*Korean J Physiol Pharmacol*
*Vol 11: 233–237, December, 2007*

# Long-Term Tropical Residency Diminishes Central Sudomotor Sensitivities in Male Subjects

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**Tropical natives (TROP) are capable of tolerating tropical heat because of their long-term adaptation to tropical environments. When exposed to heat stress, these natives tend to respond with lower sweat output, which is generally thought to be the result of heat acclimatization. The main objective of this study was to clarify central mechanisms inherent to suppressed thermal sweating in tropical natives (Malaysians) by comparing their sweating responses to those of temperate native (TEMP) (Koreans). This experiment was conducted in a thermoneutral climatic chamber (24±0.5°C, 40±3% relative humidity). Heat loads were applied to each subject by the immersion of their lower legs in a hot water bath (43°C for 30 min). Sweat onset-time and sweat volume were compared between TROP and TEMP. The sweat onset-times on four selected points on the body ranged from 10.25 to 13.47 min in TEMP subjects, and from 16.24 to 17.83 min in TROP subjects ($p < 0.001$). The local sweat volumes at the same sites ranged from 4.30 to 9.74 mg/cm$^2$ in TEMP subjects, and from between 1.80 to 4.40 mg/cm$^2$ in TROP subjects ($p < 0.001$). These results demonstrated a significant difference between TROP and TEMP subjects with regard to the manner in which they regulate their body temperatures when exposed to heat loads, and verified that long-term thermal adaptation blunts sweating sensitivities.**

**Key Words: Heat tolerance, Sweating, Central sudomotor, Environmental adaptation**

## INTRODUCTION

Sweating is an indispensable physiological response, which is activated under hot environmental conditions. In man, the sweating apparatus is well-developed, and is activated during heat stress in order to lower high body temperatures. Humans possess 3-4×10$^6$ eccrine sweat glands distributed over the body surface, and have the capacity to secrete several liters of sweat per hour, or up to 10 liters of sweat per day (Kuno, 1956). In adults, more numerous sweat glands are present on the soles of the feet (620/cm$^2$) and are least abundant on the back (62/cm$^2$) (Sato and Dobson, 1970). Sweating is regulated centrally by the preoptic area of the anterior hypothalamus, as well as peripherally by the sympathetic postganglionic innervation, in which acetylcholine (ACh) is the primary neuroglandular transmitter.

Physiological acclimatization to ambient heat provides man with an effective thermoregulatory capacity, which can prove to be life-saving under extremely hot conditions. Thermotolerance achieved via suppressed sweating and enhanced dry heat loss is a predominant feature of long-term heat adaptation, as compared to enhanced sweating, which is seen under short-term heat acclimation conditions (Matsumoto et al, 1997). In natives of cold or temperate climates, exposure to hot ambient conditions induces a high core temperature and increased heart rate (Wilkerson et al, 1986). However, prior exposure of these subjects to heat for several consecutive days can minimize these responses, thus improving heat resistance (Nielsen et al, 1997; Sato and Sato, 1983). This resistance is achieved principally through increased sweat output, lowered heart rate, and a slower rise in core temperature (Nadel et al, 1974; Nielsen et al, 1997; Ogawa and Sugenoya, 1993). Contrary to the phenomenon observed in short-term heat acclimation, when exposed to heat stress tropical natives tend to respond with lower sweat output, which is generally thought to be the result of long-term heat acclimatization (Lee et al, 1997; Matsumoto et al, 1991; Matsumoto et al, 1993; Ogawa and Sugenoya, 1993).

Heat acclimation or acclimatization is a process shared by both the central nervous system and the peripheral effectors (Horowitz, 1989), and is known to enhance thermal resistance via the induction of adaptive changes in thermoregulatory mechanisms. For instance, it has long been recognized that natives of tropical climates sweat less

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**ABBREVIATIONS**: ACh, acetylcholine; $mT_b$, mean body temperature; $mT_s$, mean skin temperature; TEMP, temperate natives; TROP, tropical natives; Tsk, skin temperatures; TSLV, total sweat loss volume; Tty, tympanic temperature.

than newcomers from cold countries (Matsumoto et al, 1993). Likewise, Africans appear to sweat less than Europeans during prolonged exercise under humid heat conditions (Lee et al, 1997). However, this excess sweat output in people from cold countries declines after several years of residence in the tropics (Matsumoto et al, 1993). Suppressed sweating in tropical natives (Lee et al, 1997; Matsumoto et al, 1991; Matsumoto et al, 1993; Ogawa and Sugenoya, 1993) is believed to provide the advantage of preserving body fluid and osmoregulation, so that individuals can better sustain thermoregulation (Sawka and Coyle, 1999). In order to further elucidate the central mechanism of suppressed sweating in tropical natives, heat tolerance in addition to local sweat responses activated by heat load (immersing the legs in 43℃ hot water for 30 min) were compared between permanent tropical residents (Malaysians) and permanent temperate residents (Koreans).

## METHODS

### Subjects

The Malaysian (n=10) and Korean (n=13) male subjects of this study were all university students. The physical characteristics of the Koreans were as follows: height, 174.2±6.24 cm; weight, 67.43±4.71 kg; and age, 29.1±4.6 years. Corresponding characteristics for the Malaysians were as follows: height, 173.6±5.6 cm; weight, 65.47±4.2 kg; and age, 30.12±4.8 years. All male subjects were selected for study and the study was conducted within 2 to 7 days of arrival in Japan. Malaysia (3°80' N, 101°42' E) is located within the tropical zone with dry and wet-seasons and minimal seasonal variations. The annual mean ambient temperature of Malaysia is 26.7°C with a relative humidity of 81%. Seoul, Korea (37°34' N, 126°34' E) is located within the temperate zone with a mean annual temperature of 11°C and a 62% relative humidity. All subjects were informed of the objectives, risks, and possible benefits of this investigation, both verbally and in writing prior to the signing of an informed consent document. We paid great attention to the subjects, and all procedures were conducted in accordance with the Helsinki Declaration of 1975.

### The climatic chamber

l experiments were conducted in a thermoneutral climatic chamber (24±.5°C, 40±3% relative humidity and less than 1 m/sec air velocity) at 2～5 PM. Upon arrival in the climatic chamber, the subject wore light indoor clothing and sat in a chair in a relaxed mood for 60 min in order to become conditioned to the chamber climate prior to the commencement of the experiments.

### Tympanic temperature measurements

After 60 min of rest, heat loads were applied to each subject via the immersion of their lower legs in a hot water bath (43°C) for 30 min. The tympanic temperature (Tty) was assessed in the left ear via the insertion of a thermistor probe with a small spring into the ear canal (K923, TAKARA instrument Co. Ltd.), connected to a personal computer (PC-8801, NEC), which was in turn connected to a data logger (K-720, Technol Seven, Yokohama, Japan). As the thermistor probe contacted the tympanic membrane, the subject felt slight discomfort and could hear a scratching noise. The inner pinna was then filled with small cotton balls in order to fix the probe.

### Skin temperature measurements

Skin temperatures (Tsk) on the chest ($T_1$), upper arm ($T_2$), thigh ($T_3$), and leg ($T_4$) were measured using thermistor thermometers (PXK-67, Technol Seven, Yokohama, Japan) connected to a data logger (K-720, Technol Seven, Yokohama, Japan) (Lee et al, 1999; Ramanathan, 1964). The mean skin temperature ($mT_s$) was calculated in accordance with the Ramanathan equation (Ramanathan, 1964):

$$mT_s = 0.3 \cdot (T_1 + T_2) + 0.2 \cdot (T_3 + T_4)$$

The mean body temperature ($mT_b$) was calculated from $T_{ty}$ and $mT_s$ by the following equation:

$$mT_b = 0.9 \cdot T_{ty} + 0.1 \cdot mTs$$

in which: mTb = Mean body temperature, Tty = Tympanic temperature, mTs = Mean skin temperature.

### Measurements of sweating rate

During heat loading, the local sweating rate on the forearm, thigh, abdomen, and chest were continuously recorded via the capacitance hygrometer-ventilated capsule method (Lee et al, 1999). In brief, dry nitrogen gas flowed at a constant flow rate of 1/min into a capsule (9.621 $cm^2$ in area) attached to the skin at the point to be measured. The humidity of the effluent gas was evaluated with a hygrometer (H211, Technol Seven, Yokohama, Japan). The sweating rate was recorded every 30 sec with a PC (PC9801, NEC, Japan) and was expressed in $mg/cm^2/min$.

### Statistical analysis

All data are expressed as means±SD. Analysis of variance for repeated measurements was utilized for the comparison of the tested parameters by Student's unpaired t-test. For all statistical procedures, significance was set at $p<0.05$.

## RESULTS

Recordings during hot water immersion of the legs in a single TEMP subject and a single TROP subject revealed sweating activity, changes in skin temperature and core temperature. Mean local sweat rates on the chest, abdomen, thigh, and forearm included. TYMP, tympanic temperature (Tty); mTs, mean skin temperature calculated from the chest, forearm, thigh and leg, as described by Ramanathan (Ramanathan, 1964); mTb, mean body temperature calculated from 0.9 · TYMP (Tty)+0.1 · mTs by Lee et al (1999). The mean skin and mean body temperatures were compared during 30 min application of heat load via the immersion of the lower legs of both TROP and TEMP subjects in a water bath. The mean skin temperature and mean body temperature of TROP subjects were found to be lower than those of TEMP subjects. These values were statistically significant at $p<0.01$ and $p<0.001$ for the mean skin and body temperatures, respectively. The sweat onset times for sweating on the chest (Fig. 1A), abdomen (Fig. 2A), thigh (Fig. 3A) and forearm (Fig. 4A) in TROP subjects were longer than those of TEMP subjects, indicating superior heat tolerance in TROP subjects as compared to TEMP subjects. Sweat onset-time (A) and volume (B) on the chest were measured during the induction of heat load via immersion of the lower legs of TEMP (11.33±4.17 min and 9.74±4.51 mg/cm$^2$) and TROP subjects (16.44±5.62 min and 4.40±2.51 mg/cm$^2$) in a hot water. The values were found to be statistically significantly different between the two groups at $p<0.001$ (Fig. 1). Sweat onset-time (A) and volume (B) on the abdomen were measured during the induction of heat load via immersion of the lower legs of TEMP (10.27±5.70 min and 8.82±3.38 mg/cm$^2$) and TROP subjects (16.24±4.32 min and 4.21±3.54 mg/cm$^2$) in a hot

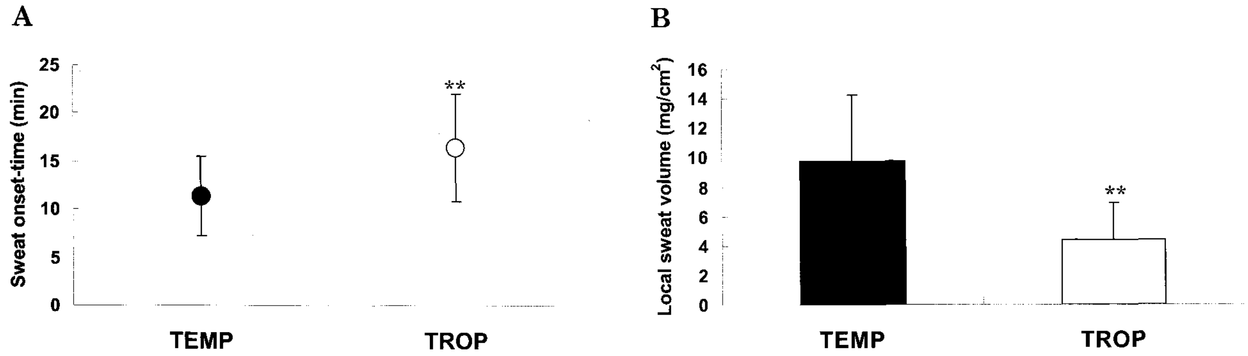


**Fig. 1.** Comparison of the sweat onset-time (A) and volume (B) on the chest during heat load induced by the immersion of the lower legs of temperate (TEMP) and tropical subjects (TROP) in a hot water (43°C for 30 min) bath. **$p<0.001$ between the groups (means±SD).

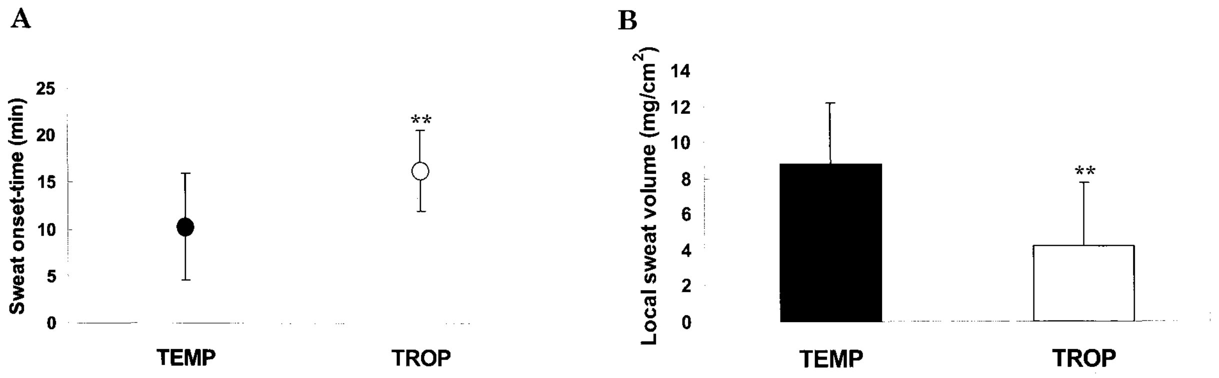


**Fig. 2.** Comparison of the sweat onset-time (A) and volume (B) on the abdomen during heat load induced via the immersion of the lower legs of temperate (TEMP) and tropical subjects (TROP) in a hot water (43°C for 30 min) bath. **$p<0.001$ between the groups (means±SD).

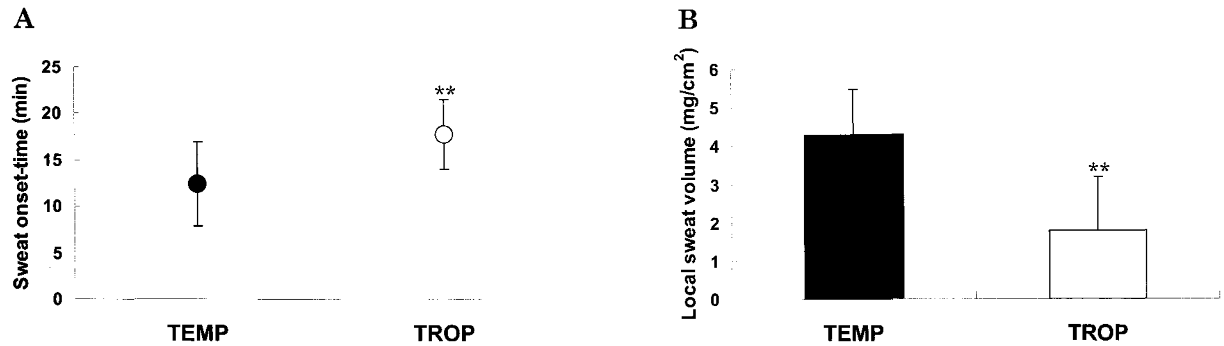


**Fig. 3.** Comparison of the sweat onset-time (A) and volume (B) on the thigh during the induction of heat load via the immersion of the lower legs of temperate (TEMP) and tropical subjects (TROP) in a hot water (43°C for 30 min) bath. **$p<0.001$ between the groups (means±SD).

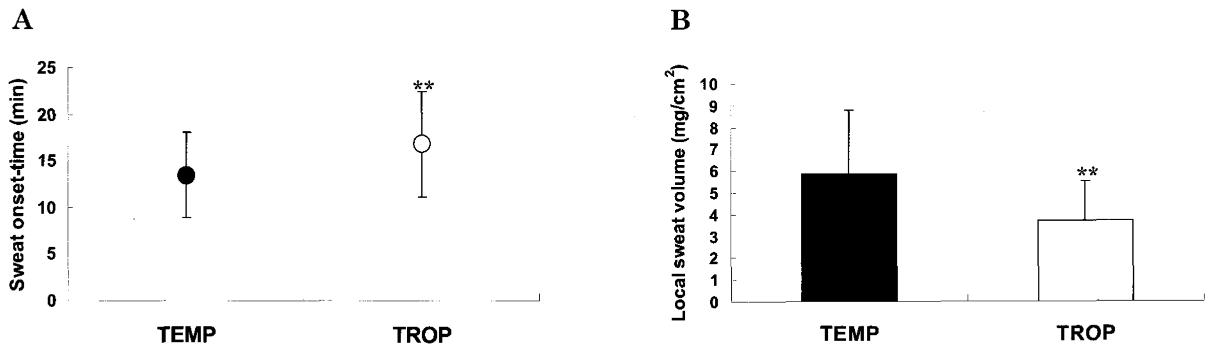


**Fig. 4.** Comparison of the sweat onset-time (A) and volume (B) on forearm during the induction of heat load induced via the immersion of the lower legs of temperate (TEMP) and tropical subjects (TROP) in a hot water (43°C for 30 min) bath. **$p<0.001$ between the groups (means±SD).

water. The values were statistically significantly different between the two groups at $p<0.001$ (Fig. 2). Sweat onset-time (A) and volume (B) on the thigh were measured during the induction of heat load via the immersion of the lower legs of TEMP (12.41±4.55 min and 4.30±1.20 mg/cm$^2$) and TROP subjects (17.83±3.74 min and 1.80±1.42 mg/cm$^2$) in a hot water. The values were statistically significantly different between the two groups at $p<0.001$ (Fig. 3). Sweat onset-time (A) and volume (B) on the forearm were measured during the induction of heat load via the immersion of the lower legs of TEMP (13.47±4.62 min and 5.84±2.95 mg/cm$^2$) and TROP subjects (16.83±5.70 min and 3.75±1.80 mg/cm$^2$) in a hot water. The values were statistically significantly different between the two groups at $p<0.001$ (Fig. 4). Total sweat loss volume (TSLV) in TEMP and TROP subjects was determined. TEMP subjects generated 117% more sweat than TROP subjects. The values were statistically significantly different between the two groups at $p<0.0001$ (Fig. 5).

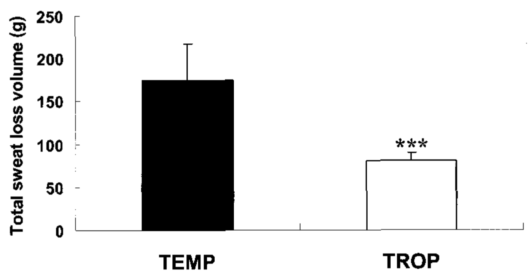


**Fig. 5.** Comparison of the total sweat loss volume due to the induction of heat load via the immersion of the lower legs induced of temperate (TEMP) and tropical subjects (TROP) in a hot water (43°C for 30 min) bath. The values (means±SD) were statistically significantly different between the two groups at ***$p<0.0001$.

## DISCUSSION

Heat load induced via the immersion of the lower legs in a hot water bath (43°C for 30 min) provided a basis for comparison of thermal-induced sweating responses between TROP and TEMP subjects, with the volume of sweat output being considered to be an indicator of central sudomotor activity. The major findings in these studies are as follows: 1) sweat onset-time during hot water-induced stimulus was significantly shorter in TEMP natives by approximately 5.2 min; 2) temperate natives lost 117% more sweat than TROP natives.

The principal implication of this finding is that central stimuli for sweat production are more sensitive in the temperate subjects than the tropical subjects. These findings are supported by similar previous findings. Kuno (1956) and Hori et al (1976) demonstrated that sweating reactions in subjects that had undergone long-term heat acclimatization differ from those who had undergone only short-term heat acclimatization. In an another study, body temperature regulation was evaluated in 6 male subjects during an acclimation procedure that involved uninterrupted heat exposure for 5 successive days and nights in a hot dry environment (Libert et al, 1988). The results indicate that, in both exercise and at rest, the successive heat exposures increased sweat gland output over the first 3 days. Afterwards, the sweat rate was reduced without any corresponding change in body temperature (Libert et al, 1988). This indicated that adjustments for both sweating and circulatory mechanisms occurred within the first 3 days of continuous heat exposure. In our previous study, we demonstrated suppressed sudomotor function in the response of tropical natives to ACh (Lee et al, 1997; 2002), suggesting that the ACh sensitivity of sweating response to passive heat stress is regulated by a peripheral mechanism rather than by active sweat gland density and sweat gland output function. This long-term thermal adaptation is efficiently developed following early exposure to high ambient temperature. We reported also recently that prolonged residence in the tropics of temperate natives modifies the sweating mechanism in the typical direction for tropical natives, which is characterized by a more delayed onset of sweating during ACh iontophoresis and by lower sweat volumes for each component, determined by quantitative sudomotor axon reflex test (Bae et al, 2006). The result suggested that long-term residence in the tropics by temperate natives can produce significant changes in peripheral sudomotor functions and its neuronal control, which contribute to an improved tolerance to heat stress. In this study, we extended our previous findings by demonstrating that the suppression is not merely a peripheral phenomenon, but also involves central mechanisms, as shown by sweating responses during hot water leg immersion.

In conclusion, the present results demonstrated a significant difference between TROP and TEMP subjects with regard to the manner in which they regulate their body temperature when exposed to heat loads, and also verified that long-term thermal adaptation blunts sweating sensitivity.

## ACKNOWLEDGMENT

This study was partially supported by Grant-in-Aid for Scientific Research (No, 20050117) for Soonchunhyang Medical Research Institute, Soonchunhyang University, Korea.

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