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Thermal Comfort and Sleep under Different Room Temperatures

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침상내 기후와 수면과의 관계

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국문초록

본 연구에서는, 수면환경의 열적 쾌적도의 측정방법으로서 생리적 반응 뿐만 아닌 국소자극의 반응에 대한 평가법(Allesthesial Response)에 의한 가능성을 제시하고자 하였다.

피험자는 19세에서 22세의 건강한 독일 여자 대학생 5명이며, 실험은 12월과 1월 독일의 KASSEL에 있는 Marburg 대학 연구소의 인공기후실에서 이루어졌다. 사용의복은 면 100%의 잠옷이며, 침구는 메트리스와 Wool 담요(두께 180 mm)를 사용하였다.

국소자극 반응의 온도는 20.0°C, 22.5°C, 25.0°C, 27.5°C, 30.0°C, 32.5°C의 set가 사용되었으며, 온도자극은 Peltier Thermode type PKE 36 HO2-1 (독일, Peltron社)로서, 온도의 도달정밀도는 60 내지 90초 동안에 각 자극 온도의 변화 조절이 가능하였다.

수면환경 온도는 15°C, 18°C, 21°C, 24°C, 27°C의 다섯 환경으로 조절하였으며, 습도는 RH 45%였다.

수면환경 18°C에서 24°C까지에서는, 수면전, 수면후 모두, 피험자는 약간의 Hypothermia의 경향을 보였지만 Neutral Situation과 큰 차이는 나타나지 않았다. 수면전과 수면후의 체온조절 반응의 차이가 Allesthesial Response와 국소의 쾌적한 온도 선택의 두 실험결과 모두에서 현저히 나타났다. 생리적 반응의 결과에서도 18°C에서 21°C까지의 수면환경이 가장 쾌적하게 나타났다.

또한, 실험결과에서 행동적 온도 조절 반응이 생리적 반응에 앞서 보다 민감하게 이루어짐을 볼 수 있었다

INTRODUCTION

To get a comfortable sleep, the most important thing is how well we do thermoregulate during the rest in bed before sleeping as well as during sleep. In other words, the ambient temperature of the sleeping room is very important in the organization of human sleep[22].

In recent years, the effect of ambient temperature on human sleep has been increasingly studied. These studies were primarily concerned with the relation between thermoregulatory processes and sleep, and more precisely with the findings that various thermoregulatory processes are inactivated or severely curtailed during REM sleep in a number of animals[25], also that panting and shivering in heat and cold, respectively, cease during REM sleep in cats[23]. Haskel et al.[13] noted that although REM sleep latency was increased at high and low temperature, REM sleep was depressed to a greater extent by lower than by higher temperatures whereas the reverse was obseved for SWS. It has also been found that a load imposed upon thermoregulatory mechanisms should markedly affect sleep processes, and that, conversely, sleep in conditions of thermic stress should interfere with adequate thermoregulatory reactions[24]. Sleep in an animal under thermic stress is, on the whole, both shorter and less deep than under normal thermic conditions[23].

In a study where the possible qualitative and quantitative variations of the sleep parameters due to slight changes of the air temperature were evaluated in the usual sleeping environmental temperatures of 13°, 16°, 19°, 22° and 25°C which are usually met in European dwellings, Muzet et al.[20,21], showed that slight changes in temperature, within the thermal comfort zone, although not accompanied by dramatic EEG sleep modifications, may affect body heat exchanges and therefore the body temperature. The results strongly suggest a coupling between body temperature cycle and the sleep mechanisms.

In the present study, as a different attempt to clarify the thermal comfort and sleep under different room temperatures considered as the thermal comfort zone from preceding studies[9,20], the thermal alliesthesial responses, global thermal pleasantness sensation, global temperature sensation, autonomic variables and bed climate were measured during two periods, before and after sleep: a bedding down period of one hour (before sleep) and a twenty minutes waking period (after two hours sleep).

The subjects, young women, were exposed to five different ambient temperatures of 15°, 18°, 21°, 24° and 27°C throughout the evening from 18.00 to 22.00 hours in winter season. In addition, we intended to suggest the range of temperatures considered as a neutral environment for clothed and covered young women subjects asleep in European winter season.

METHODS

1. Subjects

Five young women students of physiotherapy with ages ranging from 19 to 22 years, weight from 58 to 73 kg and height from 160 to 185 cm were subjected in a climatic chamber for a total of 19 evenings at five ambient conditions: 15°C, 18°C, 21°C, 24°C and 27 °C air and wall temperatures.

Other ambient parameters were kept constant: RH 45%, wind speed 0.2~0.3 m/sec. Under the extreme thermal stress of 15°C and 27°C, only two of the five subjects participated in the experiments.

2. Measurements

Behavioural parameters measured during the experiment were thermal alliesthesial responses, global thermal pleasantness sensation and global temperature sensation. The estimate of thermal alliesthesial responses was performed using two methods, namely, the thermal pleasantness ratings in response to a set of temperature stimuli and the choice of most pleasant local temperature, using a Peltier thermode (thermode area 6×6 cm).

A set of temperature stimuli of 20.0°, 22.5°, 25.0°, 27.5°, 30.0° and 32.5°C was applied on the cheek. Temperature stimuli were applied using a rectangular Peltier Thermode type PKE 36 HO2-1 marketed by Peltron in Nuernberg, Germany. Temperature on the thermode surface is selected by a control knob capable of being adjusted from −20.0°C to +70.0°C and desired temperature is reached within 60∼90 s, depending upon ambient temperature, cooling water flow rate and temperature[2].

The subjects also chose their most pleasant local temperature on the cheek by voluntary control, using the temperature control knob of the thermode without looking at the temperature scale.

At the same time, global thermal pleasantness sensation and global temperature sensation were asked. Hensel[15] presented a clear distinction between temperature sensation and thermal comfort. Temperature sensation is an "objective" MEASUREMENT process tending to estimate the external thermal stressor; the CONTROL tending to offset any deviations from the state of thermal neutrality is thermal discomfort, behavioural and autonomic temperature-regulatory response[15].

For the thermal pleasantness/unpleasantness ratings, the following five point scale was used[8].

very pleasant	+2.0
pleasant	+1.0
indifferent	0.0
unpleasant	−1.0
very unpleasant	−2.0

Global temperature sensation was rated +10 as very warm, +5 as warm, O as neutral, −5 as cool and −10 as cold.

Physiological parameters measured during the experiment were rectal temperature, skin temperature at nine locations, hear rate, energy consumption and body weight loss. Mean skin temperatures were calculated from weighted skin temperatures at four points by the Ramanathan Formula[26].

$$MST = 0.3t\ \text{Chest} + 0.3t\ \text{Upper arm} + 0.2t\ \text{Thigh} + 0.2t\ \text{Lower leg}$$

As to the bed climate, temperature and humidity at breast level were also measured, using the humidity and temperature transmitter HMP 133 Y.

3. Schedule

Experimental conditions and time schedule for measurement are shown in Fig. 1. Subjects engaged

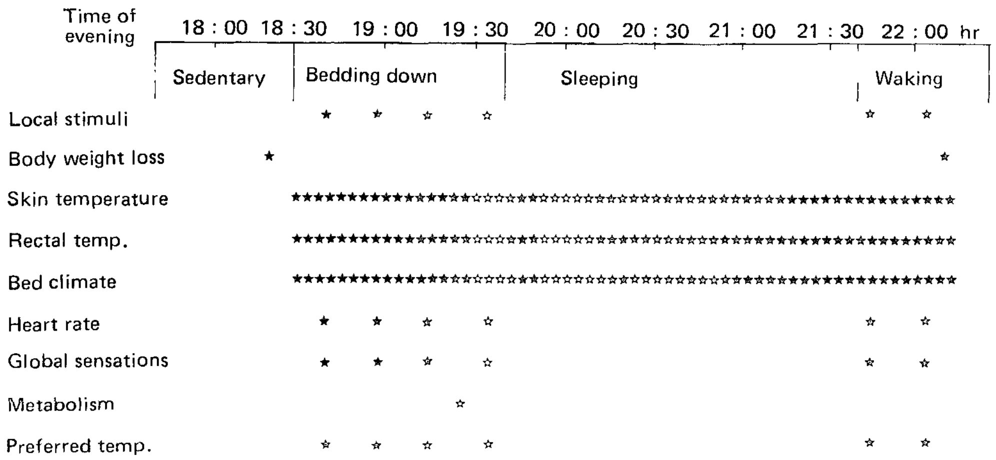

Fig. 1. Experimental conditions and time schedule for measurements.

in their hard daily school activities from morning 07.00 to evening 17.40 hours. They arrived at the laboratory around 18.00 hours and stayed for 30 minutes in normal room temperature while they were prepared for the test. They were asked to avoid afternoon exercise, naps, coffee or alcoholic drinks during the afternoon before coming to the laboratory.

After having their body weight determined precisely, subjects wore long pyjamas consisting of clothing materials of 100% cotton and bedding composition consisted of two cotton sheets and one wool blanket with usual mattress.

Thermistors for skin temperature were taped on the skin at nine locations: forehead, breast, shoulder, upper arm, forearm, hand, thigh, lower leg and foot. Core temperature was measured with a thermistor

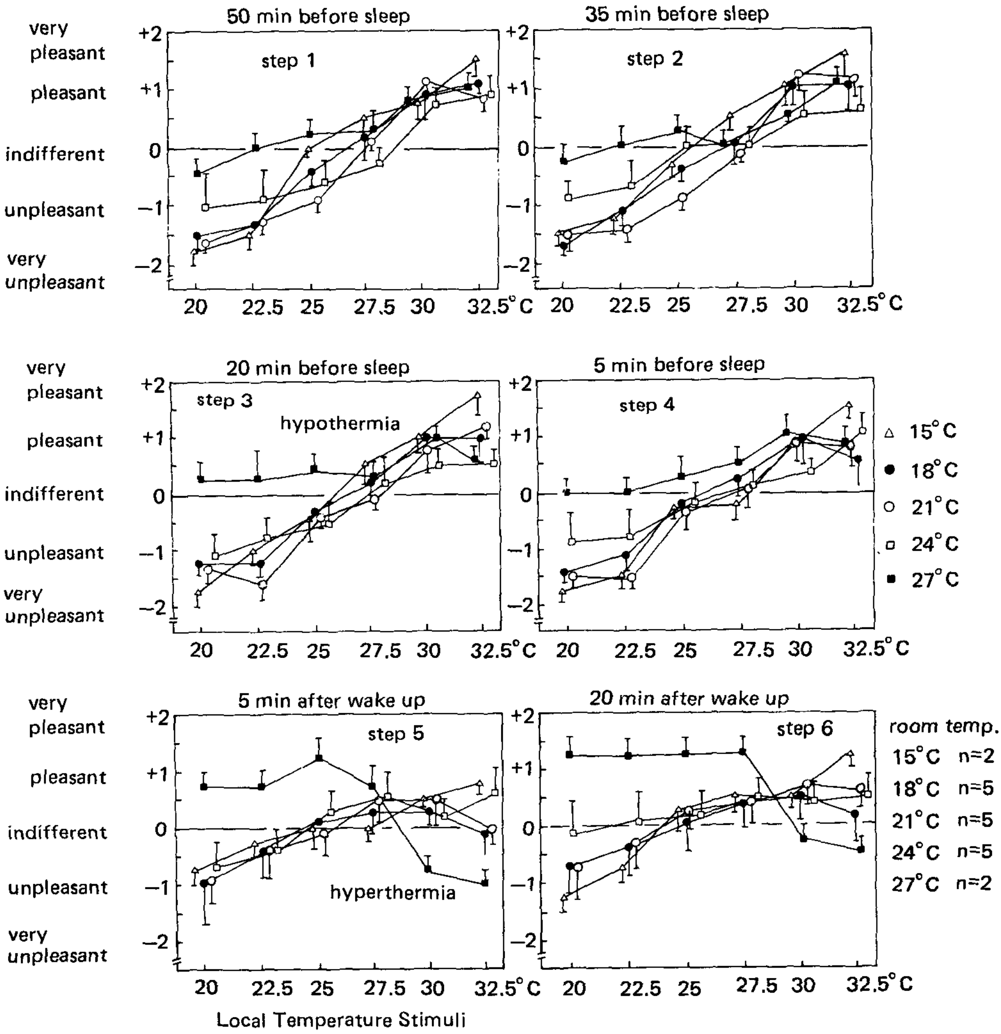

Fig. 2. Mean values of the local thermal pleasantness/unpleasantness ratings (on cheek) at the six different times of the experiment are plotted against each stimulus of 20, 22.5, 25, 27.5, 30 and 32.5°C in the climatic sleep chamber of 15, 18, 21, 24 and 27°C room temperatures (R.H. 45%; wind speed 0.2~0.3 m/sec). Each stimulus was given in a randomized sequence.

inserted 10 cm beyond the anal sphincter. Temperature and humidity sensor for the bed climate was placed under the draw sheet at the breast level. Skin temperature, core temperature and bed climate were continuously recorded from 18.30 to 20.00 hours.

At 18.30 hours, subjects were asked to be lying in bed. The light was switched off at 19.40 hours. From 19.40 hours, subjects tried to fall asleep till 21.40 hours, After these two hours of sleep, subjects were awakened by us and remained in bed till 22.00 hours. Both during the one hour bedding down period before sleeping and during the twenty minutes waking period, subjects were asked every 15 min in six steps to answer their thermal pleasantness/unpleasantness ratings in response to a set of temperature stimuli of 20.0°, 22.5°, 25.0°, 27.5°, 30.0° and 32.5℃ applied on the cheek, and also asked to choose the most pleasant local temperature again on the cheek by controlling the small peltier thermode. Each stimulus was given in a randomized sequence.

Heart rate measurement, global thermal pleasantness sensation and global temperature sensation ratings were made also during these six steps. Oxygen consumption was measured between 19.15 and 19.30 hours.

RESULTS

1. Effects of the room temperatures on the behavioural responses

In Fig. 2, mean values of thermal pleasantness/unpleasantness ratings applied on the cheek at six different times (steps 1, 2, 3, 4, 5 and 6) of the experiment are plotted against the corresponding stimulus temperatures of 20.0°, 22.5°, 25.0°, 27.5°, 30.0° and 32.5°C in five different room temperatures. The ratings for steps 1, 2, 3 and 4 were carried out between 18.30 h and 19.40 h for the bedding down period, while the ratings for steps 5 and 6 of the waking period were carried out between 21.40 h and 22.00 h.

Under all conditions except at 27°C, it can be observed that local thermal pleasantness ratings show a tendency towards hypothermia, especially during the bedding down period (steps 1, 2, 3 and 4), subjects having perceived as pleasant the stimuli above 27.5°C, as unpleasant the stimuli below 27.5° C.

During the waking period (steps 5 and 6), the subjects would tend to rate cool stimuli (22.5°C, 25.0°C) as indifferent, and stimuli above 25.0°C as pleasant. At 27°C condition, cool stimuli are answered as pleasant and warm stimuli are answered as unpleasant during the waking period.

In Fig. 3, mean values of regression coefficients and preferred local temperatures on the cheek are plotted against six different steps of the experiment at five different room temperatures. Rating/stimulus slopes (regression coefficients) were calculated for both hypothermic and hyperthermic conditions[3,7]. Positive slopes were, as expected, associated with hypothermia and negative slopes with hyperthermia. The point where the curve intersects the "a=0.0" line, corresponds to the value of the parameter when body temperature is equal to the thermoregulatory set point[3].

Regression coefficients of rating/stimulus line (Fig. 3 above) and most preferred local temperatures (Fig. 3 below) confirm that the subjects are hypothermia throughout the bedding down duration under 15°, 18° and 21°C conditions, and that, especially, preferred local temperature increased nearly to 33°C under the 15°C condition. As for the waking period, regression coefficients of the rating/stimulus line are very close to thermal neutrality under the conditions of 15°, 18° and 21°C, and preferred local temperatures are chosen between 29°C and 30°C at these three room temperatures. But under 15°C, the subjects show a tendency to return towards an hypothermic state after being awakened.

Under the 24°C condition, the slopes of rating/stimulus line show that during the bedding down

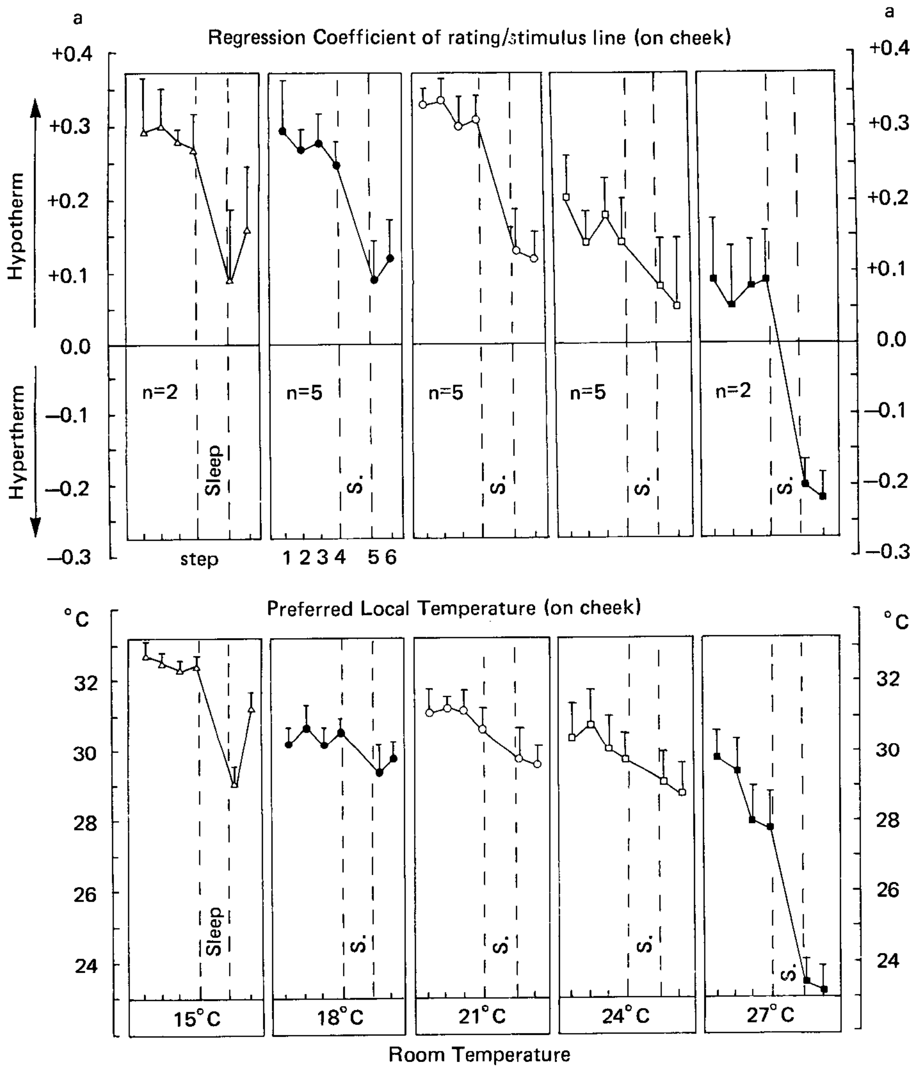

Fig. 3. Mean values of regression coefficient and preferred local temperature at the five different room tempertures. Regession coefficient "a" is the thermal pleasantness rating/stimulus slope. Preferred local temperatures are chosen by voluntary control using a small PELTIER thermode (thermode area 36 cm²).

period, a state very close to zero is maintained, while an increasing tendency towards hyperthermia and a decrease in preferred local temperatures (28°C~29°C) are observed during the waking period.

Under the 27°C room temperature condition, it can be seen that this sleep environment causes an hyperthermic state throughout the duration of the waking, characterized by increasing negative values in the rating/stimulus line and a decrease in preferred local temperatures (23°C~24°C).

The highest preferred local temperature (33°C) is observed for the 15°C condition of the bedding down period, while the lowest preferred local temperature (23°C) is obtained for the 27°C condition of the waking period, both preferred local temperatures being significant at a 0.005 level for the 18°C and

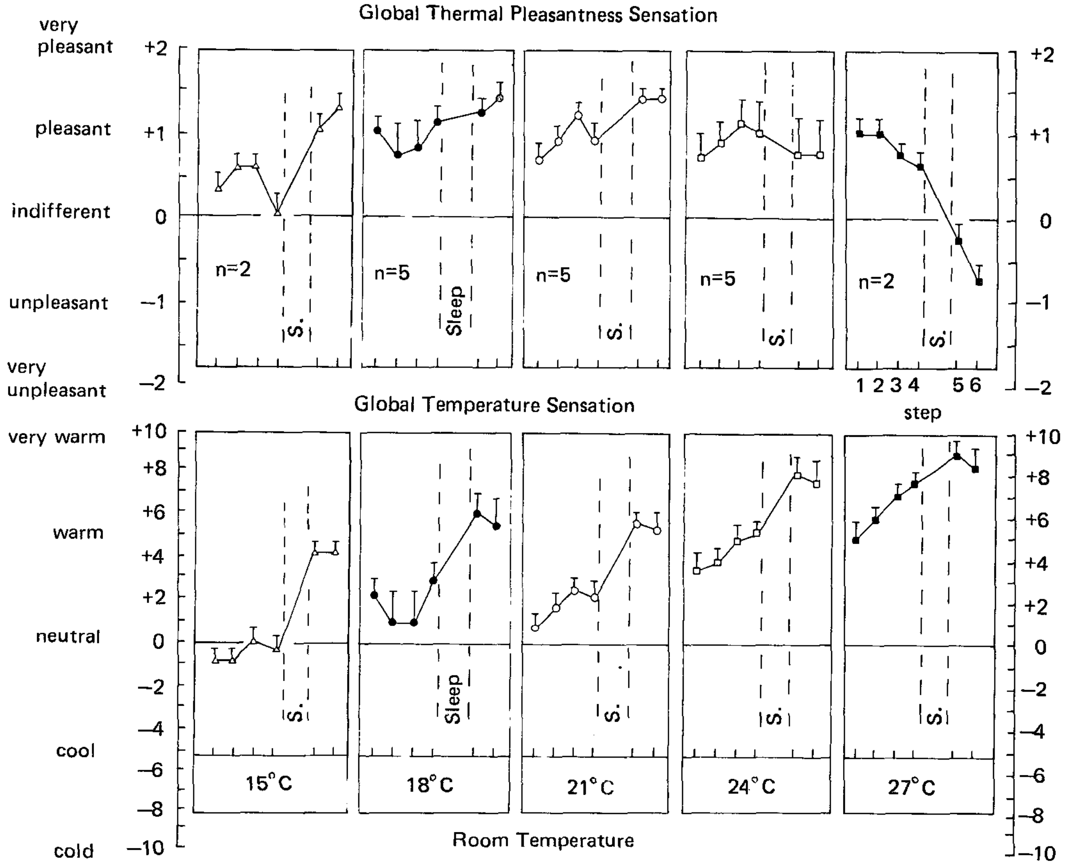

Fig. 4. Mean values of global thermal pleasantness sensation and global temperature sensation votings at the six different steps are shown. Steps 1, 2, 3, 4 are the duration of the bedding down and 5, 6 are the duration of the waking. Sleeping was taken during two hours from 19:40 hr to 21:40 hr in the evening.

21°C conditions. These values reveal an identical result to the result shown by the rating/stimulus slopes.

Mean values of global thermal pleasantness sensation and global temperature sensation votings for the six steps are shown in Fig. 4. Pleasantness ratings of around +1.0 are given for the 18°, 21° and 24°C conditions of the bedding down period, whereas during the waking period, the subjects remained feeling pleasant under the 15°, 18° and 21°C room temperatures. Global temperature sensation votes at 15°C room temperature are from the start close to −2 "cool", with a slight increase towards neutral at the step 4 (Fig. 4 below). After awakening, the subjects are voting "very warm" (between +7 and +9) under the 24° and 27°C conditions, suggesting that warmth discomfort is increasing from these 24°C and 27°C room temperatures. The results show the same tendecy to the results shown in rating/stimulus slopes and preferred local temperatures.

2. Effects of room temperatures on the physiological responses

In this section, the average physiological data, i.e., rectal temperature, mean skin temperature, heart rate, energy consumption and body weight loss obtained from a total of four hours of experiment will be compared with the results obtained from

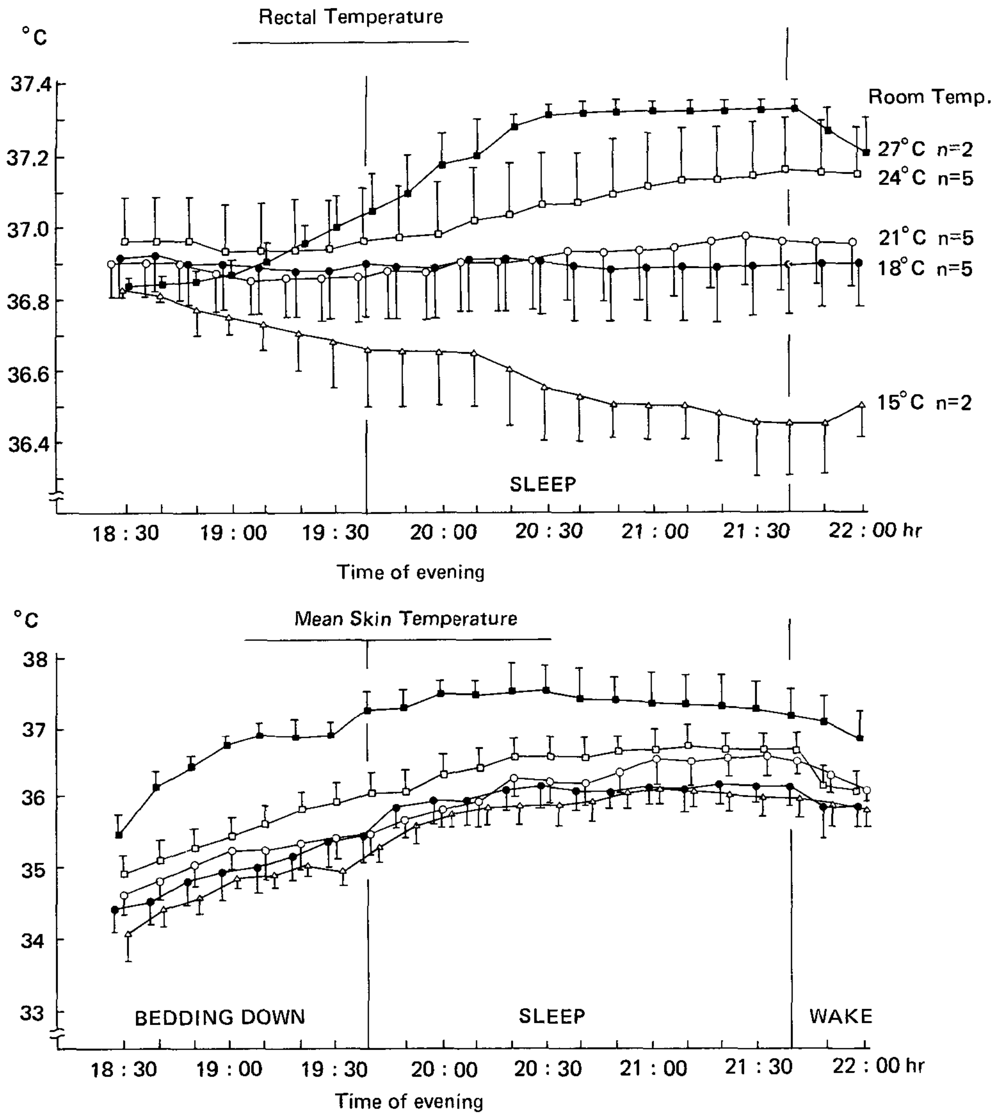

Fig. 5. Mean values of rectal temperature and mean skin temperature in five different room temperatures. Mean skin temperature was calculated from skin temperature at four locations, using a formula proposed by Ramanathan.

behavioural indicators.

The rectal and mean skin temperatures, factors which principally affect thermal comfort, have been plotted against times for five room temperatures in Fig. 5. Rectal temperature and mean skin temperature maintained a fairly constant level in the conditions of 18℃ and 21℃.

Under the 15°C room temperature, rectal temperature decreased gradually along with the passing of time. Under 27°C room temperature, there is a marked increase in both rectal and mean skin temperatures. The results for the 27°C room temperature show an increase of about 0.5°C and 2°C respectively in rectal and mean skin temperatures. Rectal temperature difference between 27°C and 15°C conditions is about 0.8°C for both sleeping and waking

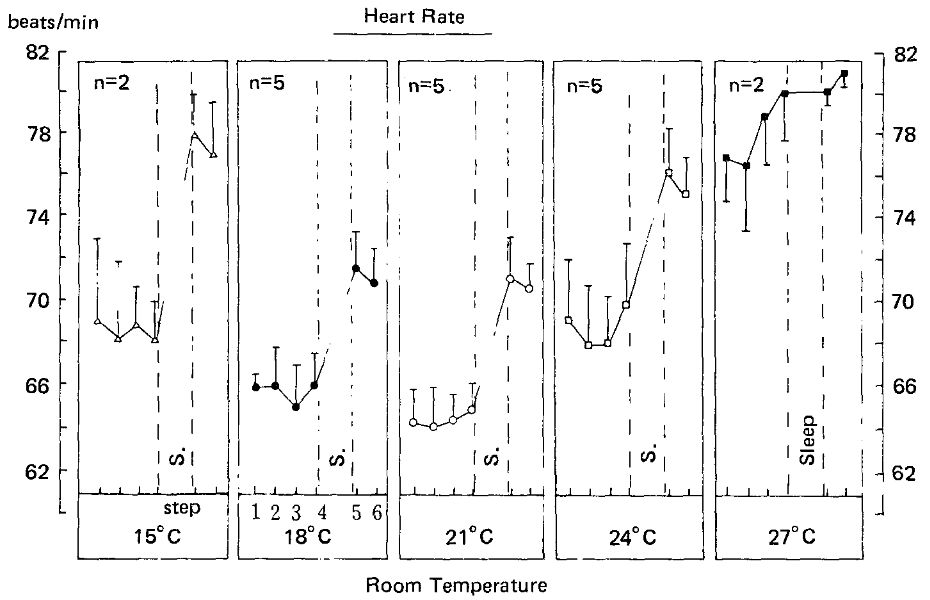

Fig. 6. Mean values of heart rate measured at the six different steps under the five different room temperatures. Steps 1, 2, 3, 4 were measured every 15 minutes during one hour of the bedding down period. Steps 5 and 6 were measured during 20 minutes of the waking period.

period, whereas for the bedding down period, the difference is only 0.3°C. Under the 24°C condition, rectal temperature remained at a steady state level during the bedding down period, then slightly increased during sleep.

Mean skin temperatures remained remarkably constant within the range of 34.5°C~36°C throughout the experimental period under room temperatures of 15°, 18° and 21°C, while at 27°C condition, it increased markedly to about 37°C approximately 30 minutes after bedding down, then remained at a steady level or slightly decreased during sleep. For the 24°C condition, mean skin temperature has sustained a little higher level than in the other three conditions of 15°, 18° and 21°C(Fig. 5 below).

Mean values of heart rate measured at the six steps under the five different room temperatures are shown in Fig. 6. The heart rate at 27°C is significantly higher ($p<0.01$) than in the 18°C and 21°C conditions. At 15°C and 24°C room temperatures, there is also a small increase of the heart rate after waking, when compared with the couditions of 18°C and 21°C.

Fig. 7 shows mean values of energy consumption and body weight loss at the same five room temperatures. Energy consumption was measured 20 minutes before the start of the sleeping period, whereas body weight loss was measured at the beginning and the end of the experiment.

Under the 18°C condition, energy consumption was lower than in any other room temperatures. The body weight loss corresponding to four hours was 441 ± 20.2 g(mean±standard error) in 27°C room temperature, 240 ± 5.7 g in 18°C, 205 ± 10.2 g in 21°C, 260 ± 10.5 g in 24°C and 166 ± 12.4 g in 15°C. Thus, the body weight loss is significantly greater in 27°C than in 18°C condition ($p<0.001$). This observation of warmth-discomfort in 27°C room temperature has already been substantiated by the results of the regression coefficient of rating/stimulus line, preferred local temperatures, rectal and skin temperatures.

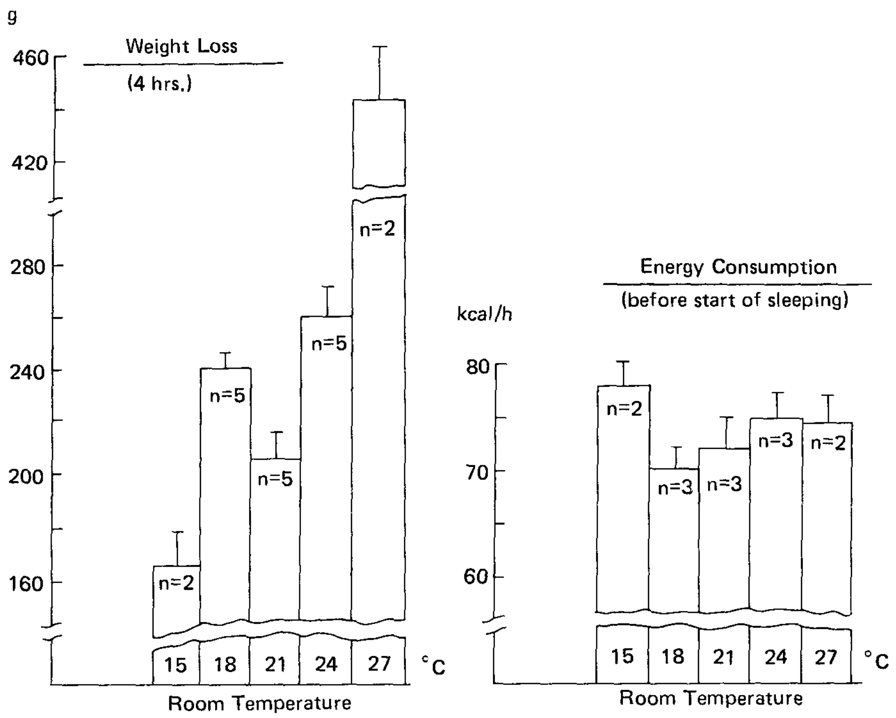

Fig. 7. Mean values of energy consumption and body weight loss at five different room temperatures. Energy consumptinon was measured at 20 min before start of sleeping. Body weight loss was measured at the beginning and the end of the experiment.

3. Effects of room temperatures on the bed climate

Fig. 8 shows the mean values of the % RH and the temperatures in bed climate, measured at the same five room temperatures. The sensor for humidity and temperature was placed under the draw sheet (mattress side) at the breast level.

Throughout the total experimental time, from bedding down to time of awakening, 18°C and 21°C room temperatures induced the same variations of bed humidity and temperature, and they were kept constantly within the range of 34%~36% for humidity, and 33°C~35°C for temperature.

During the bedding down period, the bed temperature of 29°C obtained for the 15°C condition is significantly lower ($p<0.001$) than the 34°C bed temperature obtained under the 18°C and 21°C room conditions. But it slowly increased thereafter with the duration of sleep to reach nearly 33°C.

Under the 24°C and 27°C room temperatures, humidity and temperature in bed were not much different for the bedding down period, but during sleep, bed humidity in the 27°C condition rapidly increased, reaching nearly 72%, after approximately one hour of sleeping, which is significantly higher ($p<0.001$) than under the 18°C condition. Contrary to humidity, bed temperature in 27°C showed a little decrease during sleep, which can be explained by an increase of the sweating.

These different results allow us to assume that sweating began when the bed temperature reached roughly 34°C, and increased much after 36°C.

Concerning the 24°C condition, we noticed that the bed climate was alsways maintained a little higher under the 24°C condition than under the 18°C and 21

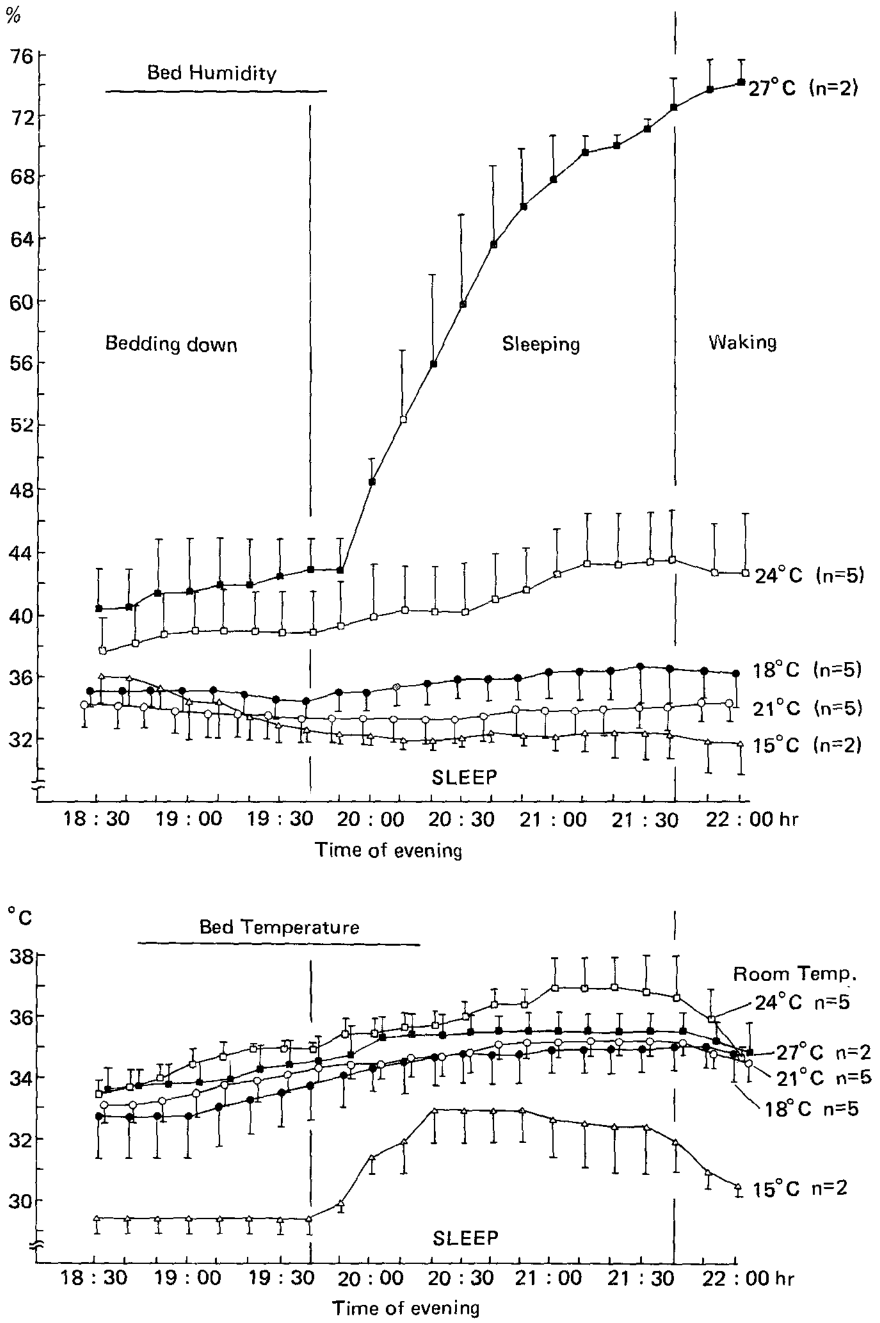

Fig. 8. Mean values of % RH and temp. in bed climate measured throughout the experiment. The sensor for humidity and temperature was placed under the sheet at the breast level.

°C conditions throughout the experimental period, but these differences were not much great.

It comes then clear from these results that the 15°C and the 27°C room temperatures should be supposed as the lower and higher limits for the thermoneutral range of ambient temperature during sleep as well as during the bedding down period, this fact being corroborated also by the results of the thermal comfort and physiological responses.

DISCUSSION

The present study demonstrates that the level of thermal status in bed can be estimated with the responses to local stimuli as well as with the autonomous responses.

The total thermoregulatory response is the sum of both the thermoregulatory autonomous or physiological responses and the thermoregulatory behavioural reactions[12]. Thermal balance is achieved in such a way that thermoregulatory physiological strain is minimized. In other words, behavioural responses modify the need for physiological or autonomous responses[12]. Physiological thermoregulatory response can be estimated by the measurement of physiological indicators such as core temperature, skin temperature, metabolic rate, sweating onset and rate, blood flow, vasoconstriction, vasodilation and shivering. The thermoregulatory behavioural responses are difficult to quantify, though measurement of thermal alliesthesial reactions may give an indication of the direction and magnitude of the thermoregulatory behavioural output of the human "thermostat"[15].

Thermal alliesthesia, however, was defined first by Cabanac[4] as pleasure/unpleasure sensation aroused by a given temperature stimulus according to the internal state of the subject. Thermal alliesthesial reactions are subjective assesment of the deviation from thermal neutrality, felt long before the autonomous thermoregulatory mechanisms are activated, thus permitting a finer control to offset heat imbalances than the autonomous defence mechanisms[4]. On the other hand, alliesthesial is not an "all-or-none" phenomenon, but it is proportional to the internal signal[6]. Thus, alliesthesial reactions reflect both subjectively and objectively the level of thermal strain.

The present results as well as earlier reports[1,6] have shown that the appreciation of "thermal comfort" is determined by the combination of level and rate of change of peripheral thermal input and the status of the internal temperature with respect to its set point. Thus, when cold stimuli are pleasant and warm stimuli unpleasant, body temperature is found to be above the set point; when warm stimuli are perceived as pleasant and cold stimuli unpleasant, body temperature is below the set point.

Under conditions of thermal neutrality, however, the temperature stimuli would arouse affective sensations, close to "indifferent" for the range of discriminative sensation from cool to warm[3,8].

Corbit compared quantitatively the physiological and behavioural thermoregulatory responses in rats and proposed a linear model to estimate the thermoregulatory behavioural responses[10].

In our results, the local thermal pleasantness/unpleasantness ratings do not deviate considerably within the range of the room temperatures 15℃ to 24℃, then local thermal stimuli which are recognized as "cold" (below 27.5℃) are perceived as unpleasant or uncomfortable, especially during the bedding down period before falling asleep. The ratings show a clear tendency towards hypothermic state, but the magnitude of these variations are not much different from neutral situation.

When the subjects awakened from sleep, the responses to local temperature stimuli show a tendency towards normothermia, which may be related to the differences in thermoregulatory responses between wakefulness and sleep durations. From the values of thermal pleasantness ratings in response to a set of temperature stimuli on the cheek, it is obvious that towards night the increased cold sensitivity corresponded to a tendency of the subjects to experience warm stimuli as more pleasant and cold ones as more unpleasant[15]. Hildebrandt[16] also presented the hypothesis that the application of heat towards evening, and the return to the warm climate of the bed, could strengthen the normal cooling down tendency.

Furthermore the results of regression coefficients of the rating stimulus line and the preferred local temperatures give also the similar tendency that the subjects are hypothermia throughout the bedding down durations for 15℃, 18℃ and 21℃. From these subjective results, 15℃, 18℃ and 21℃ seem to be a little cold environment for the bedding down period, while 24℃ and 27℃ conditions seem to be much more neutral for the same period. During the waking period, the four room temperatures of 15℃, 18℃, 21℃ and 24℃ do not cause great differences to occur. But in the 15℃ condition, the subjects whow a tendency to return towards an hypothermic state after the waking. This can be explained by the fact that the subjective sensation is more strongly affected during the awakening period, while the physiological thermoregulatory responses are strengthened during sleep. In the 27℃ condition, it is observed from the results of the rating/stimulus line and the preferred local temperatures, that the subjects are hyperthermia, especially after being awakened from sleep.

If we asume that selected local preferred temperatures are correlated with total load error in thermoregulation, then the concept of a shift in the set point temperature associated with room temperature can be suggested in the results of this experiment. Preferred local temperatures close to 28℃~27℃ are associated with thermal neutrality, higher temperatures (30℃ to 33℃) are preferred by hypothermic subjects and lower temperatures (near 23℃) are preferred by hyperthermic subjects. Thus, preferred local temperature indicates whether the apparent driving motive difference (Tbody-Tset)℃ for temperature regulation is positive, negative or zero[2,5].

The global thermal pleasantness sensation ratings of near "pleasant +1.0" are found for the sleep conditions of 18°, 21 and 24℃ of the bedding down duration, whereas during the waking period the subjects remained feeling pleasant in 15, 18 and 21℃ room temperatures. These differences might be associated with the body heat adjustment from the body core to the peripheral layers which occurred during sleep, as already described by Candas et al[9]. The global temperature sensations are also elevated to "warm" direction with two hours sleep.

Warmth-discomfort is obtained at about 24℃~27℃. Hensel[15] presented a clear distinction between temperature sensation and thermal comfort; temperature sensation is directed towards an objective world, while thermal comfort refers to the subjective state of the observer. Discomfort and temperature sensation are correlated primarily with two independent variables, the metabolic rate and ambient air temperature, and secondarily the rectal and skin temperatures[11]. In our results, it may be said that the warmth-discomfort is caused primarily by skin sweating, as already observed by Gagge et al.[11].

As for the physiological responses, it has been seen that the 18℃ and 21℃ room temperatures induced small variations of rectal and mean skin temperatures, temperatures which were maintained very constant throughout the experiment. But, subjectively, the subjects considered that these two room temperatures were a little cold for a bedding down environment.

These results confirm that behavioural indicators are more sensitive and start earlier than physiological indicators to reveal the thermal state of man[3]. Under normal conditions, the rectal temperature tends to decrease during the night until it reaches a minimum in the early morning hours.

Under cold conditions, the body temperature decreases early and is kept longer at low levels than under warm conditions[14,22]. In our study, rectal temperature decreased about 0.3℃ throughout the experiment in the 15℃ condition, and increased about 0.5℃ in the 27℃ condition.

Under the 27℃ room temperature, mean skin temperature increased to near 37℃ about 30 minutes after bedding down, then remained at a constant level and decreased slightly with sleep. This decrease of the mean skin temperature during sleep in the 27℃ condition may possibly be explained as a thermal stress reaction induced by sweating.

The results in Fig. 6 show that the heart rate increased more under the 15℃ and 27℃ conditions during both the bedding down and the waking periods than under the conditions of 18℃ and 21℃. This increase in heart rate level can be supposed as a function of activated reaction against thermal stress. The increase in heart rate in hot conditions compared to neutral conditions has also been described during sleep in man by Karacan[18]. A favorable situation is thus found with the 18℃ and 21℃ room temperatures.

Energy consumption compared to 18℃ and 21℃ conditions, also slightly increased with the 15℃ and 27℃ Conditions. In the results of body weight loss, we found that the 27℃ room temperature was judged by the subjects, who were then sweating, as a "too warm" environment for sleeping.

Looking at the bed climate, the 18℃ and 21℃ room temperatures induced throughout the total experimental period the same variations of bed humidity and bed temperature, which were kept constantly within 34%~36% for humidity, 33℃~35℃ for temperature. This has been described also by Candas et al.[9], who indicate us that the microclimate temperature measured inside the bed was found to be constant at 29.6℃ for both ambient temperatures of 19℃ and 22℃. These results also suggested that the preferred room temperature during sleep was found to be around 19℃ and subjects' reports showed that subjective discomfort increased as room temperature deviated from this condition[9].

In our results, bed humidity in the 27℃ condition rapidly increased with sleeping, reaching nearly 72% after about one hour of sleep, which is significantly higher ($p<0.001$) than in the 18℃ condition. We can assume that bed humidity probably played an important role in inducing greater "warmth-discomfort" in the 27℃ condition than in any of the four other conditions. Bed temperature sustained during the bedding down period under the 15℃ room temperature was greatly lower than under the other four conditions of 18℃, 21℃, 24℃ and 27℃, causing increased "cold-discomfort" in the 15℃ condition. This explanation is also supported by the investigations of Macpherson[19] and Humphreys[17] who proposed a thermal comfort zone for the bed room temperature.

Thus, it could be concluded that for thermal alliesthesial responses as well as for physiological responses and bed clinmate responses, the room temperatures between 18℃ and 21℃ must be considered as a neutral environment for clothed and covered young women subjects asleep in a European winter season. Aside from these tentative explanations as to how the ambient temperature affects the thermal comfort of sleep, our results suggest that the responses to peripheral stimuli (thermal alliesthesial reactions) can be used as indicators of the thermal status corresponding to the definition of the thermoneutrality of the sleep environment, almost as well as the physiological responses, and also present that the thermal conditions of the bedding down duration before falling asleep might play an important role in inducing "good sleep".

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