J. Human Ergol., **33**: 61-67, 2004

Communications

EFFECTS OF BAREFOOT HABITUATION IN WINTER ON THERMAL AND HORMONAL RESPONSES IN YOUNG CHILDREN - A PRELIMINARY STUDY -

SHIN-JUNG PARK[1], NORI KIKUFUJI[2], KI-JA HYUN[3], AND HIROMI TOKURA[4*]

[1]*Dept. of Fashion Design, Sungkyunkwan University, Seoul 110-745, Korea*
[2]*Dept. of Living Sciences, Kyoto Bunkyo Junior College, Uji 611-0041, Japan*
[3]*Graduate School of Humanities and Sciences, Nara Women's University, Nara 630-8506, Japan*
[4]*Institute of Textiles & Clothing, The Hong Kong Polytechnic University, Kowloon, Hong Kong, China / *Email : tchiromi@polyu.edu.hk*

This study investigated how socks-wearing habit or habitual barefoot in the cold winter affected skin temperatures of distal lower extremities, the urinary excretion of adrenaline, noradrenaline and cortsisol in young children. In Experiment I for preschool children, the measurements of foot and leg skin temperatures were conducted for 30 min in the classroom controlled at 23±2°C and 50±5%RH, and the excretion of urinary catecholamines and cortisol during nocturnal sleep were analyzed. In Experiment II for elementary school children, nocturnal secretion of urinary catecholamines and cortisol was analyzed. While leg skin temperature tended to be lower in barefoot group than in socks group during Experiment I, foot skin temperature was not significantly different between the two groups. Fall of leg skin temperature during 30 min measurement tended to be smaller in barefoot group than in socks group. Urine volume and urinary excretion of cortisol tended to be greater in barefoot group than in socks group for preschool children. Urinary noradrenaline was significantly greater and cortisol tended to be greater in barefoot group than in socks group for elementary school children. Considering that most of the findings shown above were in the proximity of the established level of statistical significance, it was provisionally concluded that young children with barefoot habituation might show more effective cold adaptation of metabolic type than those without the habituation do, by keeping their skin temperatures higher even in the cold and enhancing the metabolic rate.
Key Words: children; barefoot habituation; leg skin temperature; urinary noradrenaline; urinary cortisol

INTRODUCTION

It is well known that the extremities play an important role in the control of heat loss in thermoregulation in humans (Burton, 1963; Aschoff and Heise, 1972; Heising and Werner, 1985; Jeong and Tokura, 1988, 1993; Park and Tokura, 1997, 1998). This has been repeatedly demonstrated by comparing the thermoregulatory responses between subjects wearing clothing uncovering distal extremities (Type H), e.g. short-sleeved shirts and knee-length trousers and those wearing clothing covering them (Type L), e.g. long-sleeved shirts and full-length trousers. Jeong and Tokura (1988) found that core temperature was kept higher during acute cold exposure of 10°C when wearing Type H than Type L clothing. They discussed this result by countercurrent heat exchange system (Bazett, 1949) and the volumetric ratio of core to shell of the human body (Aschoff and Wever, 1958). Li et al. (1994a, b) demonstrated that lowering of rectal temperature during the period from September to November, when season gradually became colder, was greater in subjects wearing short skirts during

Received for publication January 23, 2004

the daytime than in subjects dressing full-length trousers. Thus uncovering legs seems to promote seasonal cold acclimatization.

Moreover, our previous study (Park and Tokura, 1998) disclosed that urinary adrenaline and noradrenaline in a thermal environment of 24°C were significantly greater in the morning and lesser in the nighttime with Type H clothing than with Type L clothing. We discussed that these results might be caused by the more activated sympathetic nervous system during the daytime because of the need for stronger vasoconstriction in the extremities with less thermal insulation, and the more relaxed one during nocturnal sleep. In addition, we found that nocturnal salivary immunoglobulin A (IgA) was significantly higher when wearing Type H than Type L clothing (Park and Tokura, 1997). Also, Araki and Inoue (1982) reported that respiratory infections were more likely to develop in children group wearing heavy clothes habitually compared to the group wearing lightly. Therefore, what is worn habitually might affect the endocrine and immune responses to the cold stimuli.

The observation enumerated above might lead one to extrapolate the barefoot habituation in winter to the habitual exposure of lower extremities with Type H clothing, in inducing thermoregulatory adaptation. So far as the present authors are aware, however, studies dealing with the relationship between barefoot habituation and thermo-physiological responses are very few. This paucity motivated the present study, in which the influences of habitual barefoot in winter on skin temperatures of leg and foot and urinary excretion of stress hormones were investigated in young children.

MATERIALS AND METHODS

Two series of experiments by field tests were performed on preschool young children (Experiment I) and elementary school children (Experiment II). These experiments were performed with assistance and cooperation of the children's teachers and parents, and the informed consents were obtained from the parents before data collection.

Experiment I

Fifteen apparently healthy young children, 4 years of age, took part in the experiment. Even in winter, eight of them spent with barefoot habitually (Group B-1) and seven of them were wearing socks (Group S-1). This experiment was conducted in February 2001 in Nara and Kyoto, Japan. As usual, the participants came to the preschool at 08:00 h and spent in the classroom controlled at 23±2°C and 50±5% RH. The participant had a light snack at 10:00 h. In the morning from 10:30 h to 11:00 h, skin temperatures of the lateral crural region and dorsal foot were measured every minute for 30 minutes by thermistor probes with an accuracy of 0.01°C (LT-ST08-12, Gram Corp, Japan) and continuously recorded by an LT Logger (LT-8, Gram Corp, Japan). During the experiment, all participants of the two groups were playing under the teacher’s guidance in sitting position, and they wore the formal preschool uniform consisting of long-sleeved undershirts, jumpers, underpants and knee-length trousers on shorts. But they did not wear socks.

Besides, nocturnal urine samples were collected from the children by their parents. Their parents were fully explained on the collection method and asked to get their children to urinate without collection just before retiring and to collect the secreted whole urine during nighttime sleep. They measured urine volume, and placed 5 ml of the collected urine in a sample tube, and stored in a freezer for subsequent analysis. The concentrations of urinary adrenaline and noradrenaline were analyzed by HPLC (High-Performance Liquid Chromatography), and that of the cortisol (extricated type) by radio immunoassay. Total of bonding and extricated types in the catecholamines was analyzed at SRL, a commercial biochemical laboratory in Tokyo.

Experiment II

Seventy five children ranging in age from 9 to 11 years old participated. They were the third to fifth grade students in the elementary school located in Nara or Kyoto, Japan. Twenty five of them had worn socks in winter (Group S-2) and fifty of them had barefoot habituation over 3 years (Group B-2). All participants were in full health and good sleepers. They spent their time normally, usually having classes at the school, returning home and spending with their parents. They retired at their normal bedtime and took their normal sleep time. They urinated without collection just before retiring and collected whole amount of urine as soon as they rose. The collected urine sample was treated and analyzed as in Experiment I for the total volume, adrenaline, noradrenaline and cortisol.

Data analysis

A two-way ANOVA with repeated measures (the two main factors were socks and time in the experiment) was performed to test the difference between Group B-1 and Group S-1 in leg and foot skin temperatures. When the interaction between socks and time was found to be significant, a pairwise difference was identified using unpaired *t*-test. Also, for urine volume and urinary excretion of adrenaline, noradrenaline and cortisol, the difference between Group B and Group S was analyzed by unpaired *t*-test. Values were given in mean ± standard error of mean (SEM).

RESULTS

Figures 1a, 1b, 1c and ld compare raw data and the changes of leg and foot skin temperatures during 30 min between Group B-1 and Group S-1. The result of statistical analysis by ANOVA is shown in Table 1. Leg skin temperature was not significantly different between the two groups, but the temperature was significantly different by the time ($p<0.001$). Also, the effect of socks on leg skin temperature tended to be different by the time ($p=0.072$). By a pairwise comparison, leg skin temperature tended to be lower in Group B-1 than in Group S-1 during the experiment (Fig. 1a). The change of leg skin temperature showed a tendency of interaction between socks and time ($p=0.065$).

Foot skin temperature also appeared to be lower in Group B-1 than in Group S-1 (Fig. 1c), but the tendency was not significant. By contrast, the temperature was significantly different by the time ($p<0.001$). The interaction was not significant.

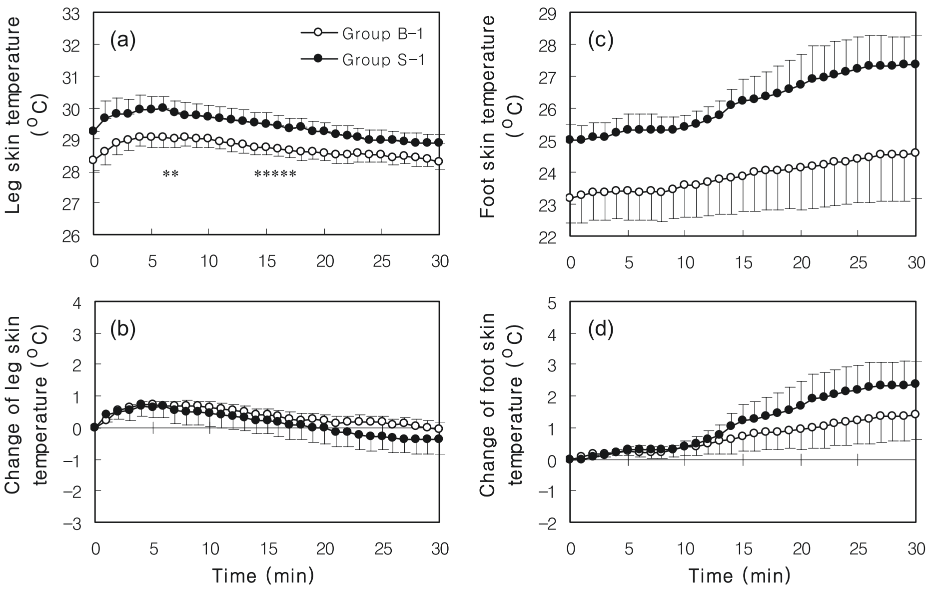

Fig. 1. Temporal changes of skin temperatures recorded on the lateral crural region (a, b) and dorsal foot (c, d) in the two groups. Values are mean and SEM. An asterisk indicates that the corresponding values differ significantly at 5% level.

Table 1. Statistical results by ANOVA of skin temperatures and its temporal changes in leg and foot sites.

	Socks		Time		Interaction	
	F-value	*p*	F-value	*p*	F-value	*p*
Temperature						
	df =1, 13		df = 30, 390		df = 30, 390	
Leg	2.665	*p*=0.127	19.702	*p*<0.001	1.425	*p*=0.072
Foot	2.848	*p*=0.115	8.822	*p*<0.001	0.886	*p*=0.643
Change of temp.						
	df =1, 5		df = 30, 150		df = 30, 150	
Leg	0.278	*p*=0.607	21.543	*p*<0.001	1.441	*p*=0.065
Foot	0.561	*p*=0.467	8.822	*p*<0.001	0.886	*p*=0.643

Table 2. A comparison of skin temperatures in leg and foot sites for the first and last 5 minutes of experiment between Group B-1 and Group S-1 (F: first 5 minutes; L: last 5 minutes; F-L: difference of L from F).

	Leg			Foot		
	Group B-1	Group S-1	unpaired *t*-test	Group B-1	Group S-1	unpaired *t*-test
First 5 min						
Mean	28.94	29.85	*p*=0.061	23.36	25.18	*p*=0.052
SEM	0.324	0.457		0.872	0.473	
Last 5 min						
Mean	28.39	28.91	*p*=0.093	24.54	27.34	*p*=0.069
SEM	0.228	0.295		1.440	0.919	
paired *t*-test	*p*=0.002	*p*=0.001		*p*=0.069	*p*=0.013	
F-L difference						
Mean	-0.55	-0.94	*p*=0.055	1.17	2.16	*p*=0.176
SEM	0.131	0.196		0.701	0.740	

Table 2 compares the skin temperatures for the first and last 5 minutes between Group B-1 and Group S-1 at leg and foot sites. Data are the means for 5 minutes. Leg and foot skin temperatures tended to be higher in Group S-1 than in Group B-1 for the first and last 5 minutes (unpaired *t*-test, *p*=0.061 and 0.052, for the first; 0.093 and 0.069 for the last, in leg and foot sites, respectively). From the first to the last 5 minutes, leg skin temperature decreased significantly in both groups, while foot skin temperature tended to increase in Group B-1 or significantly increased in Group S-1 (paired *t*-test, *p*=0.002 and 0.001 for leg; 0.069 and 0.013 for foot in Group B-1 and Group S-1, respectively). Moreover, the difference of mean leg temperature between the first and last 5 minutes was nearly significantly greater in Group S-1 than in Group B-1 (unpaired *t*-test, *p*=0.055), while the difference of

Table 3. A comparison of urinary components between Group B-1 and Group S-1 in preschool children.

	Group B-1 (n=8)		Group S-1 (n=7)		
	Mean	SEM	Mean	SEM	unpaired *t*-test
Total volume (ml)	50.00	11.88	31.43	5.64	*p*=0.100
Adrenaline (μg)	0.876	0.216	0.707	0.088	*p*=0.252
Noradrenaline (μg)	6.882	2.659	4.970	2.527	*p*=0.305
Cortisol (μg)	2.920	1.291	0.776	0.161	*p*=0.074

Table 4. A comparison of urinary components between Group B-2 and Group S-2 in elementary school children.

	Group B-2 (n=50)		Group S-2 (n=25)		
	Mean	SEM	Mean	SEM	unpaired *t*-test
Total volume (ml)	220.40	10.99	202.12	16.86	*p*=0.213
Adrenaline (μg)	2.547	0.382	1.882	0.237	*p*=0.122
Noradrenaline (μg)	25.250	2.411	18.090	1.918	*p*=0.028
Cortisol (μg)	6.850	0.914	5.010	0.517	*p*=0.067

mean foot temperature was not significant between the two groups.

Table 3 shows urine volume and urinary excretion of adrenaline, noradrenaline and cortisol for the two groups of preschool children. Urine volume and urinary cortisol tended to be greater in Group B-1 than in Group S-1 (unpaired *t*-test, *p*=0.100 and 0.074, respectively). However, adrenaline and noradrenaline were not significantly different between the two groups.

Table 4 demonstrates urine volume and urinary excretion of adrenaline, noradrenaline and cortisol for the two groups of elementary school children. Urine volume and urinary adrenaline were not significantly different between the two groups, but the secreted noradrenaline was significantly greater (*p*=0.028) and cortisol tended to be greater (*p*=0.067) in Group B-2 than in Group S-2.

DISCUSSION

The present investigation has shown a tendency to exist that the skin temperatures in lower extremities and urinary components in preschool and elementary school children are influenced by the habitual barefoot. Most of these observations, however, were only nearly or marginally significant in the statistical evaluation. The reason for these results might be that factors were not controlled other than the socks-wearing habit, while the sample size was not so large as to cause canceling out of the influences of irrelevant factors. Although these situations allow the authors to draw only provisional conclusions, the findings will be briefly discussed within the limitations.

Despite that the barefoot and socks groups dressed identically during the experiment, the barefoot group tended to keep lower skin temperatures in the distal extremities. In contrast, the lowering of leg skin temperature tended to be greater in socks group than in barefoot group from the first to the last 5 minutes of the experiment. Generally, in winter, the environmental temperature falls, so thermoregulation adjusts to make heat loss be suppressed. Thus, sympathetic nervous system is more active, then cutaneous vasoconstriction ensues and blood shifts from the surface to deeper tissues, resulting in temperature fall in the extremities and reduction of heat loss (Yoshimura, 1960).

Accordingly, it appears that children of the barefoot group compared with the socks group have more effective regulation of heat loss from the body to the cold air by means of vasoconstriction.

It is of interest that urine volume and urinary cortisol for preschool children and urinary noradrenaline and cortisol for elementary school children were significantly or tended to be greater in barefoot group than in socks group. There are two different methods of cold adaptation; continuous exposure to moderate cold (CM) and short intermittent exposure to severe clod (IS). Some researchers (Radomski and Boutelier, 1982; LeBlanc, 1978; LeBlanc and Pouliot, 1964) have demonstrated that cold adaptation by CM and IS method is characterized by an increase and decrease in sympathetic response, respectively. In consequence, CM adaptation causes initial transitory increases in the excretion of adrenaline and cortisol and a sustained increase in noradrenaline excretion, thus giving rise to a metabolic type of adaptation characterized by a higher metabolic response to cold (Rennie et al., 1962; Andersen et al., 1960; Scholander et al., 1958; Radomski and Boutelier, 1982).

Although we did not measure metabolic heat production in the experiment, and the hormonal response did not show a consistent result between the two groups, the barefoot group appeared to show CM type of adaptation; the lower skin temperatures might be due to vasoconstriction in the shell resulting from elevated noradrenaline excretion by chronic cold exposure, which would increase intrathoracic blood volume leading to hypertension (Radomski and Boutelier, 1982). In this blood redistribution, the intrathoracic stretch receptors could mediate the change of antidiuretic hormone (ADH) secretion (Suzuki, 1972). The greater urine volume observed in the barefoot group might be caused by the elevated cold diuresis due to a diminished secretion of ADH.

The measurement of leg and foot skin temperatures was performed in a neutral room temperature in Experiment I. The leg skin temperature adhered to the previous value in the barefoot group, while considerably deviated in the socks group. It is probable that this behavior shall be kept in the cold outside the building in winter. If so, the leg skin temperature might become higher in the barefoot group than in the socks group in a cold air temperature usually experienced outside. Under such conditions, the heat loss from legs to surrounding air may be higher constantly in the barefoot group than in the socks group. The metabolic heat must be elevated in order to compensate for the increased heat loss. It is presumable that higher urinary noradrenaline and cortisol excretion in the barefoot group may reflect such physiological states.

Urinary cortisol excretion had the similar tendency, i.e. the barefoot group tended to have higher values, between the children of preschool and elementary school. While the excretion of urinary noradrenaline was also significantly higher in the barefoot than in the socks group of elementary school, there did not exist any significant difference between the barefoot and socks groups of preschool. Such a trend is presumably related with the fact in winter that elementary school children play often outside the building, while preschool children stay mostly inside the building. On the contrary, there did not exist any different trend for adrenaline excretion between the barefoot and socks groups both of preschool and elementary school. This discrepancy remains to be clarified.

Based on the above discussion, our provisional conclusion is that barefoot habituation in the cold winter could induce effective acclimatization of metabolic type in young children.

REFERENCES

Andersen, KL, Lyning, Y, Nelms, JD, Wilson, O, Fox, RH, and Bolstad, A (1960) Metabolic and thermal response to a moderate cold exposure in nomadic Lapps. *J. Appl. Physiol*. **15**: 649-653.

Araki, T and Inoue, Y (1982) Effects of lightly dressing on the thermoregulation function in children; as considered from standpoint of cold contraction. *Jpn. J. School Health* **24**: 344-349.

Aschoff, J and Heise, A (1972) Thermal conductance in man: its dependence of time of day and on ambient temperature. *In*: Advances in Climatic Physiology, ed. by Itoh, S, Ogata, K, and Yoshimura, H, Igaku Shoin, Tokyo: pp. 334-348.

Aschoff, J and Wever, R (1958) Kern und Schale im Warmehaushalt des Menschen. *Naturwissenschaften* **45**: 477-485 (in German).

Bazett, HC (1949) The regulation of body temperature. *In*: Physiology of Heat Regulation and the Science of Clothing, ed. by Newburgh, LH, W. B. Saunders, New York: pp.109-192.

Burton, AC (1963) The pattern of response to cold in animals and evaluation of homeothermy. *In*: Temperature, ed. by Herzfeld, CM, Reinhold, New York: pp. 363-371.

Heising, M and Werner, J (1985) Differential heating of trunk and extremities. *Eur. J. Appl. Physiol.* **54**: 79-83.

Jeong, WS and Tokura, H (1988) Effects of wearing two different forms of garment on thermoregulation in men resting at 10°C. *Eur. J. Appl. Physiol.* **57**: 627-631.

Jeong, WS and Tokura, H (1993) Different thermal conditions of the extremities affect thermoregulation in clothed man. *Eur. J. Appl. Physiol.* **67**: 481-485.

LeBlanc, J (1978) Adaptation of man to cold. *In*: Strategies in Cold, ed. by Wang, LCH and Hudson, JW, Academic Press, New York: pp. 695-715.

LeBlanc, J and Pouliot, M (1964) Importance of noradrenaline in cold adaptation. *Am. J. Physiol.* **207**: 853-856.

Li, X, Tokura, H, and Midorikawa, T (1994a) The effects of two different types of clothing on seeasonal cold acclimation of thermophysiological responses. *Int. J. Biometeorol.* **38**: 40-43.

Li, X, Tokura, H, and Midorikawa, T (1994b) The effects of two types of clothing on seasonal cold tolerance. *Eur. J. Appl. Physiol.* **69**: 498-501.

Park, S-J and Tokura, H (1997) Effects of two types of clothing on the day-night variation of core temperature and salivary immunoglobulin A. *Chronobiol. Int.* **14**: 607-617.

Park, S-J and Tokura, H (1998) Effects of different types of clothing on circadian rhythms of core temperature and urinary catecholamines. *Jpn. J. Physiol.* **48**: 149-156.

Radomski, MW and Boutelier, C (1982) Hormone response of normal and intermittent cold-preadapted humans to continuous cold. *J. Appl. Physiol.: Respirat. Environ. Exercise. Physiol.* **3**: 610-616.

Rennie, DW, Covino, BG, Blair, MR, and Rodahl, K (1962) Physiological regulation of temperature in Eskimos. *J. Appl. Physiol.* **17**: 326-332.

Scholander, PF, Hammel, HT, Hart, JS, Lemessurier, DHL, and Steen, J (1958) Cold adaptation in Australian Aborigines. *J. Appl. Physiol.* **13**: 211-218.

Suzuki, M (1972) Thyroid activity and cold adaptability. *In*: Advances in Climatic Physiology, ed. by Itoh, S, Ogata, K, and Yoshimura, H, Springer, New York: pp. 178-196.

Yoshimura, H (1960) Acclimatization to heat and cold. *In*: Essential Problems in Climatic Physiology, ed. by Yoshimura, H, Ogata, K, and Itoh, S, Nankodo Publishing Co, Kyoto: pp.61-106.