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Seasonal acclimatization to the hot summer over 60 days in the Republic of Korea suppresses sweating sensitivity during passive heating

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ABSTRACT

The main objective of this study was to determine the central mechanisms involved in suppression of thermal sweating after seasonal acclimatization (SA) during passive heating (immersing the legs in 43 °C hot water for 30 min). Testing was performed in July (before-SA) and August (after-SA) [25.2 ± 2.2 °C, 73.9 ± 10.3% relative humidity (RH), Cheonan (Chungnam,126° 52′N, 33.38′E), in the Republic of Korea. All experiments were carried out in an automated climatic chamber (25.0 ± 0.5 °C and RH 60.0 ± 3.00%). Twelve healthy men (height, 174.6 ± 5.40 cm; weight, 65.4 ± 5.71 kg; age, 22.7 ± 2.90 yr) participated. The local sweat onset time was delayed in the after-SA compared to that in the before-SA ($p < 0.001$). The local sweat rate and whole body sweat loss volume decreased in the after-SA compared to those in the before-SA ($p < 0.001$). In addition, evaporative loss volume decreased significantly in the after-SA compared to that in the before-SA [chest, upper-back, thigh and forearm ($p < 0.001$)]. Changes in tympanic temperature and mean body temperature were significantly lower ($p < 0.05$) and the basal metabolic rate decreased significantly in the after-SA compared to those in the before-SA ($p < 0.001$). These results suggest that maintenance of a lower body temperature and basal metabolic rate can occur and blunt the central sudomotor mechanisms following seasonal acclimatization, which suppresses sweating sensitivity.

1. Introduction

Sweating is a critical physiological response that is activated by hot environmental conditions. In humans, the sweating apparatus is well-developed and is activated during heat stress to lower high body temperature. Many studies have shown that an increase in the secretory capacity of the eccrine sweat glands occurs following heat acclimation (Pandolf et al., 1988; Nielsen et al., 1997; Buono et al., 2007). In unacclimatized individuals, exposure to hot ambient conditions causes high core temperature and increased heart rate (Robinson et al., 1953; Wilkerson et al., 1986), whereas prior heat exposure of several consecutive days improves heat resistance (Sato and Sato, 1983; Sato et al., 1990; Nielsen, 1998) by increasing sweat output, lowering heart rate, and slowing the rise in core body temperature (Wyndham, 1967; Nadel et al., 1974; Ogawa and Sugenoya, 1993; Nielsen, 1998). For example, 11 non-adapted males were acclimated over 3 weeks (16 exposures) by cycling 90 min/day, 6 days/wk (40 °C, 60% relative humidity) using the controlled-hyperthermia acclimation technique; the work rate was modified to achieve and maintain a target core temperature (38.5 °C). As a result, chest and forearm sweating rates increased 110% under these conditions (Patterson et al., 2004).

Sweating is regulated centrally by the preoptic area of the anterior hypothalamus and peripherally by sympathetic postganglionic innervation, where acetylcholine (ACh) is the primary neuroglandular transmitter (Lee et al., 2007). Peripheral adaptation, including increased cholinergic sensitivity and sweat gland hypertrophy, contributes to improved secretory capacity (Wyndham, 1967; Nadel et al., 1974; Sato et al., 1990; Armstrong and Kenney, 1993; Nielsen, 1998; Inoue et al., 1999; Yamazaki and Hamasaki, 2003). Experimental evidence indicates that the medial preoptic hypothalamic area, dorsomedial nucleus of the hypothalamus, periaqueductal gray matter of the midbrain, and the nucleus raphe pallidus in the medulla all play a critical role in thermoregulation (Boulant, 2006; Mekjavic and Eiken, 2006; Romanovsky, 2007).

Preoptic neurons compare and integrate central and peripheral thermal information and orchestrate the most appropriate thermoregulatory final output, including secretion of sweat (Vetrugno et al., 2003). Therefore, the sweating mechanism involves both central and peripheral activity, and heat acclimation is mediated by both the central nervous system and peripheral effectors (Horowitz, 1989).

Abbreviations: BSA, body surface area; TYMP, tympanic temperature; mTs, mean skin temperature; mTb, mean body temperature; SA, seasonal acclimatization; WBSLV, whole body sweat loss volume.

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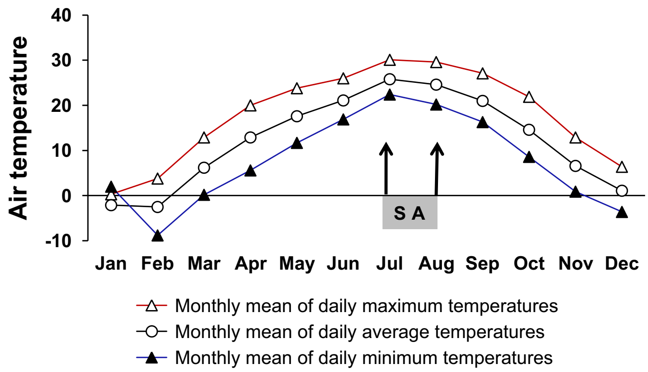

Fig. 1. Monthly mean daily average ambient temperatures from January to December 2011 at Cheonan (126º 52′N, 33.38′E; Republic of Korea). Cheonan is located in a temperate zone (four distinct geopolitical seasons). The monthly mean daily average ambient temperature during the experimental period was from July 1 to August 31, 2011. SA, seasonal acclimatization from July to August.

The summer in Cheonon, Republic of Korea (four distinct geopolitical seasons, Fig. 1) is similar to that in tropical climates, as there is an increasing tendency to experience intense heat during the summer months due to global warming. The hot summer season, from July to August, in the Republic of Korea, is currently similar to subtropical and tropical regions; during which the most active people in Korea are exposed to heat stress and undergo spontaneous seasonal acclimatization (SA). Sweating signals likely provide the primary mechanism responsible for conferring seasonal habituation during SA (exposure to hot summer temperatures, from July 1 to August 31) in the Republic of Korea. However, the mechanism of physiological adaptation (effects on internal environment) has not been determined.

The local sweat responses activated by passive heating (immersing lower legs to the knees in 43 °C water at the same environmental condition for 30 min) were compared between before-SA measurements obtained in July and the after-SA measurements obtained in August to further elucidate the central mechanisms associated with suppressed sweating and exposure to hot summer temperature, as well as heat tolerance.

The primary purpose of this study was to examine the difference in the sweating responses under passive heating after-SA in August and compare the results to before-SA in July.

2. Material and methods

2.1. Subjects

Normotensive volunteers were enrolled in the study following approval of the experimental protocol from the University of Soonchunhyang Research Committee and obtaining written informed consent. Each subject provided written informed consent after the purpose and experimental procedures were explained. All potential risks were thoroughly discussed. The protocol complied with the 1975 Declaration of Helsinki, as revised in 1983. Twelve healthy male subjects that lived all of their lives in the city of Cheonan (Chungnam), the Republic of Korea, participated. All research subjects were at university student and lived in Cheonan for the 60 days before the experiment and during the experimental period (from July 1 to August 31, 2011, the first and second experiments were performed within 60 days). The physical characteristics of the subjects were: mean height, 174.60 ± 5.40 cm; mean weight, 65.40 ± 5.71 kg; mean age, 22.70 ± 2.90 years; and mean body surface area, 1.80 ± 0.14 m2. Cheonan is located in the southwest part of Korea (126° 52′N, 33.38′E) and extends northeast (130° 4′N, 43.0′E). Mean annual ambient temperature during July (25.6 °C, 82.1%) and August (25.5 °C, 81.3%) is 25.55 °C with a 81.7% relative humidity (Republic of Korea Meteorological Administration, 2011).

2.2. Experiments and climate chamber

All experiments were conducted in a thermoneutral climate chamber (25 ± 0.5 °C, 60 ± 3% relative humidity and less than 1 m/s air velocity) from 2 to 5 PM. Upon arrival to the climate chamber, each subject wore light indoor clothing without shoes and socks. The subjects were seated in a chair in a relaxed posture for 60 min to become conditioned to the chamber climate prior to commencement of the experiments (Fig. 2).

2.3. Basal metabolic rate (BMR) measurements

BMR was measured with an expired air gas analyzer (Cosmed; Quark Pulmonary Function Testing Lung Volume Module 2 ergo, Rome, Italy).

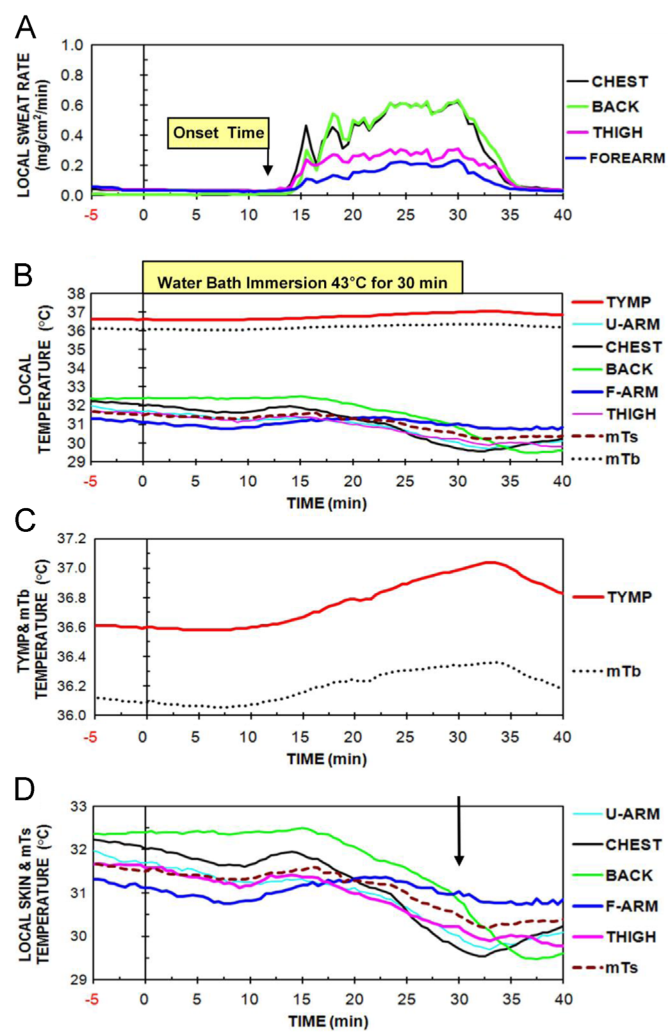

Fig. 2. A typical recording of single subject revealing sweating responses during passive heating. Upper panel (A) showed local sweat onset time (latency) and local sweat rates on the chest, forearm, thigh, and back (upper back). Mean skin (B and D) and body temperatures (B and C) were determined during passive heating. Passive heating, immersing lower legs to the knees in 43 °C water at the same environmental condition for 30 min; TYMP, tympanic temperature; mTs, mean skin temperature calculated from the chest, forearm, thigh and leg, as described by Ramanathan (1964); mTb, mean body temperature calculated from 0.9 × TYMP +0.1 × mTs (Lee et al.,2007).