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Original scientific paper

Influence of Two Different Light Intensities from 16:00 to 20:30 Hours on Evening Dressing Behavior in the Cold

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A B S T R A C T

The present experiment tested our hypothesis that the subjects will wear more clothing in the evening cold under the influence of bright light exposure in the late afternoon and evening. Nine young female adults participated in this study. Light intensity was controlled from 9:00 h to 16:00 h at 100 lx, and from 16:00 h to 20:30 h either at 3000 lx in the bright light (»Bright«) or at 10 lx in the dim light (»Dim«) conditions. Light intensity was maintained at 10 lx from 20:30 h to 23:00 h. They were instructed to wear garments to maintain themselves to feel comfortable during the fall of ambient temperature from 30 °C to 15 °C (21:00 h ~ 22:00 h) and its constant temperature at 15 °C (22:00 h ~ 23:00 h). Most subjects dressed in heavier clothing in the »Bright« than in the »Dim« conditions. The evening fall of core temperature was significantly smaller and the urinary melatonin secretion was significantly lower in the »Bright« condition, suggesting that the set-point of core temperature has been set at a higher level during the evening and at night, being influenced by the less amount of melatonin secretion. Thus, it is concluded that the late afternoon and evening bright light exposure could accelerate the dressing behavior in the evening cold.

***Key words**: dressing behavior, bright/dim light exposure, melatonin, core temperature, set-point*

Introduction

The fact that the internal body temperature varies over 24 h is well known. Autonomic and behavioral regulatory responses to a given thermal stimulus are dependent on the time of the day. The dressing behavior, one of the behavioral regulatory responses, has been discussed in relation to several factors such as time of day, menstrual cycles and bright/dim light[1–3] In the previous studies, the authors have reported that the dressing behavior should be considered in relation to the circadian rhythm and the differences between the set-point and the actual value in core temperature.

There is some evidence that melatonin is a major regulator of the circadian rhythm of body temperature[4–7]. According to Cagnacci et al.[4], the circadian rhythms of plasma melatonin and core temperature are inversely related. On the other hand, Bojkowski et al.[8] reported that the magnitude of suppression of melatonin depends on the illuminance levels, a finding which has been supported by other's researches[6,9,10].

Recently, Kanikowska et al.[11] have found that salivary secretion in humans was significantly higher when women were sitting in bright light (5,000 lx), compared to the dim light (200 lx) in the morning, while it was significantly lower when subjects sat in bright rather than dim light in the evening. Also, if women are instructed to select their preferred ambient light intensity during wakefulness, they prefer a bright light intensity in the forenoon and a lower light intensity in the late afternoon and evening[12,13]. Bright light during the daytime increases the ability of the small intestine to digest and absorb carbohydrate compared with dim light while bright light in the evening inhibits its activity[14]. These all results suggest that bright light has different influences on physiological parameters, depending on the bright light exposure time of day and humans prefer different light intensity as function of time of day.

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Kim and Tokura[3] found that women wore less clothing in the evening cold when they had spent time in bright light (4,000 lx) for 8 hours from 10:00 h to 18:00 rather than in dim light (10 lx) during this time. In our present experiment, we hypothesize that, if subjects are exposed to bright light in the late afternoon and evening, subjects will wear more clothing in the evening cold, since although diurnal bright light exposure could increase nocturnal rise of melatonin more markedly, resulting in reduced set-point of core temperature[14], the late afternoon and evening bright light exposure could probably decrease nocturnal rise of melatonin, resulting in less reduction of set-point. In our previous results[3], we suggested how accurately the behavior was qualitatively useful for physiological needs since a change of a few tenths of a degree Celsius in the subject's set-point had an influence on dressing behavior. Thus, the present experiment was designed to examine the response of dressing behavior under the influence of different exposure time of bright light.

Materials and Methods

Subjects

Nine healthy young females (age 22±2.9 years, body height 161.7±2.6 cm, body weight 51.7±2.9 kg, body surface area 1.49±0.04 m^2, mean±SD) participated as subjects and gave written informed consent. The subject did not take oral contraceptives, and they were studied in the follicular phase to avoid the changes of temperature rhythm associated with ovulation. Although they were informed about the experimental procedure, the experimental aims and expectations were never told to them. All subjects were asked to go to bed at about 23:00 h and to get up at 7:00 h and to abstain from alcohol for one week before the test.

Procedure

The subjects entered the chamber at 8:30 h, the ambient temperature (T_a) and a relative humidity of which were regulated at 27 °C and 50% R.H. The subjects rested for 30 min in the chamber wearing comfortable garments, and sensors for the measurements of core and skin temperatures were attached. Light intensity was controlled from 9:00 h to 16:00 h at 100 lx, and from 16:00 h to 20:30 h either at 3,000 lx in the bright light condition (»Bright«) or at 10 lx in the dim light condition (»Dim«). Light intensity was maintained at 10 lx from 20:30 h to 23:00 h, and then completely dark until 07:00 h the next morning. During the sleep period, the subjects were covered with bedclothes (100% cotton). Figure 1 shows the experimental light conditions and experimental schedules.

Each subject participated on two days, one day for the »Bright« and the other day for the »Dim« condition, the sequence of exposure being a randomized cross-over design. Light exposure was from fluorescent tubes, which provided a light intensity of 3,000 lx at the distance of 1.5 m in front of the subjects. A rheostat controlled the light intensity, and the illuminance at an eye level was measured using an illuminance meter (Tokyo Photo-Electric Co.). During light exposure, the subjects were allowed to read, but not to close their eyes. The ambient temperature was then increased from 27 °C to 30 °C at 20:30 h and was regulated at 30 °C until 21:00 h, decreased gradually to 15 °C between 21:00 h and 22:00 h, and then maintained at 15 °C for an additional hour (22:00 h ~ 23:00 h). The period from 21:00 h to 23:00 h was used for measuring dressing behavior.

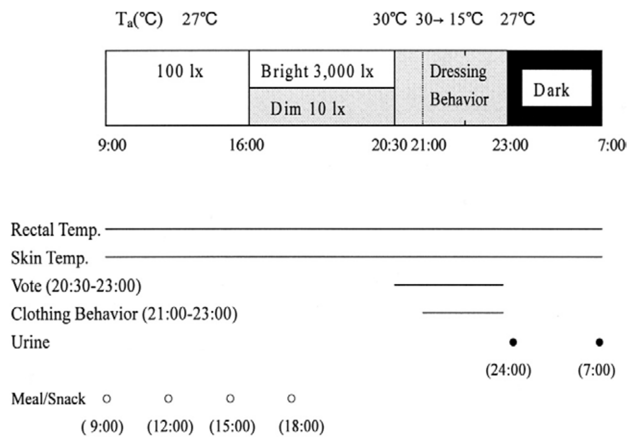

Fig. 1. Experimental schedule.

TABLE 1
THE WEIGHT AND CLO VALUE OF THE GARMENTS

		Weight (g)	Clo value
Upper part			
A1	camisole sleeveless	80	0.1225*
A2	camisole	120	0.1829*
A3	T-shirt	180	0.2578**
A4	half-shirt	140	0.1994**
A5	A4+ sleeve	40	0.0534**
A6	vest	220	0.3162**
A7	jumper	260	0.3746**
Lower part			
B1	shorts	60	0.0923*
B2	half pants	100	0.1410**
B3	B2+ pant leg	100	0.1410**
B4	thick pants	400	0.5790**
Socks			
C1	socks	60	0.0600#
	Total	1760	1.7778##

Clo values were calculated from equations of 0.0015W + 0.017 for *, 0.00146W – 0.0005 for **, 0.00075W + 0.015 for #, 0.00103W – 0.035 for ##, where W is weight of garment. (1981)

During the period from 20:30 h to 21:00 h, the subjects sat down while the chamber temperature was 30 °C, and they were then instructed to wear garments to maintain themselves to feel comfortable during the decrease of T_a (21:00 h ~ 22:00 h) and its maintenance at 15 °C (22:00 h ~ 23:00 h). The garments that were selected by the subjects are summarized in Table 1.

Subjects emptied their bladders at 20:00 h, and the first urine sample was collected at 24:00 h. The second urine sample was collected at 07:00 h. Urine volumes were measured by a mass cylinder. Five mL were then stored in a freezer for later analysis for melatonin. Meals were provided at 09:00 h, 12:00 h and 18:00 h, and a snack at 15:00 h. The subjects ate the same amount of calories in both experiment conditions and they were not permitted to take a nap during the daytime. They were allowed to listen to taped light music and read at book, while sitting on a sofa placed in front of the light source.

Physiological Measurements

Rectal temperature (T_{rec}) and skin temperatures (T_{sk}) at seven sites were recorded by thermistor probes every 5 min with accuracy of 0.01 °C with LT Logger (LT-8, Gram Corp., Japan). A rectal thermistor probe was inserted 12 cm beyond the anus and probes for T_{sk} were attached with adhesive tape on the skin surfaces of the forehead, trunk, thigh, arm, hand, leg, and foot. For proximal skin temperature, forehead, trunk and thigh skin temperature were combined later (forehead × 0.093 + trunk × 0.56 + thigh × 0.347), for distal skin temperature arm, hand, leg and foot skin temperature was combined (all later averaged) according to Kräuchi et al[15]. Temperature sensation and thermal comfort were assessed every 15 min during the dressing behavior period. Table 2 shows the scales for subjective assessments of temperature sensation and thermal comfort.

TABLE 2
VOTING SCALE

Temperature sensation		Thermal comfort	
3	hot	1	comfortable
2	warm	2	slightly uncomfortable
1	slightly warm	3	uncomfortable
0	neutral	4	very uncomfortable
–1	slightly cool		
–2	cool		
–3	cold		

Data Analysis

A two-factor analysis of variance (ANOVA) was performed (factor 1, the Bright and Dim lighting conditions;

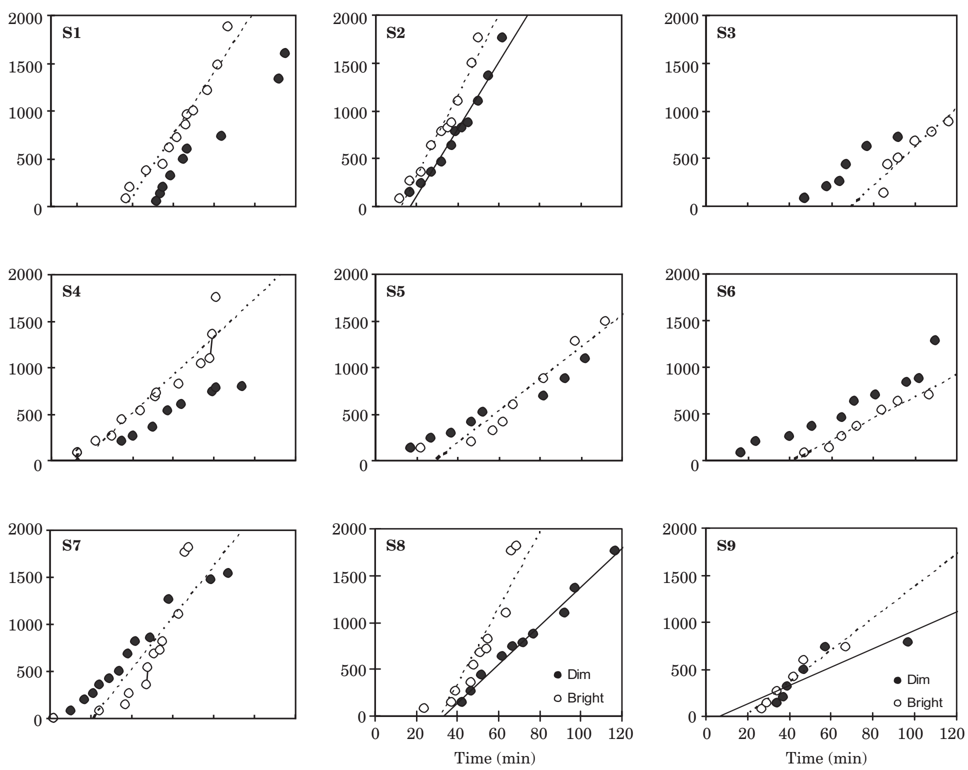

Fig. 2. An individual comparison in the time-course of the cumulative increases of the weight in the »Bright« and »Dim« conditions. 0 at the abscissa is the time when the ambient temperature (T_a) began to decrease at 21:00 h from 30 °C to 15 °C. T_a was then kept at 15 °C for an additional hour. Ordinate is the cumulative clothing weight worn by subjects in grams. Open circles and dotted line; »Bright« condition. Closed circles and solid line; »Dim« condition.

factor 2, the time courses of the variables). The two-tailed Student's *t*-test for paired differences was used to evaluate the mean values between two conditions. In all tests $p<0.05$ was regarded as significant.

Results

Figure 2 compares the time-courses of the cumulative increases of clothing weight in the »Bright« and »Dim« conditions, when the ambient temperature (T_a) was decreased from 30 °C to 15 °C (21:00 h ~ 22:00 h) and maintained at 15 °C for an additional hour (22:00 h ~ 23:00 h). In this Figure, the origin is the time (21:00 h) when the ambient temperature (T_a) began to decrease. It should be noted that all subjects except S6 dressed in heavier clothing and/or more quickly in the »Bright« condition than in the »Dim« condition. The amount of clothing worn by subject was 1429±159 g (mean±SEM) in the »Bright« and 1256±136 g in the »Dim«. It was significantly less in the »Dim« ($P<0.05$, df=8, F=4.3). The linear regression analysis of the relationship between cumulative increase of clothing weight and time are listed in Table 3. This table disclosed that the slopes of the equations were clearly greater (that is, clothing was put on more quickly) in the »Bright« than in the »Dim« condition ($p<0.01$, df=8, F=12.65)

The time-course of the mean rectal temperature (T_{rec}) of the 9 subjects in the two conditions is shown in the upper part of Figure 3. As seen in the figure, there were circadian changes in rectal temperature. It rose in the afternoon to reach a peak in the late evening, before falling rapidly after going to bed. It began to rise again during sleep in the early morning hours. The maximum rectal temperature value was 37.32±0.086 °C (mean±SEM) in the »Bright« and 37.37±0.110 °C in the »Dim« condition, which was significantly lower in the »Bright« ($p<0.01$, df=8, F=7.81). The minimum rectal temperature was significantly higher during the »Bright« condition ($p<0.05$, df=8, F=5.32), having the value of 36.49±0.084 °C in the »Bright« and 36.42±0.114° C in the »Dim« condition. The fall of rectal temperature from 23:00 h was less in the »Bright« condition (Fig. 3 bottom left, $p<0.05$) as was the rise from 03:00 h (Fig. 3 bottom right, $p<0.01$).

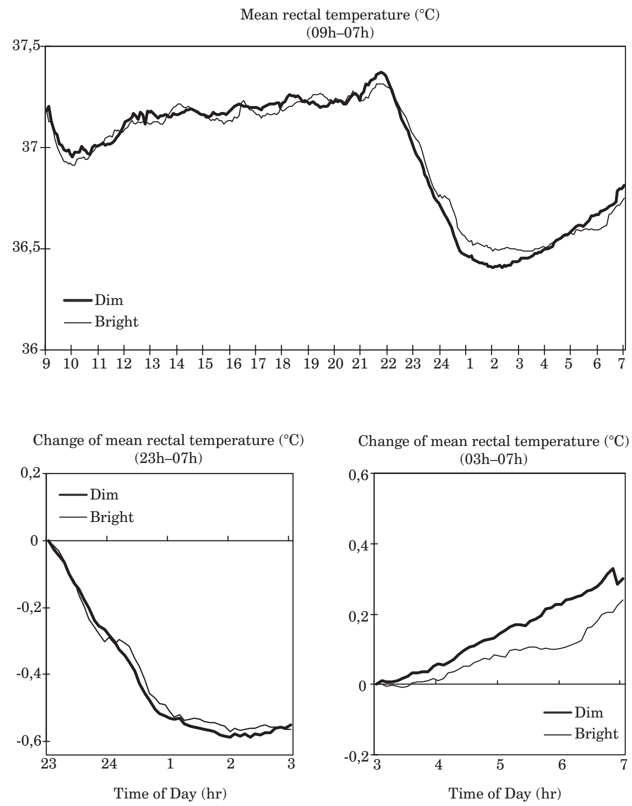

Fig. 3. The time-course of the mean rectal temperature (T_{rec}) of the 9 subjects in the in the »Bright« and »Dim« conditions (Top). The change of T_{rec} from 23:00 h to 03:00 h (Bottom, Left) and the change of T_{rec} from 03:00 h to 07:00 h (Bottom, Right) in the two conditions. Abscissa is the time of day. Dotted line; »Bright« condition. Solid line; »Dim« condition. Values are mean in 9 subjects.

TABLE 3
A COMPARISON OF CORRELATION EQUATION BETWEEN CLOTHING WEIGHT AND TIME IN THE DIM AND BRIGHT CONDITIONS

	Dim		Bright	
	y = ax + b	R^2	y = ax + b	R^2
S1	y = 21.628x – 982.15	0.9736	y = 32.456x – 1200.4	0.9531
S2	y = 34.815x – 578.25	0.9660	y = 41.777x – 514.68	0.9618
S3	y = 15.542x – 662.41	0.9355	y = 20.345x – 1423.80	0.8693
S4	y = 10.868x – 142.26	0.9669	y = 20.326x – 306.93	0.8979
S5	y = 10.464x – 58.94	0.9721	y = 17.024x – 494.40	0.9174
S6	y = 10.973x – 150.90	0.9292	y = 11.637x – 485.87	0.9633
S7	y = 20.076x – 105.95	0.9760	y = 27.119x – 561.98	0.7035
S8	y = 20.683x – 689.54	0.9884	y = 40.31x – 1277.4	0.8375
S9	y = 9.6915x – 55.675	0.7072	y = 16.915x – 320.17	0.9237
Mean	a = 17.19		a = 25.32	

a; $p<0.01$

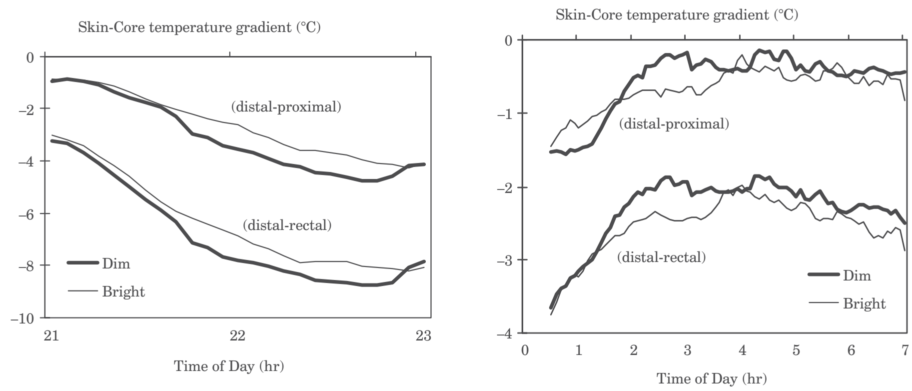

Fig. 4. The change of distal-proximal skin temperature gradient and distal-rectal temperature gradient during the dressing behavior and night sleep. Abscissa is the time of day. Dotted line; »Bright« condition. Solid line; »Dim« condition. Values are mean in 9 subjects.

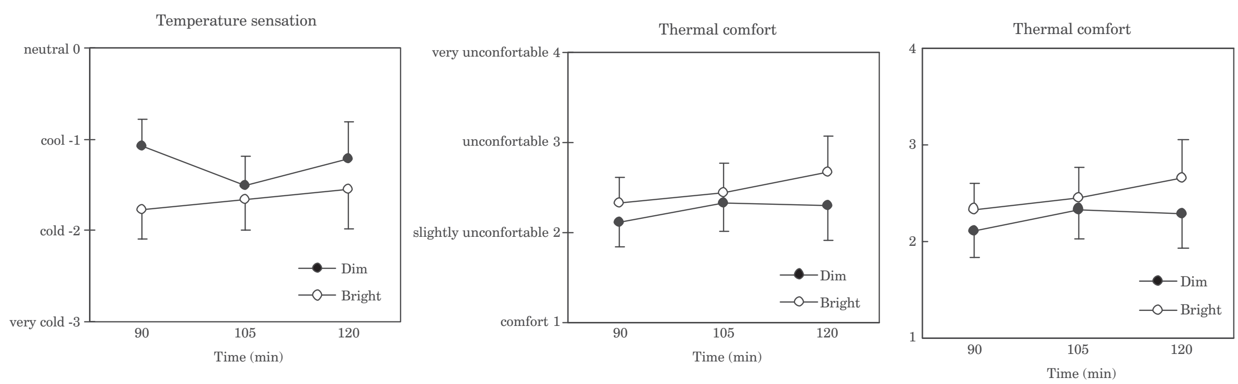

Fig. 5. Temperature sensation (Top) and thermal comfort (Bottom) during the last 30 min when dressing behavior is assessed. Abscissa is the same as Figure 2. Open circles; »Bright« condition. Closed circles; »Dim« condition. Values are X±SEM.

The differences between distal skin and proximal skin temperatures, and between distal skin and rectal temperatures are shown in Figure 4 during dressing behavior period (21:00 h ~ 23:00 h, Fig.4 top) and night sleep period (24:30 h ~ 7:00 h, Figure 4 bottom). Bearing in mind that urine was collected at 24:00 h, skin temperature gradient was calculated from 24:30 h. Distal-to-proximal skin temperature gradient (DPG) and distal-to-rectal temperature gradient (DCG) showed significantly high in »Bright« condition during dressing period ($p< 0.01$, both). However, distal-to-proximal skin temperature gradient and distal-to-rectal temperature gradient showed significantly high in »Dim« condition during sleep period ($p<0.01$, both). On the basis of these findings, during the dressing period the subjects put the heavier clothing in »Bright«, and during sleep period the decrease of rectal temperature was high in »Dim« condition.

Throughout the dressing period, when there was a decrease of T_a, the subjects felt cooler and less comfortable in the »Bright« condition than in the »Dim« condition. Figure 5 compares the assessments of temperature sensation and thermal comfort during the last 30 min when dressing behavior was assessed in two conditions. Temperature sensation was scored as being significantly lower in the »Bright« condition than in the »Dim« condition (Figure 5 top, $p<0.05$), indicating the subjects felt cooler in the »Bright« condition. Also the thermal comfort score was significantly higher in the »Bright« condition (Figure 5 bottom, $p<0.05$), indicating that the subjects felt less comfortable in this condition.

Figure 6 shows the urinary melatonin secretion in the two lighting conditions. The values of melatonin amount were 3759.24 pg in the »Dim« condition, 4134.16 pg in the »Bright« condition at 24:00 h and 20918 pg in the »Dim« condition, 14438 pg in the »Bright« condition at 07:00 h. The values are significantly lower in the »Bright« condition than in the »Dim« condition at 07:00 h. ($p< 0.05$)

Discussion

What physiological mechanisms might be responsible for our main finding – that subjects put on clothing more quickly in response to the cold if they had previously been exposed to bright light rather than dim light from 16:00 h to 20:30 h (Figure 2, Table 3)?

Our previous studies[1,2] showed that the subjects dressed faster with thicker clothing in the morning than in the evening and dressed more in the luteal phase than in

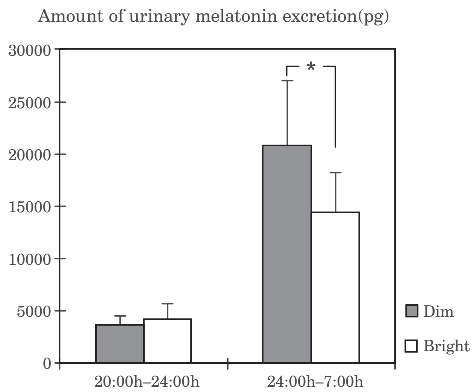

Fig. 6. Temporal changes of melatonin in the urinary. Abscissa is the same as Figure 2. Open bar; »Bright« condition. Solid bar; »Dim« condition. Values are X±SEM.

the follicular phase. We discussed these results in terms of load error between the actual and set-point values in the core temperature. Thermoregulatory responses including behavioral and autonomic changes can help bring the actual core temperature towards its set-point. In the previous experiments – with diurnal exposure to bright light[3,16] – in order to lower temperature towards a reduced set-point, the subjects did not feel cold, did not wear much clothing, and the skin temperature at their extremities rose more. We discussed these results in terms of the resetting of the core temperature at bright light condition. If the set-point values in the core temperature is set to be lower in the bright than in the dim light condition, the dressing behavior with thinner clothing in the bright light condition is advantageous, since it enables the core temperature to reach its reduced set-point value more easily. Furthermore, the subjects did not feel cooler significantly in the bright light exposure during the daytime, in accordance with the view that the set-point was set to be lowered.

In the present experiment, by contrast, the evening fall of core temperature was significantly less following bright light exposure from 16:00 h to 20:30 h. This suggests that the set-point of core temperature has been set at higher level during the evening and at night. This idea is supported by the finding that the subjects felt significantly cooler after the bright light exposure (Figure 5), and had significantly lower increases of skin temperature in the extremities after they retired (Fig. 4).

In decreasing of the set-point of core temperature, there are many evidence that melatonin is a major regulator of the circadian rhythm of core temperature. The circadian rhythms of core temperature and plasma melatonin are inversely related[6,7]. It is well known that melatonin has anapyretic properties[4,5], and a reduced amount of melatonin may be responsible for the reduced fall of core temperature after the subjects retired. Hashimoto et al.[17] found that midday exposure to bright light increased nocturnal plasma melatonin level. Park and Tokura[14] also confirmed the findings. They suggested how deeply the bright or dim light intensities during the daytime could influence the human body.

TABLE 4
A COMPARISON OF TEMPERATURE SENSATION AND THERMAL COMFORT DURING THE DRESSING BEHAVIOR PERIOD

Subject	Tepmperature sensation		Thermal comfort	
	Dim	Bright	Dim	Bright
S1	–2.00	–2.00	2.7	3.0
S2	–2.67	–3.00	3.3	3.7
S3	–0.33	0.00	1.0	1.0
S4	0.00	–0.33	1.0	1.3
S5	–0.67	–2.00	1.67	2.7
S6	–0.73	–1.00	2.6	1.3
S7	–2.67	–2.33	3.67	3.3
S8	–1.67	–2.00	2.3	3.3
S9	–1.00	–2.00	2.0	2.0
Mean	–1.30	–1.63	2.25	2.40
SEM	0.330	0.326	0.311	0.340
p	p<0.01		p<0.01	

Kräuchi et al.[18] investigated the phase-shifting capacity and thermoregulatory effects of a single oral administration of melatonin at 18 h. They suggested that, in addition to immediated thermoregulatory changes, a phase advance of circadian system had occurred. Wirz-Jusice et al.[19] found that the only change was an altered wave form of the core temperature rhythm after a single morning melatonin administration: longer duration of higher-than-average temperature after melatonin administration. Under the same modified CR (Constant Routine) conditions they have previously demonstrated a clear phase advance of the above circadian rhythms following a single administration of 5 mg melatonin in the evening. Exposure to bright rather than dim light during the daytime induced a deeper fall of core temperature during the day time and the nighttime[3,20,21], suggesting that the diurnal and nocturnal set-point of core temperature had been lower level. In the present experiment, the fall of nocturnal core temperature after the subjects had retired was significantly less when they had spent time between 16:00 h and 20:30 h in the bright rather than dim light (Figure 3, bottom left). After bright light exposure also, urinary melatonin excretion from 24:00 h to 07:00 h was significantly lower (Figure 6). Thus, the great differences of core body temperature responses to bright light existed, dependent on exposure time of day. This might be due to different melatonin responses.

Rubinstein and Sessler[22] investigated that skin-temperature gradients are an accurate measure of thermoregulatory peripheral vasoconstriction. Kräuchi et al.[15] showed that DPG was the best predictor variable for sleep-onset latency, compared with core body temperature or its rate of change, heart rate, melatonin onset, and subjective sleepiness ratings. In our findings, the highest correlation of light exposure was found with the

DPG during the dressing period and sleeping period. The finding that DPG was significantly smaller in »Bright« during the dressing period might reflect that the subjects wore more heavily, and the finding that DPG was significantly smaller in »Dim« during the sleep period might have induced that the rectal temperature fell down more deeply in »Dim«.

In the viewpoint of behavioral thermoregulatory response, it is concluded that the late afternoon and evening bright light exposure could accelerate the dressing behavior in the evening cold.

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UČINAK DVAJU RAZLIČITIH INTENZITETA SVJETLOSTI IZMEĐU 16:00 I 20:30 SATI NA VEČERNJE OBLAČENJE NA HLADNOĆI

SAŽETAK

Ovaj eksperiment testirao je našu hipotezu da će ispitanici obući više odjeće na večernjoj hladnoći ako su bili pod utjecajem jake svjetlosti u kasno poslijepodne i večer. Devet mlađih žena sudjelovalo je u istraživanju. Intenzitet svjetlosti od 9:00 do 16:00 sati održavan je na 100 lx. Od 16:00 do 20:30 sati svjetlost je kontrolirana na 3000 lx (uvjeti jakog svjetla – »Svjetlo«) ili na 10 lx (uvjeti slabog svjetla – »Mrak«). Između 20:30 do 23:00 sati intenzitet svjetlosti održavan je na 10 lx. Ispitanicama je rečeno da obuku odjevne predmete kako bi se osjećale ugodno tijekom pada temperature ambijenta sa 30 °C na 15 °C (21:00 ~ 22:00 sata) i njenog održavanja na 15 °C (22:00 ~ 23:00 sata). Većina ispitanica obukla je topliju odjeću u uvjetima »Svjetlosti« nego u »Mračnim« uvjetima. Pad tjelesne temperature u večernjim satima bio je značajno smanjen, a sekrecija urinarnog melatonina bila je značajno niža u uvjetima »Svjetla«, upućujući na to da je tjelesna temperatura podešena na viši nivo tijekom večeri i noći, zbog utjecaja smanjene sekrecije meletonina. Stoga je zaključeno da izlaganje jakoj svjetlosti u kasno poslijepodne i večer potiče oblačenje pri večernjoj hladnoći.