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The impact of morning light intensity and environmental temperature on body temperatures and alertness

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ABSTRACT

Indoor temperature and light exposure are known to affect body temperature, productivity and alertness of building occupants. However, not much is known about the interaction between light and temperature exposure and the relationship between morning light induced alertness and its effect on body temperature. Light intensity and room temperature during morning office hours were investigated under strictly controlled conditions. In a randomized crossover study, two white light conditions (4000 K, either bright 1200 lx or dim 5 lx) under three different room temperatures (26, 29 and 32 °C) were investigated. A lower room temperature increased the core body temperature (CBT) and lowered skin temperature and the distal-proximal temperature gradient (DPG). Moreover, a lower room temperature reduced the subjective sleepiness and reaction time on an auditory psychomotor vigilance task (PVT), irrespective of the light condition. Interestingly, the morning bright light exposure did affect thermophysiological parameters, i.e. it decreased plasma cortisol, CBT and proximal skin temperature and increased the DPG, irrespective of the room temperature. During the bright light session, subjective sleepiness decreased irrespective of the room temperature. However, the change in sleepiness due to the light exposure was not related to these physiological changes.

1. Introduction

Light and temperature exposure can increase our alertness during the day and sleepiness in the evening and night. Many temperature and light studies have been carried out in search for optimal conditions. However, most studies tested light and temperature effects separately while the interaction between ambient temperature and lighting conditions may result in a larger acceptance range for one of the conditions without performance decrements. For example, bright light may be able to (partly) mitigate the performance decrements that can occur under more elevated ambient temperatures. It is demonstrated that the intensity, wavelength and duration of light exposure affect alertness and performance during cognitive tasks [1,2]. Experiments on only the effects of light, show that daytime bright light decreases reaction time and sleepiness [3]. Additionally, experiments in a simulated office environment show that the addition of the task lighting improved performance as compared to ceiling luminaries only [4]. During a laboratory study it was found that bright light (2000 lx) improves alertness and productivity during the night and has a positive effect on mood during the day compared to dim light [5]. Studies on the relation between indoor temperature and office tasks productivity revealed that there is an room temperature for which performance of building occupants is highest [6]. Additionally, a higher thermal satisfaction is associated with improved productivity and mood [7,8]. Romeijn et al. (2012) also found an optimum to obtain the highest alertness, which is at lower skin temperatures compared to the optimum for sleepiness [9].

A larger distal-proximal skin temperature gradient (DPG) in the evening is associated with a higher sleepiness. Experiments show that evening light can delay the natural decline in core body temperature (CBT), proximal skin temperature and the natural increase in DPG along with a reduced sleepiness [10]. Yet, little is known about the effects of light intensity on thermophysiology at different times of day and its relation to alertness. Contrary to our expectations, a few studies indicate that bright light exposure in the morning decreases the CBT [11,12]. Ruger et al. (2006) found no effect of afternoon bright light on

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CBT, but bright light reduced sleepiness [13]. Due to the absent of physiological changes, they suggest that the effect on sleepiness must be caused by an alternative mechanism or pathway which immediately influences alertness in humans. Although light can affect body temperatures, it remains unknown how light history, timing, duration, intensity and spectrum of a light exposure impact thermophysiology [14].

The main objective is to test the effects of morning light intensity and temperature condition on alertness and body temperature. We hypothesise that bright light reduces sleepiness and improves task performance independently of the temperature exposure. We expect that during the morning bright light results in a faster increase of CBT and faster decrease of the DPG due to its suppressive effect on melatonin production. Secondly we hypothesise that a relatively high temperature increase sleepiness and reduces task performance along with a higher means skin temperature and a higher DPG. The second objective is to investigate whether morning light induced alertness changes coincide with changes in body temperature (distribution).

2. Method

The Medical Ethical Committee of Maastricht University Medical Centre + approved the study protocol. All participants provided a written informed consent prior to the experiments. All procedures were conducted in accordance with the principles of the Declaration of Helsinki.

2.1. Participants

Nineteen healthy female participants took part in the study. Participants were recruited by advertisements on local billboards at the university and at the website www.digi-prik.nl. Participants were screened to meet the following inclusion criteria: Caucasian, generally healthy, age 18 to 30 years, BMI 18–25 kg/m^2, using microgynon 30 or any other anti contraceptive pill consisting of a levonorgestrel/ethinylestradiol combination, and a normal chronotype (Table 1). Exclusion criteria consisted of: colour blindness, ocular pathologies, medication use, pregnancy, hypertension, general feeling of illness at day of experiment, (history of) cardiovascular diseases, contraindication of the telemetric pill, and employees of our research group. Participants were screened by means of a medical questionnaire and a chronotype questionnaire [15].

2.2. Protocol

In a randomized crossover design all participants took part in two identical laboratory sessions that only differed in lighting exposure; one session occurred under dim light (5 lx) and the other under bright light (1200 lx) (Fig. 1). The order of the sessions was randomized among participants. The time between on participants' two experimental sessions was 1 or 2 weeks. Both sessions started with baseline exposure at a thermo neutral ambient temperature (29 °C) and a moderate light intensity of 250 lx and 4000 K measured in the outward direction of the optical axis at the outer surface of the volunteers eye in its most usual viewing direction. After the baseline, participants were exposed to a series of three ambient temperatures (cool, 26 °C; thermo-neutral, 29 °C; and warm, 32 °C), either under bright light or under dim light. The order of the cool and warm condition was randomized across participants; after baseline half of the participants started with the warm condition and ended with the cool condition, the other half started with the cool condition, ending with the warm condition. The thermo-neutral condition was always used as the second condition, to ensure that the magnitude of the change in ambient temperature between the conditions was equal. For each participant, the order of the temperature conditions was identical in both light sessions.

Table 1
Participant characteristics.

Characteristic	Average (± SD)
Age (yr)	22.3 ± 1.9
Body mass (kg)	62.7 ± 5.5
Height (m)	1.70 ± 0.07
BMI (kg/m^2)	21.7 ± 1.8
Body fat (%)	30.2 ± 3.2

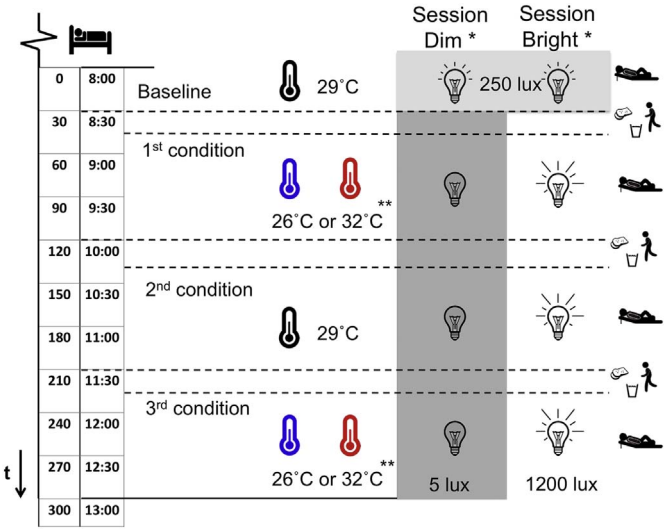

Fig. 1. Schedule of the experiments. *The order of the sessions was randomized among participants; half of them started with the dim light session and the others with the bright light session. **The order of the temperature was randomized among participants, but remained identical between the two sessions of each participant.

A week prior to the experiments the participant kept an evening and morning sleep diary (see Section 2.3 Measurements for details). All participants took the anti contraceptive pill during the days of the experiments. The evening before the experiments, the participants arrived at the university at 9:00 PM. They refrained from food, caffeine and alcoholic consumption 12 h before the experiment started. In the evening, the Psychomotor Vigilance Task (PVT) and the questionnaires were trained. The participants also swallowed a capsule to measure CBT (see Measurements Section 2.3.5 for details). They slept in a respiration/climate chamber with a constant indoor ambient temperature of 21 °C, between 11.00 PM and 7.00 AM participants were in dim light (i.e., the lighting was switched off (< 1 lx)). During the night they wore an actiwatch to monitor sleep. About 15 min after waking up, the participant ate a small, standardized breakfast (cracker (53 kcal) and water). After that, skin temperature loggers, and devices for measuring CBT were attached and a venous catheter was placed in the antecubital vein. Participants were clothed in underwear (0.04 clo). The preparations between 7:30 and 8:00 AM were done under baseline lighting conditions (250 lx). Subsequently, the participant entered the respiration chamber for the start of the baseline measurements at 8:00 AM. Here, the skin blood flow probes were attached to the ventral surface of the hand and the underarm. Finally a mask of the indirect calorimetry meter was put over the mouth and nose. The blood pressure monitor was placed on the arm without the catheter.

Once the participants were lying in semi-supine position, the experiment started with a 30-minute lasting baseline with lighting at 250 lx and a thermo-neutral room temperature (29 °C). During the experiment participants filled out questionnaires about (e.g.) self assessed sleepiness (KSS) every 15 min and at the end of the baseline (t = 25 min) 40 ml blood was drawn. After 10 min blood pressure was measured and at the end of the baseline (t = 25 min) 40 ml blood was drawn. After the 30 min baseline, the participant moved to an adjacent