighting and Human-Centric Lighting [9].

2. Methodology

2.1 Participants

Participants had no history of drug or alcohol abuse, no psychological or psychiatric problems, and no history of sleep disorders. Considering the above factors, a total of 12 postgraduate students (8 males and 4 females, aged 22-25 years) were screened in the university.

2.2 Experimental design

2.2.1 Experimental site

The experimental site was Dalian, Liaoning Province, China, and a windowless laboratory within the Dalian Polytechnic University was chosen as the napping room for this experiment. The room dimensions were 4.2 × 2.7 × 3 (m). A recliner was placed in the middle of the laboratory, and the elevation angle of the recliner was adjusted to the vertical height of the participant's head to the ground of 1.2 (m), as shown in Fig. 1, for a comfortable nap while facilitating the measurement and calculation of ocular perpendicularity. Each participant napped in the same position.

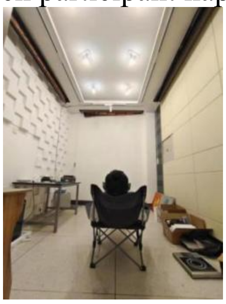

Fig. 1. Participants were recorded in a nap experiment using L2 (300 lx,2800 k) as an example.

2.2.2 Light parameters

The light in the laboratory is provided by 6 sets (groups of 3) of dimmable LED (Kodect) mounted on the top, and the entire spatial light environment is designed to be evenly distributed, with no natural light intervening. This study set three illuminance levels (60 lx, 300 lx, 600 lx of desktop illuminance) and two CCT levels (2800 k, 5800 k) as independent variables in a within-subjects design. The seven nap lighting conditions were composed as L0 (darkness), L1 (60 lx, 2800 k), L2 (300 lx, 2800 k), L3 (600 lx, 2800 k), L4 (60 lx, 5800 k), L5 (300 lx, 5800 k), and L6 (600 lx, 5800 k). The specific light parameters are shown in Table 1 and the relative spectral power distribution is shown in Fig. 2. The tabletop illuminance, eye vertical illuminance, photon irradiance and α-Opic irradiance followed CIE S026 [10].

Table 1. Light parameters for different lighting conditions

Measures	L0	L1	L2	L3	L4	L5	L6
Eh (lx)	/	60	300	600	60	300	600
Ev (lx)	/	20	100	200	20	100	200
CCT (K)	/	2800	2800	2800	5800	5800	5800
EML(Em. lx)	/	28.2	149.7	296.4	52.86	274.8	547.2
ED65v, mel(lx)	/	25.93	131.93	272.38	49.26	243.93	502.39
ED65v, sc (lx)	/	19.3	104.07	207.86	53.74	272.94	545.94
ED65v, mc (lx)	/	48.24	234.91	485.94	59.45	282.14	582.48
ED65v, lc (lx)	/	61.77	295.55	616.73	61.64	290.21	600.93
ED65v, rh (lx)	/	31.22	156.05	321.69	52.19	254.41	523.69

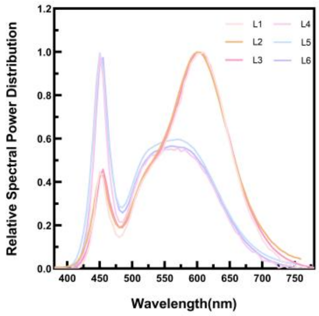

Fig. 2. Relative spectral power distribution for 6 lighting conditions.

2.2.3 Experimental Procedure

As shown in Fig. 3, participants arrived at their work position at around 9:00 am on each weekday (Monday to Friday) to carry out research-related tasks until lunch (around 11:40 am) to fill in the KSS scale once, and returned to their work position at the end of lunch to carry out relaxation activities (playing with their mobile phones or reading, etc.). Arrive at the laboratory 10 minutes before the nap experiment (around 12:30), put on the EEG, heart rate, and temperature equipment, and fill out the KSS once, then gradually enter the nap state in the recliner (around 5 minutes). The recorder observed from outside the room and began recording data when the real-time trends in brain waves and heart rate and temperature gradually approached a plateau (12:40). Participants were given a 30-minute nap opportunity. After 30 min (13:10), the data were saved, the participant was awakened by gently knocking on the door and the KSS was reported verbally to end the experiment. Before 5 p.m., participants remained engaged in a certain amount of research and study work as in the morning, and the KSS was recorded once for each half hour after the nap, for a total of six times.

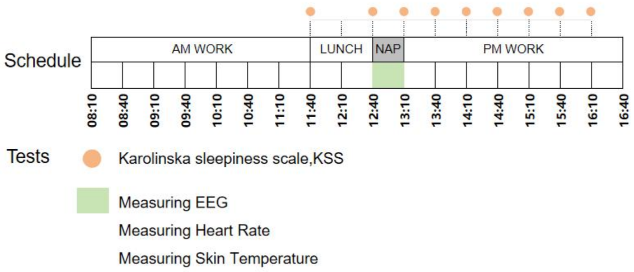

Fig. 3. Experimental Procedures and Tests.

2.3 Measurements

2.3.1 Sleep parameters

Participants' EEG signal data were recorded continuously throughout the 30-minute nap and then imported into EEGLAB, and four EEG bands, α (8-13 HZ), δ (0.5-4 Hz), θ (4-7 Hz), and β (13-30 HZ), were extracted by FFT. Participants' heart rates during napping were recorded by the bracelet (Xiaomi Bracelet 7) every five minutes, recording data a total of seven times. Skin temperature was continuously monitored by a second-by-second Smart Thermometer Pro instrument placed in the depression below the chest, every five minutes, recording data a total of seven times.

2.3.2 Subjective variables

The Pittsburgh Sleep Quality Index (PSQI) is widely used to assess sleep quality[11]. All participants' scores were between 4 and 6 before the experiment, indicating that nighttime sleep quality was good and did not have a negative impact on napping. We used the Karoliska Sleepiness Scale (KSS) [12]. Higher KSS scores mean greater sleepiness.

2.4 Statistical analyses

All data were analysed in IBM SPSS Statistics 25.0 and GraphPad Prism 8 for analysing the effects of seven sets of light environments set up to influence napping. A one-way repeated measures ANOVA followed by a paired t-test was performed to account for individual differences between participants and within-subjects design.

3. Results

3.1 Polysomnography

In Fig. 4(a), it is shown that the α band share is highest at L0 (darkness). Under L2, the α band percentage was the lowest. This indicates that participants are more relaxed and calm when napping in a dark environment. Fig. 4(b) shows that under L0, the β band is the lowest. Under the L6 group, the β band was the highest, indicating that alertness in napping is still affected by light. Fig. 4(c) shows that the θ band share is the highest at L2, which indicates that the participants outperformed the other groups in the napping state. Under L6, the θ band is the lowest, which is the same as Fig. 4(b) showing the β band, indicating that high brightness and high CCT affect the napping state, and there was a significant difference between L2 and L6 ($p < 0.05$). Fig. 4 (d) shows that under L5, the δ band was the highest, indicating that the participants had deeper naps and higher quality naps.

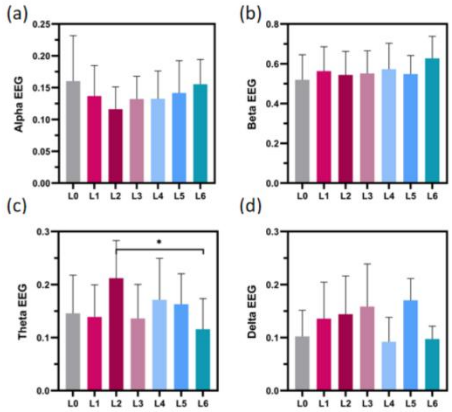

Fig. 4. Standard deviation of the converted EEG Alpha (a), Beta (b), Theta (c), Delta (d) power in each trial under illumination conditions (L0-L6).

3.2 Drowsiness and Alertness

In Fig. 5(a), under the nap just awake time phase (0 a), KSS scores are highest and sleepiness is strongest at L0, followed by 60 lx, 300 lx, and 600 lx. At the same time, the difference in alertness exhibited between L0 and 600lx was statistically significant ($p < 0.05$) . It indicates that the higher illuminance, the higher level of alertness when the eyes are open. Post-nap KSS scores under L0 were highest and most alert at the 90th minute after nap, around 3 p.m., but decreased substantially over the next two hours. Individual subjective sleepiness was at its highest around 4:00 to 4:30 p.m.

In Fig. 5(b), the highest KSS scores and the strongest sleepiness were observed at L0 under the nap just awake time phase (0 a), followed by 5800 k, 2800 k. Individual drowsiness reflected significant differences at both L0 and 2800 k at the 30th and 90th minutes after afternoon naps, suggesting that around two hours after afternoon naps at low CCT, subjective alertness would be lower than in darkness, and to a lesser extent at high CCT. Fig. 6(a) shows the statistically significant ($p < 0.05$) difference in subjective sleepiness before and after napping at L2 vs. L6. (L0-L6) during the 30 min after nap are shown by Fig. 6(b). Sleep inertia faded the fastest and reached the highest alertness quickly after napping in L0, then L4, L1 followed by all three groups with statistical significance ($p<0.05$).

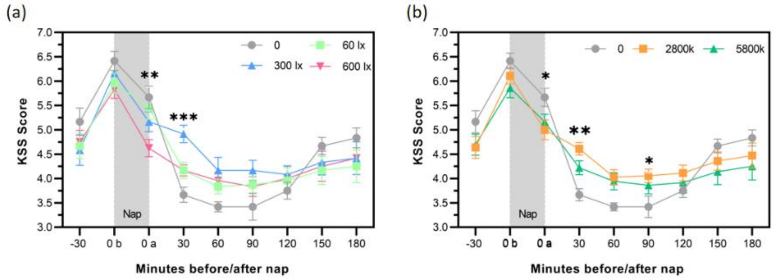

Fig. 5. Standard Error of Mean (SEM) of KSS during different working hours before and after light perception and nap. (a) and (b) are comparisons between different EV (0 lx vs. 60 lx vs. 300 lx vs. 600 lx) and CCT (0 k vs. 2800 k vs. 5800 k), respectively.

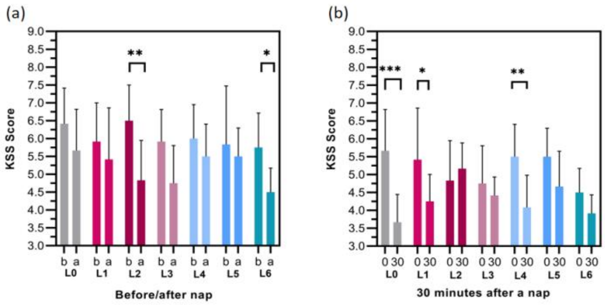

Fig. 6.(a) Difference in KSS scores between one minute before and one minute after a nap under illuminated conditions (L0-L6). (b) Difference in KSS scores between one minute after a nap and 30 minutes after a nap under lighting conditions (L0-L6).

3.3 Heart rate and skin temperature

All lighting conditions (L0-L6) showed increased levels of nap arousal (elevated heart rate) within 20, 25, and 30 minutes of napping.In Fig. 8, there is an overall increasing trend in skin temperature under various lighting conditions (L0-L6). The overall body temperature under L4 was slightly lower than the other groups, and the body temperatures under L2 & L5 stayed higher, but no significant difference was found under the specific time period ($p > 0.05$).

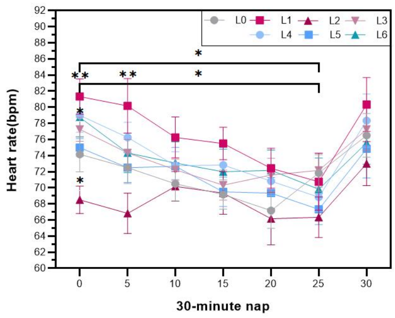

Fig.7. Changes in heart rate every five minutes during nap time under illuminated conditions (L0-L6).

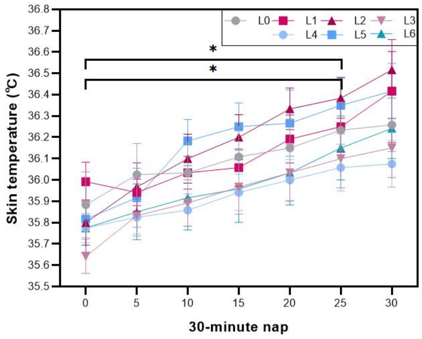

Fig. 8. Changes in skin temperature every five minutes in the afternoon nap under lighting conditions (L0-L6).

4. Discussion

In terms of nap quality, according to the participants' recount orally, all could nap normally and fall asleep in a bright environment. The highest percentage of EEG δ band was observed at L2 nap, indicating that participants slept more deeply in this condition. θ band which reflects the sleepy state, is significantly different between L2 and L6 and L6 also has the highest percentage of α and β bands, which indicate the active state, so it is not recommended to use high illuminance and high CCT for napping. And from the analysis of the KSS data before and after the nap, the nap at L2 showed the greatest recovery of subjective alertness, the lowest heart rate, and the fastest increase in body temperature, and all of them were statistically significant. This suggests that illuminance and CCT can have an effect on the nap itself. So in terms of nap quality, it is better to choose at L2. During the arousal phase of the nap (25 min-30 min), heart rate and skin temperature did not show significant differences. Whether the delayed drop or rapid increase in body temperature and heart rate during naps is related to the acute effects of light needs to be studied over a longer period of time[13].

In terms of sleep inertia after the nap (30 minutes), analysis of the KSS showed that subjective sleepiness was higher in all individuals just after the nap than in the following 3 hours, with each person experiencing some degree of sleep inertia, but also subsiding within 30 minutes (subjective sleepiness decreased), which is in line with what has been reported in previous studies[14]. We analysed and assessed differences in sleep inertia within 30 minutes after a nap and individual subjective vigilance within about 3 hours of afternoon work time after a nap. Both high illuminance and high CCT perform well when the eyes are just opened from a nap, which may be useful for designing dynamic lighting for naps and for getting into operation immediately after a nap by removing sleep inertia. While daytime light affects the body's melatonin production and reduces sleepiness, the opposite is true for daytime naps avoiding light[15].

5. Conclusion

The present study of 12 participants who took light-intervened naps under seven lighting conditions showed that individual subjective alertness during the day was significantly affected by napping, and that individuals with diminished subjective alertness in the afternoon did not show a dependence on light in napping. Immediate post-nap vigilance at high illuminance (300 lx, 600 lx) was significantly different from that at low illuminance (0 lx, 60 lx). A deeper level of drowsiness exists after waking up from a nap in a dark environment, and a certain amount of risk needs to be considered for immediate operations. Napping at desktop illuminance (300 lx) with a low CCT (2800 k) can be an effective light strategy to block fatigue and restore alertness.

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