EFFECTS OF SEASONAL THERMAL AND LIGHTING ENVIRONMENT ON SLEEP IN ELDERLY LIVING IN THE DETACHED HOUSES

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INTRODUCTION

The effects on circadian rhythm and sleep quality are explained by photoperiod. Seasonal variation also affects sleep quality, with decreased stage 4 and increased rapid eye movement sleep (REM) under the thermoneutral condition in winter as compared to in summer (Kohsaka et al. 1992).These direct effects on sleep quality are difficult to explain on the basis of photoperiodic time cues (Kohsaka et al. 1992) and suggest that the effects of air temperature (Ta) demonstrate seasonal variation (Askenasy and Goldstein 1995). Sleep complaints related to difficulty in initiating and maintaining sleep increase with age due to increased brief awakenings and decreased SWS. Light exposure time and illuminance are the important factors in the determination of sleep quality, since a previous study reported that light exposure during the daytime improved sleep quality in the elderly (Mishima et al. 2001). However, this previous study was performed on resident elderly persons of a nursing home with an average age of over 70 years. Many old persons live independently before entering nursing home; thus, over the years, they have experienced some of the changes that tend to happen in them as they grow older. The objective of the present study was to investigate the actual thermal and illuminance conditions in the real life of old persons in 4 seasons and to determine the effect of seasonal Ta and illuminance variation on sleep in older men by using actigraphic measurements.

METHOD

SUBJECTS

The subjects were screened from a pool of volunteers aged over 65 years in the Tsukuba area of Japan. In the first screening, based on the volunteers' replies to a questionnaire, those with chronic disease, insomnia, and snoring; those habituated to taking naps and medication; those who had been admitted to a hospital; and those who were extremely long or short sleepers were rejected. Based on their replies to the questionnaire, 8 volunteers were selected. The mean and standard deviations of the following physical characteristics were measured: age (64 ± 1 years), height (162 ± 6 cm), weight (67 ± 8 kg), and body surface area (1.7 ± 0.1 m^2). They were informed about the protocol of the study and provided their written consent. This study was approved by the ethics committee of AIST. The subjects answered a questionnaire regarding their physical and mental condition, sleep, morningness and eveningness preferences (Horne and Ostberg 1976) prior to the measurements, and the results showed that the subjects were physically and mentally healthy.

PROCEDURE

The study was performed at the subjects' homes for 4 consecutive seasons: spring (from late April to early May), summer (from late July to early August), autumn (from late October to early November) and winter (from late January to early February). The same subjects participated in all 4 seasons. The subjects were requested to wear a wrist actigraph on the nondomiant hand for 5 consecutive days. The subjects were asked to expose the actigraph to the ambient environment, without covering it by their clothing.

During the activity monitoring period, the temperature outside and the temperature and relative humidity (RH) of the bedroom were measured continuously for 1-min time intervals. Two nocturnal sleep during the activity monitoring, skin temperature (Ts), microclimate, and bed climate were continuously measured at 1-min time intervals using a thermistor and hygrometer (LT8A, Gram Corporation). The mean weighted Ts was calculated according to Ramanathan (1964).

The subjects were requested to lead their life as normally as possible. A total of 3 sets of answers to the questionnaire were obtained from each subject at regarding their subjective experiences before sleep, after sleep, and during sleep. A questionnaire regarding bedding and clothing was administered. The thermal sensation scale for the whole body was similar to the Society of Heating, Air-conditioning, and Sanitary Engineers of Japan (JIS TR S 0002, 2006) 9-point scale (9: very hot, 8: hot, 7: warm, 6: slightly warm, 5: neutral,4: slightly cool, 3: cool, 2: cold, −4: very cold). The comfort sensation scale was similar to the Japan Society of Refrigerating and Air-conditioning Engineers (JIS TR S0002, 2006) 7-point scale (1: very comfortable, 2: comfortable, 3: slightly comfortable, 4: neutral, 5: slightly uncomfortable, 6: uncomfortable, 7: very uncomfortable). Humid sensation was used 7-point scale (1: very dry, 2: dry, 3: slightly dry, 4: neutral, 5: slightly humid, 6: humid, 7: very humid).

DATA ANALYSIS

The sleep parameters were determined according to the actigraph-based sleep-wake identification algorithm (Cole, et al., 1992). In order to test the statistical significance of the data, one-way analysis of variance (ANOVA) (conditions: spring, summer, autumn and winter) was used to analyze the effect of conditions on activity, sleep parameters and thermal and lighting parameters. For each subject, the numbers of minutes of illuminance above 1000 and 2500 lux were counted for all complete days of recording. The illuminance values were log-transformed and calculated for 75%, 50%, and 25% values of the cumulated value of the daytime, for average of an entire day, for average of sleeping period, and average of 30-min before morning awake. To investigate the effect of illuminance on sleep parameters and activity, the illuminance values were compared among 4 seasons, and correlation analysis was performed between the illuminance values and sleep parameters. Fisher's protected least significance difference (PLSD) was applied for post-hoc pairwise comparison. The level of significance was considered to be $P < 0.05$.

RESULTS

BED CLIMATE AND BEDDING CONDITIONS

Sunrise was earlier in spring (4:47 ± 0:11), summer (4:45 ± 0:03), autumn (5:53 ± 0:03) and winter (6:41 ± 0:02), while sunset was later in spring (18:26 ± 0:09) , summer (18:44 ± 0:03) , autumn (16:53 ± 0:04) and winter (17:03 ± 0:04) during the measuring period. The daylight hours were longer in spring (13:39 ± 0:21) and summer (13:59 ± 0.06) than autumn (10:59 ± 0.08) and winter (10:21 ± 0:07).

Table 1. Bed room climate during the sleep

		Spring average (SD)	Summer average (SD)	Autum average (SD)	Winter average (SD)
Outdoor	(℃)	18.0 (1.8)	24.9 (1.0)	12.4 (3.6)	0.4 (1.1)
Toilet	Ta (℃)	21.4 (1.4)	27.5 (1.0)	16.9 (3.1)	7.3 (2.4)
	RH (%)	72.8 (9.1)	79.8 (6.2)	77.2 (7.3)	61.4 (7.9)
Bedroom	Ta (℃)	22.5 (1.4)	27.8 (1.0)	18.4 (1.8)	10.3 (2.6)
	RH (%)	64.8 (7.5)	72.6 (7.4)	69.8 (6.7)	59.4 (5.9)

Significant seasonal variation was observed in the outside Ta ($F(3,60) = 340.10$; $P < 0.001$) and bedroom temperatures ($F(3,60) = 240.64$; $P < 0.001$) and humidity ($F(3,60) = 203.41$; $P < 0.001$). The temperature and humidity was significantly higher in summer than in spring, autumn and winter (Table 1). In bedding conditions, there was no significant seasonal difference in the number of bed mattresses (F(3,60)= 0.45; ns) and clothing values (F(3,60) = 0.043; ns) used by the subjects. However, the number and insulative value of bed coverings significantly differed among seasons (F(3,60) = 24.51; P < 0.0001;F(3,60) = 49.26; P < 0.0001), i.e., a lower number were used in summer than in spring, autumn, and in spring than in winter. However, clothing insulation of futon in spring was not different that in autumn.

Significant seasonal variation was observed in the average F(3,28) = 4.71; P < 0.008), cumulative F(3,28) = 4.55; P < 0.05),, and median F(3,28) = 6.10; P < 0.002) of illuminance, the number of minutes of illuminance above 2500 lux F(3,28) = 3.51; P < 0.028), and the average illuminance of 30-min before morning awake (F(3,28) = 2.46; P < 0.08). Those values were significantly higher in spring than in summer, autumn and winter.

Table 2. Lighting environments during a whole day and sleep

	Spring	Summer	Autumn	Winter
Cumulated illuminance(Lx h)*	989(589)bcd	546(307)a	371(379)a	278(162)a
Average (lx)*	16.5(9.8)bcd	9.1(5.1)a	6.2(6.3)a	4.6(2.7)a
Median (lx)**	19.8(13.7)bcd	9.7(6.2)a	5.7(4.8)a	3.3(2.2)a
Minutes of illuminance above 2500 lux (minutes）**	133.8(92.3)bcd	48.9(33.1)a	46.6(60.7)a	47.1(39.3)a
Minutes of illuminance above 1000 lux (minutes）	180.4(100.8)	100.4(55.2)	72.6(65.6)	63.6(56.3)
Average during daytime (lx)*	124.8(114.2)bcd	41.2(23.3)a	41.1(63.9)a	28(22.7)a
Average during sleeping period (lx)	1(1.8)	1.5(2.8)	1.4(2.7)	2.1(3.8)
average of 30-min before morning awake (lx)#	2.8(5)bd	20.2(49.5)a	4.6(8.3)	1.6(3.6)a

a Differs from Spring, P<0.05 Values are average(SD).
b Differs from Summer, P<0.05
c Differs from Autumn, P<0.05
d Differs from Winter, P<0.05

Table 3. Sleep parameter and activity under 4 seasons

	Spring			Summer			Autumn			Winter		
Night time	average	(SD)		average	(SD)		average	(SD)		average	(SD)	
Bedtime (h:m)	22:31	(1:17)		22:35	(0:57)		22:35	(0:43)		22:51	(0:55)	
Wake-up time (h:m)	5:41	(1:07)	d	5:58	(0:37)	d	6:09	(0:34)		6:30	('0:32)	ab
Time in bed (min)	431.2	(100.8)		443.88	(56.2)		455.25	(51.6)		460.31	(59.0)	
Total sleep time (min)	381.8	(96.3)		366.38	(61.2)		405.5	(57.9)		412.06	(64.0)	
Wake (min)	49.4	(25.3)	b	77.5	(45.6)	acd	49.75	(18.7)	b	48.25	(20.2)	b
Sleep efficiency index (%)	88.3	(5.9)	b	82.666	(10.4)	acd	88.86	(4.7)	b	89.262	(5.5)	b
Sleep latency (min)	15.3	(22.8)		19.25	(16.7)		13.75	(11.0)		16.313	(14.6)	
Number of wake episode	9.3	(5.0)		12.313	(8.6)	d	8.6875	(3.5)		7.4375	(3.4)	b
Longest wake episode (min)	21.1	(14.4)		29.5	(19.6)		19.813	(6.2)		22.875	(15.5)	
Activity index	17.2	(7.0)	b	25.459	(12.8)	acd	17.139	(4.5)	b	16.089	(6.3)	b
Daytime												
Activity index	207.5	(34.5)		199.81	(35.1)		170.35	(42.6)		185	(55.7)	
Sleep time (min)	36.6	(50.5)		30.125	(39.9)		86.125	(70.2)		18.22	(25.9)	

a Differs from Spring, P<0.05
b Differs from Summer, P<0.05
c Differs from Autumn, P<0.05
d Differs from Winter, P<0.05

SLEEP PARAMETERS

Based on wrist activity, a significant difference in sleep parameters was observed mainly between summer and other seasons (Table 2). There was no significant difference in bed time (F(3,60)=0.96), while wake - up time (F(3,60)=3.35; P < 0.05) in spring and summer were significantly earlier than in winter. There was no significant difference in sleep latency (F(3,60) = 0.30), period of lying down (F(3,60) = 0.55), total sleep time (F(3,60)=1.40) , however, wake time (F(3,60) = 3.70, P<0.05) in summer was significantly longer in spring, autumn, and winter. The number of wake episodes (F(3,60) = 2.24, P< 0.1) was significantly higher in summer than in winter. As compared to in spring, autumn, and winter, the sleep efficiency index (F(3,60) = 3.15; P < 0.05) significantly decreased by 5% in summer. The total activity (F(3,60) = 4.43; P < 0.007) was higher in summer than in spring, autumn and winter. No significant difference with season was observed with regard to the total activity and sleep time during the day.

Table 4. Retrospective thermal sensations during sleep

	Spring	Summer	Autumn	Winter
Thermal sensation of whole body **	6.6 (0.9) [bcd]	5.4 (1.2) [a]	5.4 (1.1) [a]	5.8 (0.8) [a]
Thermal sensation of foot	5.9 (0.9)	5.4 (0.8)	5.4 (0.8)	5.7 (0.8)
Comfort sensation **	3.9 (0.7) [c]	4.1 (0.9) [c]	3.3 (0.8) [abd]	3.9 (0.3) [c]
Feeling of Sweating **	1.4 (0.6) [cd]	1.6 (0.9) [cd]	1.0 (0.0) [ab]	1.0 (0.0) [ab]
Requirement for changing ta **	3.8 (0.4)	3.7 (0.5) [cd]	4.1 (0.3) [b]	4.1 (0.3) [b]
Requirement for changing humidity **	3.8 (0.4) [cd]	3.6 (0.5) [cd]	4.1 (0.3) [ab]	4.1 (0.3) [ab]

a Differs from Spring, P<0.05
b Differs from Summer, P<0.05
c Differs from Autumn, P<0.05
d Differs from Winter, P<0.05

SUBJECTIVE SENSATION

No significant difference was observed in the subjective evaluation of sleep. However, retrospective subjective wakefulness due to the thermal environment was significantly affected by the season (F(3,60) = 4.54; P < 0.006); it was higher in spring and summer than in autumn and winter. Regarding the retrospective sensations during sleep (Table 4), a significant effect of season was observed for the humidity sensation (F(3,60) = 4.33; P < 0.007), thermal sensation of the whole body (F(3,60) = 4.33; P < 0.0078) and leg (F(3,60) = 1.70; ns), comfort sensation (F(3,60)=4.70, 0.005), the requirement for changing the Ta (F(3,60) = 4.35; P < 0.007) and humidity (F(3,60) = 5.93; P < 0.0013). The thermal sensation of the whole body was significantly higher in spring than that in summer, autumn, and winter. The comfort sensation was significantly higher in autumn than spring, summer, and winter. The humidity sensation was higher, thermal sensation of the whole body and leg was lower, and the requirement for decreasing the Ta and humidity was higher in summer than in autumn and winter.

CONCLUSION

During the sleep and after the sleep the subjects felt warmer in spring than in summer, however, the Ta and Rh were higher in summer than in spring. Illuminance was higher in spring than in the other seasons. The sleep efficiency was worst in summer due to increased length and number of wakefulness. However, no significant difference was found in the subjective evaluation of sleep among the 4 seasons. The subjects in this study are also exposed to acute Ta change from bed climate of about 32°C to Ta lower than 10°C, since most subjects go to lavatory after sleep onset and at wake up time in the winter season. The acute Ta change affects thermoregulation and cardiovascular response in the old man, especially increase in blood pressure (Inoue et al. 1992; Collins et al. 1995). The acute Ta change may also have relation with this cardiac disease.

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