The Effect of Season and Light Intensity on the Core Interthreshold Zone

Naoshi Kakitsuba¹⁾, Igor B. Mekjavic²⁾ and Tetsuo Katsuura³⁾

1) Department of Environment and Technology, School of Science and Technology, Meijo University

2) Jozef Stefan Institute, Ljubljana, Slovenia

3) Graduate School of Engineering, Chiba University

Abstract The hypothesis tested in the present study is a seasonal difference in the core interthreshold zone (CIZ), as we suggested in an earlier study that individual awareness of heat may change the CIZ due to thermoregulatory behavior. A series of human experiments were carried out in a climatic chamber in January and August of 2009 and January of 2010. The air temperature in the chamber was controlled at 20–24°C. Subjects wore a water-perfused suit that was perfused with 25°C water at a rate of 600 cc/min. They exercised on an ergometer at 50% of their maximum work rate for 10–15 min until their sweating rate increased and then remained seated without exercise until oxygen uptake increased. Subjects' rectal temperature and skin temperatures at four sites were monitored by thermistors. The sweating rate was measured at the forehead with a sweat rate monitor (SKD 4000, Skinos Co.). Oxygen uptake was monitored with a gas analyzer (Respiromonitor RM-300i, Minato Med. Science Co.). In the 2009 winter experiment, 5 male subjects were exposed to lighting of 36 cd/m²/1,050 lx, and in the 2009 summer and 2010 winter experiments, 10 male subjects were exposed to lighting of 18 cd/m²/510 lx. The results showed that the CIZ of $0.69 \pm 0.29^\circ\text{C}$ ($n=22$, data from 2005–2007 experiments) at 36 cd/m² and that of $0.37 \pm 0.17^\circ\text{C}$ ($n=10$) at 18 cd/m² in summer were greater than the CIZ of $0.37 \pm 0.13^\circ\text{C}$ ($n=5$) at 36 cd/m² and that of $0.18 \pm 0.17^\circ\text{C}$ ($n=10$) at 18 cd/m² in winter, and thus demonstrated a seasonal difference in the CIZ as well as an effect of lighting conditions on the CIZ. *J Physiol Anthropol* 30(4): 161–167, 2011 <http://www.jstage.jst.go.jp/browse/jpa2>
[DOI: 10.2114/jpa2.30.161]

Keywords: body temperature regulation, shivering, sweating, core interthreshold zone, lighting condition

Introduction

The core interthreshold zone (CIZ) is defined as the range between the core temperature at the onset of shivering and that

at the onset of sweating. A constant mean skin temperature ($\bar{T}_{sk}$) is required to be independent of thermal responses due to changes in $\bar{T}_{sk}$. Mekjavic et al. (1991) proposed a water immersion method to maintain $\bar{T}_{sk}$ at 28°C and validated this methodology. Since then, they have collected data from human experiments using the water immersion method to demonstrate the effect of nonthermal factors on the CIZ, for example, nitrogen narcosis (Mekjavic et al., 1995), blood glucose (Passias et al., 1996), and motion sickness (Mekjavic et al., 2001). Recently, Mekjavic and Eiken (2006) summarized the effect of nonthermal factors on the CIZ.

In geographical locations, where there are substantial seasonal effects on the environmental conditions, humans may adapt to the conditions of the season, particularly summer and winter. Brück et al. (1971) demonstrated that the CIZ of cold- and heat-acclimated subjects was almost twice as wide as that of cold-acclimated subjects. Their result may be strongly associated with the seasonal change in the CIZ. In our recent study (Kakitsuba et al., 2009), we analyzed individual variability in the CIZ as related to body physique, somatotype, and physical constitution and showed a good correlation between susceptibility to heat and the CIZ. Considering that individual awareness of heat may change the CIZ due to thermoregulatory behavior, a difference in the CIZ between summer and winter is expected. Therefore, we focused on the seasonal difference in the CIZ between summer and winter.

The sweating-to-vasoconstriction interthreshold range has been extensively studied. Stephenson et al. (1984) demonstrated the circadian variation in the range. By measuring esophageal temperature, forearm blood flow, and local sweat rate at the chest continuously, they found that the thresholds for sweating and forearm vasodilation were significantly higher at 16:00 and 20:00 than at 24:00 and 04:00, whereas the zone did not change significantly over the 24-h day. On the other hand, Tayefeh et al. (1998) demonstrated that the interthreshold range at 3:00 was twice that observed at the other study times: 8:00, 15:00, and 20:00. These findings imply that the circadian rhythm may be more complex than just a shift in the central reference temperature,

and nonthermal factors such as light exposure may play an important role in body temperature regulation in humans. In the studies of circadian rhythm of core temperature, exposure to bright light is known to trigger an increase in core temperature in the morning (e.g., Foret et al., 1993; Takasu et al., 2006). This suggests an effect of lighting on body temperature regulation in humans. Therefore, we also focused on the effects of lighting conditions on the CIZ.

In the present study, we collected the data of healthy young Japanese male subjects in winter and summer in two different lighting conditions to demonstrate a seasonal difference in the CIZ as well as the effect of lighting on the CIZ.

Methods

Subjects

A series of human experiments were carried out in January and August of 2009 and January of 2010. Five young healthy Japanese male subjects participated in the January 2009 experiment, and ten subjects participated in the remaining experiments. They all gave their informed consent to participate in the study, and were fully aware that they could withdraw from the study at any time without prejudice. The protocol of the study was approved by the institutional ethics

review process.

Following the comprehensive procedure outlined by Drinkwater (1980), anthropometric measurements of skinfold thickness at multiple sites, and girth, length, and bone breadth of the specific body compartments were made of each subject. The obtained values were then used to estimate regional weights of the skin, adipose tissue, skeletal muscle, bone, and residual tissues. The mass percentages of the skin and adipose tissues were combined to obtain a value of adiposity. To estimate the subjects' maximum work capacity during an incremental load exercise on a cycle ergometer, the subjects were asked to pedal at a rate of 60 rpm, and the work rate was increased incrementally by 10 W/min until exhaustion or until they could no longer maintain the required cadence.

Susceptibility to heat and cold was subjectively evaluated. Subjects were asked to answer simply "yes (=1)" or "no (=0)." The height (Ht), weight (Wt), body surface area (BSA), adiposity, and subjective evaluations of the subjects who participated in the 2009 winter experiment and those who participated in the 2009 summer and 2010 winter experiments are presented in Table 1 and Table 2, respectively.

Experimental protocol

The details of the experimental protocol were described in

Table 1 Subjects' physical and psychological characteristics (2009 winter experiment)

Subjects	Age	Height (cm)	Weight (kg)	BSA (m ²)*	Adiposity (%)	Susceptibility to heat**	Susceptibility to cold**
a	24	180.4	65.0	1.8	27.9	1	1
b	22	160.0	49.40	1.87	29.1	0	1
c	22	168.5	55.2	1.6	21.6	1	0
d	22	182.2	70.4	1.9	30.1	1	1
e	22	160.0	49.40	1.50	18.3	0	1
AV±SD	22.4±0.89	170.22±10.7	57.87±9.46	1.74±0.17	25.4±4.62	-	

* BSA: body surface area (m²); **Y: yes (=1); N: no (=0).

Table 2 Subjects' physical and psychological characteristics (2009 summer and 2010 winter experiments)

Subjects	Age (yr)	Height (cm)	Weight (kg)	BSA (m ²)*	Adiposity (%)	Susceptibility to heat**	Susceptibility to cold**
A	21	166.9	66.3	1.73	31.0	0	0
B	22	172	58.9	1.69	35.8	0	1
C	23	179.6	66.2	1.82	41.4	1	0
D	23	171.1	63.0	1.73	27.4	0	0
E	22	178.4	61.7	1.77	24.7	1	1
F	23	177.5	63.7	1.78	33.9	1	1
G	22	175.5	74.2	1.88	34.7	0	0
H	22	168.3	54.2	1.61	25.6	1	1
I	21	175	58.0	1.70	32.6	0	1
J	22	179	61.0	1.76	24.8	1	1
Mean±SD	22.1±0.7	174.3±4.5	62.7±5.5	1.75±0.07	31.2±5.53	—	

The average values measured in summer and winter experiments are indicated.

* BSA: body surface area (m²); ** Y: yes (=1); N: no (=0).

our previous works (Kakitsuba et al., 2007; Kakitsuba et al., 2009). Briefly, we maintained the mean skin temperature ($\bar{T}_{sk}$) at 28°C by perfusing a water-perfused suit with water at 25°C and controlling ambient temperature at 25°C/60%. The entire system is shown in Fig. 1. Subjects wearing a water-perfused suit commenced exercising at 50% of their maximum work rate on a cycle ergometer. The exercise was terminated at the onset of sweating, which occurred after 10 to 15 min of exercise. The subjects then remained seated on the cycle ergometer for an additional 100 min. The onset of shivering was observed when oxygen uptake started to increase during the last part of the trial, while $\bar{T}_{sk}$ remained at 28°C. The thresholds were defined as the rectal temperature (T_{re}) at which sweating rate (E_{sk}) and oxygen uptake were elevated above the median resting levels.

Measurements

Rectal (T_{re}) and skin (arm, chest, thigh, and calf) temperatures were monitored with thermistors, and the values were stored every ten seconds using a data logger system (Cadac2 Model 9200A; Cadac, Tokyo, Japan). The sweating rate was measured at the forehead with a sweat rate monitor (Model SKD-4000; Skinos Company, Nagoya, Japan). Oxygen uptake was monitored with a gas analyzer (Respiromonitor RM-300i; Minato Medical Science Company, Tokyo, Japan).

Maintenance of $\bar{T}_{sk}$ while simultaneously extracting 120 W/m² of heat was achieved by having the subjects wear a Cool Tubesuit™ (Med-Eng Systems, Inc., Ottawa, Ontario, Canada) water-perfused suit. The water perfusing the suit was pumped at a rate of 600 cc/min (Water Pump Model Super Tepcon; Terada, Tokyo, Japan) from a bath in which the water temperature was maintained at 25°C by a Cool Mate Model TE-105M heat exchanger (Toyo Seisakusho Co., Tokyo, Japan).

When the fluorescent lights (FHF32EX N-H32W, 5,000K; National Co., Ltd.) were on throughout the experimental

period, we measured the vertical brightness level of the climatic chamber and the vertical light intensity with an illuminance meter (Luminance Meter LS-100, KONICA MINORUTA, Tokyo, Japan) and a luminance meter (Illuminance meter 510-05, Yokogawa Meters & Instruments Co., Tokyo), respectively. In the 2009 winter experiment, the brightness level was 36 cd/m² at the eye level of the seated subject at a light intensity of 1,050 lx, whereas it was 18 cd/m² at the eye level of the seated subject at a light intensity of 510 lx in the 2009 summer and 2010 winter experiments. The subjects chose “bright” and “slightly dark” to describe the light in the 2009 winter experiment and the 2009 summer and 2010 winter experiments, respectively.

Statistical analysis

All physiological and psychological variables measured were presented as the means $\pm$ SD. A comparison of the CIZs between seasons and the brightness levels was made using a factorial ANOVA. The Bonferroni test was used for *post-hoc* analysis of significant differences. Significant difference was set at $p < 0.05$.

Results

Determination of sweating and shivering thresholds

We designed the experiment to maintain $\bar{T}_{sk}$ (calculated from the equation suggested by Ramanathan, 1976) consistently at 28°C. However, in some cases, $\bar{T}_{sk}$ changed slightly (from 32°C during exercise to 30°C at the end of the recovery period) during the experimental period because of the cooling method using the water-perfused suit instead of water immersion. The difference between local skin temperatures and $\bar{T}_{sk}$ was within $\pm 0.2^\circ\text{C}$ throughout the experimental period. Typical responses of $\bar{T}_{sk}$ and T_{re} are shown in Fig. 2. According to unpublished data we obtained previously, skin temperatures at uncovered

Fig. 1 Diagram of the cooling system. This diagram appeared in the previous publications by Kakitsuba et al. (2007, 2009). For the purpose of providing details of the system, it is shown again here. A chiller cooled the water in the bath, and a pump supplied the cool water into the vinyl tubes incorporated in the suit. After water was perfused through the tubes, it was returned to the water bath and cooled again.

Fig. 2 An example of changes in rectal temperature and mean skin temperature during the experiment. The T_{re} and $\bar{T}_{sk}$ indicate rectal temperature and mean skin temperature, respectively. The onset of sweating was observed during exercise. Following exercise, the subjects rested until shivering was observed at 70 to 90 min after the beginning of exercise.

locations such as the back of the hand and the step were also controlled in the range of 26°C to 28°C.

CIZ at a brightness level of 36 cd/m² in winter

The results from the 2009 winter experiment are indicated in Table 3. The mean CIZ of the five subjects was $0.37 \pm 0.13^\circ\text{C}$. This value was about half as wide as that ($=0.69^\circ\text{C}$, $n=22$) observed from the past experiments carried out in summer in the same lighting condition (Kakitsuba et al., 2007; Kakitsuba et al., 2009). There was a significant effect of season ($p=0.05$), and the post-hoc analyses showed that the CIZ in summer was significantly ($p<0.01$) wider than that in winter at a brightness level of 36 cd/m².

CIZ at a brightness level of 18 cd/m² in winter and summer

The results from the 2009 summer and 2010 winter experiments are indicated in Table 4. Subject B in summer had a higher T_{re} ($=37.8^\circ\text{C}$) before the experiment as compared with the T_{re} ($=37.2^\circ\text{C}$) in winter. However, he insisted he was healthy, so we carried out the experiment. The CIZ of Subject D was consequently zero, in support of the set point theory (Hammel et al., 1963). In his case, the sweating threshold was

observed 15 min after the beginning of exercise, and T_{re} continued increasing for 5 min and then decreased gradually until shivering occurred. At the onset of shivering, T_{re} was the same as that at the onset of sweating. Since all the procedures for this subject were carried out in an identical way to those for other subjects, we did not exclude his data. The *post-hot* analyses showed that the CIZ in summer was significantly ($p<0.01$) wider than that in winter.

CIZ at two different brightness levels in summer and winter

We have collected CIZs since 2004, and the results are tabulated in Table 5. As already mentioned, the CIZs in summer were significantly wider than those in winter, regardless of the lighting conditions. There was a significant effect of brightness level ($p=0.05$), and the post-hot analyses showed that the CIZ at 36 cd/m² was significantly ($p<0.01$) wider than that at 18 cd/m². Thus, both season and lighting conditions appear to be nonthermal factors related to the CIZ.

Discussion

The CIZ was significantly wider in summer ($p<0.01$) than that in winter, as shown in Table 4. In addition, the CIZ at a brightness level of 36 cd/m² was significantly wider ($p<0.01$) than those at a brightness level of 18 cd/m², as shown in Table 5. Therefore, a seasonal difference in the CIZ and an effect of light conditions on the CIZ was also clearly demonstrated.

In comparison of the CIZs for the different subject groups, the effect of factors reflecting physical constitution and susceptibility to heat on the CIZ should be excluded. Physical factors such as height, weight, and adiposity for three groups were then tested. The results indicated that there were no significant differences of height and weight between the three groups with the exception of adiposity. Adiposity of $31.2 \pm 5.53\%$ (mean $\pm$ SD) for the subject group who participated in the 2009 summer and 2010 winter experiments

Table 3 Core interthreshold zone in winter at a brightness level of 36 cd/m²*

Subjects	$T_{\text{re-sw}}$	$T_{\text{re-shivering}}$	CIZ ($^\circ\text{C}$)
a	37.49	37.11	0.38
b	37.45	37.19	0.26
c	37.24	37.01	0.23
d	37.35	36.9	0.45
e	37.37	36.82	0.55
Mean $\pm$ SD	37.38 ± 0.097	37.01 ± 0.15	0.37 ± 0.13

* Results from the 2009 winter experiment.

$T_{\text{re-sw}}$: sweating threshold; $T_{\text{re-shivering}}$: shivering threshold.

Table 4 Core interthreshold zone in summer and winter at a brightness level of 18 cd/m²*

Subjects	Summer			Winter		
	$T_{\text{re-sw}}$	$T_{\text{re-shivering}}$	CIZ	$T_{\text{re-sw}}$	$T_{\text{re-shivering}}$	CIZ
A	38.39	37.04	0.29	37.29	37.15	0.14
B	37.49	37.65	0.74	37.56	36.99	0.57
C	37.62	37.03	0.46	37.10	36.83	0.27
D	37.26	37.62	0.00	37.46	37.42	0.04
E	37.21	37.11	0.15	36.89	36.83	0.06
F	37.43	36.47	0.74	37.01	36.67	0.34
G	36.97	37.16	0.27	37.16	37.07	0.09
H	36.97	36.76	0.21	36.95	36.82	0.13
I	37.5	36.53	0.44	37.29	37.18	0.11
J	37.33	37.1	0.4	36.87	36.85	0.02
Mean $\pm$ SD	37.42 ± 0.40	37.05 ± 0.40	0.37 ± 0.24	37.16 ± 0.24	36.98 ± 0.22	0.18 ± 0.17

* Results from the 2009 summer and 2010 winter experiments. $T_{\text{re-sw}}$: sweating threshold; $T_{\text{re-shivering}}$: shivering threshold.

Table 5 Comparison of core interthreshold zones between summer and winter under two different lighting conditions

Lighting conditions	Summer	Winter
18 cd/m ²	0.37±0.17*	0.18±0.17*
36 cd/m ²	0.69±0.29***	0.37±0.13**

* 2009 summer and 2010 winter experiments ($n=10$)** 2009 winter experiment ($n=5$)*** A series of experiments from 2004 to 2008 ($n=22$)

(See data presented by references: Kakitsuba et al., 2007, 2009)

was significantly ($p<0.01$) higher than for the other two groups. However, according to the study by Kakitsuba et al. (2009), who analyzed the relationship between the CIZ and factors reflecting physical constitution, no physical factors appeared to be correlated with the CIZ. In addition, their analyses demonstrated that onset of shivering of the subjects who answered “susceptible to heat” becomes lower as compared with that of the subjects who answered “not susceptible to heat.” Percentages of the number of subjects who answered “susceptible to heat” for the three groups were in the range of 50% to 60%. Although the 50% for the subject group who participated in the 2009 summer and 2010 winter experiments was lower than those for the other two groups, we thought that such a difference of susceptibility to heat was unlikely to result in any difference in the CIZs between those groups.

Seasonal difference in the CIZ

At a brightness level of 18 cd/m², the CIZ in summer was significantly wider ($p<0.01$) than that in winter, as shown in Table 4. At a brightness level of 36 cd/m², the CIZ in summer was also significantly ($p<0.01$) wider than that in winter, as shown in Table 5. Therefore, a seasonal difference in the CIZ was clearly demonstrated.

Using the results in summer shown in Table 4, the CIZ for the “susceptible to heat” group was $0.39\pm0.23^{\circ}\text{C}$ (mean±SD), whereas that for the “not susceptible to heat” group was $0.35\pm0.27^{\circ}\text{C}$. Although there is no significant difference, it appears that the CIZ for the “susceptible to heat” group was wider than that for the “not susceptible to heat” group in summer, as demonstrated in our previous study (Kakitsuba et al., 2009). On the other hand, using the results in winter shown in Table 4, the CIZ for the “susceptible to heat” group was $0.16\pm0.14^{\circ}\text{C}$, whereas that for the “not susceptible to heat” group was $0.19\pm0.22^{\circ}\text{C}$. So, it can be confirmed that the CIZ for the “susceptible to heat” group was not wider than that for the “not susceptible to heat” group in winter, and thus the effect of susceptibility to heat on making the CIZ wider may only be expected in summer.

In our previous study carried out in summer (Kakitsuba et al., 2007; Kakitsuba et al., 2009), we demonstrated that the lower shivering threshold of the “susceptible to heat” group may be reflected in their thermoregulatory behavior, and

speculated that the “susceptible to heat” group preferred the use of air-conditioning devices more than did the “not susceptible to heat” group, according to the replies of the questionnaire on everyday life. In summer, the “susceptible to heat” group may be more acclimated to both heat and cool or cold in summer than are the “not susceptible to heat” group.

Brück et al. (1971) proved the difference in the CIZ between cold-acclimated subjects and cold- and heat-acclimated subjects. The sweating threshold of cold- and heat-acclimated subjects was higher than that of cold-acclimated subjects. On the other hand, the shivering threshold of both subject groups was the same. As a result, the CIZ of cold- and heat-acclimated subjects was almost twice as wide as that of cold-acclimated subjects. This may be the physiological background for the seasonal difference in the CIZ. Regardless of susceptibility to heat, all the subjects may be acclimated to heat and cool or cold in summer, and therefore such acclimatization may result in a wider CIZ.

Effect of light conditions on the CIZ

As indicated in Table 5, the CIZ at a brightness level of 36 cd/m² was significantly wider ($p<0.05$) than that at a brightness level of 18 cd/m². This result indicates that the higher intensity of lighting induces a wider CIZ, and implies that parasympathetic nervous activity is prevailing in brighter conditions than darker conditions because shivering or sweating did not occur promptly in response to a change in core temperature. Thus, the result suggests that autonomic control of core temperature is reduced by higher intensity of lighting.

Saito et al. (1996) reported that sympathetic nervous activity increased in high illuminance conditions. Dijk et al. (1991) also reported that arousal level increased and hypothermia was alleviated in high illuminance conditions. On the other hand, some studies (Kim and Tokura, 2000; Tokura, 2005; Jin et al., 2007) reported that parasympathetic nervous activity increased with inhibition of sympathetic nervous activity in high illuminance conditions. Thus, the effect of exposure to light on autonomic functions has not been clearly evaluated. It appears that the manner of light exposure may be one of the reasons for this controversy. Some factors related to, for example, exposure time and a difference in light intensities before and after exposure may be associated with the effect of exposure to light on autonomic functions.

In the present study, the subjects were exposed to a given brightness level for 2 hours or longer. This may be enough to evaluate the effect of lighting on the CIZ, as the effect of morning bright light on core temperature was demonstrated when subjects were exposed to bright light for 2 hours (e.g., Foret et al., 1993; Takasu et al., 2006). Intensity of lighting was set at 500 and 1,000 lx in the present study, substantially lower than 2,000 lx to 5,000 lx set at by Foret et al. (1993). However, Jin et al. (2007) demonstrated the effect of lighting on EEG when their subjects were exposed to 200 lx and 1,500 lx for 20 min on each trial. So the lighting conditions set in the

present study seem to be appropriate for evaluating change in autonomic control of core temperature.

Apart from the pathway of visual sensation, there is another pathway called the “nonvisible pathway” or “nonimage-forming photoreceptive system” in response to visual stimuli. According to Klein et al. (1983), visual information received by the retina is transferred to a suprachiasmatic nucleus (SCN) and then further transferred to the paraventricular nucleus of the hypothalamus and reticular formation. Finally, it reaches the pineal body, which controls the secretion of melatonin. The secretion of melatonin is strongly associated with the circadian rhythm of core temperature. Concerning the nonvisual pathway, the literature has demonstrated the effect of light exposure on the autonomic nervous system (e.g., Jacobs and Hustmyer, 1974; Kobayashi and Sato, 1992; Jin et al., 2007), as well as the thermal regulation system (e.g., Scheer et al., 2005), showing the interaction of environmental light and the SCN in body temperature regulation. Since the pineal body is located near the hypothalamus, which regulates core temperature, reciprocal or one-sided afferent information may be incorporated into the body temperature regulation system, and the results suggest that afferent information via the nonvisual pathway on light exposure may play a significant role of reducing the autonomic control of core temperature.

In the present study, a seasonal difference in the CIZ and the effect of light exposure on the CIZ were demonstrated. The effect of light intensity on the CIZ indicates the possible incorporation of a nonvisual pathway into the body temperature regulation system in response to visual stimuli.

Acknowledgements This study was supported in part by Grants-in-Aid #15107005 and #20370098 for Scientific Research, Japan.

References

- Bruck K, Wunnenberg W, Gallmeier H, Ziehm B (1971) Shift of threshold temperature for shivering and heat polypnea as a mode of thermal adaptation. *Pflugers Arch* 321: 159–172
- Dijk DA, Cajochen C, Borbely A (1991) Effect of a single 3 hour exposure to bright light on core body temperature and sleep in humans. *Neurosci Lett* 121: 59–62
- Drinkwater DT (1980) Anthropometric fractionation of body mass. In Osytn M, Beunen G, Simons J eds. *Kinanthropometry*, University Park Press, Baltimore, 177–189
- Foret J, Aguirre A, Touitou Y, Clodre M, Benoit O (1993) Effect of morning bright light on body temperature, plasma cortisol and wrist motility measured during 24 hour of constant conditions. *Neurosci Lett* 155: 155–158
- Hammel HT, Jackson DC, Stolwijk JAJ, Hardy JD, Stromme SB (1963) Temperature regulation by hypothalamic proportional control with an adjustable set point. *J Appl Physiol* 18: 1146–1154
- Jacobs KW, Hustmyer FE (1974) Effects of four psychological primary colors on GSR, heart rate and respiration rate. *Percept Mot Skills* 38: 763–766
- Jin XQ, Katsuura T, Iwanaga K, Shimomura Y, Inoie M (2007) The influence of taste stimuli and illumination on electrogastragram measurements. *J Physiol Anthropol* 26: 91–195
- Kakitsuba N, Mekjavic IB, Katsuura T (2007) Individual variability in the peripheral and core interthreshold zones. *J Physiol Anthropol* 26: 403–409
- Kakitsuba N, Mekjavic IB, Katsuura T (2009) Individual variability in the core interthreshold zone. *J Physiol Anthropol* 28: 275–281
- Kim HE, Tokura H (2000) Influence of light intensities on dressing behavior in elderly people. *J Physiol Anthropol Appl Human Sci* 19:13–19
- Klein DC, Smoot R, Weller JL, Higa S, Markey SP, Greed GJ, Jacobowitz DM (1983) Lesions of the paraventricular nucleus area of the hypothalamus disrupt the suprachiasmatic-spinal cord circuit in the melatonin rhythm generating system. *Brain Res Bull* 10: 647–652
- Kobayashi H, Sato M (1992) Physiological responses to illuminance and color temperature of lighting. *Ann Physiol Anthropol* 11: 45–49
- Mekjavic IB, Sundberg CJ, Linnasson D (1991) Core temperature “null zone.” *J Appl Physiol* 71: 1289–1295
- Mekjavic IB, Savic S, Eiken O (1995) Nitrogen narcosis inhibits shivering thermogenesis in man. *J Appl Physiol* 78: 2241–2244
- Mekjavic IB, Tipton MJ, Gennser M, Eiken O (2001) Motion sickness potentiates core cooling during immersion in humans. *J Physiol* 535: 619–623
- Mekjavic IB, Eiken O (2006) Contribution of thermal and nonthermal factors to the regulation of body temperature in humans. *J Appl Physiol* 100: 2065–2072
- Passias TC, Meneilly GS, Mekjavic IB (1996) Effect of hypoglycemia on thermoregulatory responses. *J Appl Physiol* 80: 1021–1032
- Ramanathan NL (1976) A new weighting system for mean surface temperature of the human body. *J Appl Physiol* 41: 256–258
- Saito Y, Shimizu T, Takahashi Y, Mishima K, Takahashi K, Ogawa Y, Kogawa S, Hishikawa Y (1996) Effect of bright light exposure on muscle sympathetic nerve activity in humans. *Neurosci Lett* 219: 135–137
- Scheer FA, Pirovano C, Van Someren EJ, Buijs RM (2005) Environmental light and suprachiasmatic nucleus interact in the regulation of body temperature. *Neurosci* 132: 465–477
- Stephenson LA, Wenger CB, O'Donovan BH, Nadel ER (1984) Circadian rhythm in sweating and cutaneous blood flow. *Am J Physiol* 246: R321–R324
- Takasu N, Hashimoto S, Yamanaka Y, Tanahashi Y, Yamazaki A, Honma S, Honma K (2006) Repeated exposures to daytime bright light increase nocturnal melatonin rise and maintain circadian phase in young subjects under fixed sleep schedule. *Am J Physiol Regul Integr Comp Physiol* 291:

1799–1807

- Tayefeh F, Plattner O, Sessler D I, Ikeda T, Marder D (1998) Circadian changes in the sweating-to-vasoconstriction interthreshold range. *Pflügers Arch–Eur J Physiol* 435: 402–406
- Tokura H (2005) Physiological significance of bright vs. dim light intensities during the daytime for thermoregulatory responses, digestive functions and evening dressing behavior in the cold. *Environmental Ergonomics*, Elsevier Ltd., 25–30

Received: June 23, 2010

Accepted: April 25, 2011

Correspondence to: Naoshi Kakitsuba, Department of Environment and Technology, School of Science and Technology, Meijo University, 1–501 Shiogamaguchi, Tenpaku-ku, Nagoya 468–8502, Japan

Phone: +81–52–838–3282

Fax: +81–52–838–3282

e-mail: naoshi@ccmfs.meijo-u.ac.jp