An Observational Study on the Individual Thermal Sensations, Skin Temperatures and Their Relationship with Exercise Experiences

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Abstract

Thermal sensation is influenced by both individual and environmental factors. However, it is unknown which individual factors are significant to determine thermal sensation of humans. The purpose of this study was to clarify the relationship between the thermal sensations, skin temperatures and individual factors such as exercise experiences by observational methods. 334 young examinees who entered Tokyo Metropolitan University in 2003 cooperated with these experiments during the classes of physical education. Interview and questionnaire on individual factors (gender, exercise experiences, climates in the past-to-present habitations and thermal sensation votes) of examinees, taking thermal infrared images of them and meteorological observations were conducted in the gymnasium of the university in the seven days. To evaluate the relationship with exercise experiences, obtained data were divided into 3 categories, i.e., (1) no exercise experiences in schools, (2) experiences until the end of junior high school, and (3) experiences until the end of high school or still getting exercise. The following results were obtained.

In thermal neutrality (around 21–24°C) for most young people wearing exercise clothing in the gymnasium, exercise experiences did not have statistically significant relationship with thermal sensation. Neither skin temperature on the forehead nor hand showed significant difference among the three groups. These results indicated that thermal sensations and skin temperatures did not have strong relationship with exercise experiences.

Key words: thermal sensations, skin temperatures, exercise experiences, climate of pre-school habitation

Introduction

The body temperature of homeothermic humans is regulated by behavioral and autonomic thermoregulation. In the former system, thermal comfort is responsible for initiating behavior (Weiss and Laties, 1961). On the other hand, sweating and cutaneous vasodilation, as autonomic thermoregulation, are employed to accelerate heat dissipation, when body temperature is rapidly increased by exposure of hot environments or heavy exercise. Numerous studies have examined the modification of autonomic thermoregulatory responses, by personal (e.g. gender, age and anthropometry) or individual factors (e.g. endurance training, climate in the habitation in babyhood and heat stress acclimation) in a controlled climatic chamber. Prolonged exercise training is one of the best ways to induce heat adaptation of autonomic thermoregulation (Taylor, 2000). It is also known that subjective thermal sensation, comfort and unpleas-

antness vary among individuals. Nevertheless, it is at present unknown which individual factors, such as exercise experience, are significant to determine thermal sensations in humans.

The main purpose of this study was to clarify the relationship between thermal sensations and individual factors related to the duration of exercise experiences and events of sports. Also, we evaluated the effect of exercise experiences on skin temperatures, which is a relatively greater contribution to subjective thermal comfort than to the autonomic thermoregulatory responses (Frank et al., 1999). To this end, we took thermal infrared images and performed interviews and questionnaires on individual factors. Finally, the relationship between thermal sensations and exercise experiences was compared with the relationship between thermal sensations and climates in the past-to-present habitation in another report (Matsuyama et al., 2006).

Methods

Experimental protocol and data collection

Interview and questionnaire on individual factors (gender, exercise experiences, duration of exercise, events of sports, climates in the past-to-present habitations and thermal sensation votes) of 334 young examinees who entered Tokyo Metropolitan University (TMU) in 2003 were conducted in the university gymnasium in the seven days from 18th, April to 13th, May 2003. Also, meteorological observations in the gymnasium were carried out, along with taking thermal infrared images of the examinees to measure skin temperatures on the forehead and hand. All examinees wore exercise clothing, and did not do any exercise within one hour that may have affected thermal sensations. They agreed with participating in these experiments after explanation of this study by experimental staff.

It was already clarified that the thermal neutrality of these examinees was around 21–24°C (Matsuyama et al., 2006). In this sense, air temperatures of 22nd and 25th in April were within this range ($n=54$). Also, data of these days were suitable for studying the individual thermal sensations, skin temperatures and their relationship with exercise experiences. These data were, therefore, analyzed in this study.

In order to investigate climates of past-to-present habitations, Digital Map 25000 (Geographical Names & Public Facilities) and Digital Map 50 m Grid (Elevation) issued by Geological Survey Institute were used to extract latitude, longitude and elevation of a city office where an examinee had lived or has been living. Daily maximum and minimum temperatures from 1985 to 2002 were derived from AMeDAS (Automated Meteorological Data Acquisition System) of Japan Meteorological Agency.

Procedure of data analysis

Categorization of the data obtained

Gender was classified into two categories. Thermal sensation votes were classified into seven categories, i.e., very hot (+3), hot (+2), rather hot (+1), neither hot nor cold (0), rather cold (−1), cold (−2), and very cold (−3).

Based on the duration of exercise, exercise experiences were classified into three categories, i.e., (1) no exercise experiences in schools, (2) experiences until the end of junior high school, and (3) experiences until the end of high school or still getting exercise.

Another classification was conducted, based on events of sports. Namely, if more than five people experienced a same exercise, it was categorized as one event (category) regardless of the duration of the exercise experience. If a person experienced several exercises, this person was repeatedly classified into dif-

ferent categories.

Calculating temperatures of past-to-present habitations

Since 90% of the examinees were 18–19 years old, the years of 2000–2002 were defined as the stage of high school. Also, the years of 1985–1990 and 1985–2002 were defined as the stage of pre-school habitation and the period of longest habitation, respectively. For the stages of high school and pre-school habitation, AMeDAS stations with no missing data were selected. For the period of longest habitation, AMeDAS stations within two missing years were selected.

In these stations, monthly mean temperatures of February and August in each year, along with annual mean temperature of each year were calculated from the daily maximum and minimum temperatures. These temperature data were merged to the database of questionnaire using Digital Map 25000. In this case, the difference of elevations between a city office and the nearest AMeDAS station was considered, then the temperature data at the city office were estimated with the AMeDAS data using the formula of $-0.6^{\circ}\text{C}/100\text{ m}$. The almost same formula is often applied to climatological study and the mean temperature lapse rate of $-0.61^{\circ}\text{C}/100\text{ m}$ is calculated under an altitude of 1,500 m on the ground in Japan (Ishizuka, 1977).

For the statistical analyses, these temperature data, along with skin temperature data were classified into 1°C bins, and were used as category data.

Statistical analysis

Data on thermal sensation votes and skin temperatures were subjected to one-way analysis of variance to detect a difference among exercise experiences or events of sports. The level of significance was set at $p<0.05$ and $p<0.01$.

Also, the quantification method of the first type was applied to investigate how individual factors were related to thermal sensation votes and skin temperatures. In the quantification method of the first type, the number of parameters corresponding to all explanatory variables is equal to “number of all categories” minus “number of explanatory variables”. This study carried out the comparison of different models with different number of parameters, therefore, the results were evaluated with AIC (Akaike Information Criterion; Akaike, 1974) which is calculated as follows;

$$AIC = n \left(\log 2\pi \frac{S_e}{n} + 1 \right) + 2(p+2) \quad (1)$$

Here, n is the number of samples, S_e is the sum of squares due to error, and p is the number of parameters.

Multiple regression equation with smaller value of AIC is more suitable to explain a phenomenon. When several values of AIC are compared, the difference of AIC larger than 1 is statistically significant (Sakamoto et al., 1983). Otherwise, multiple regression equation with smaller number of parameters is more suitable.

Results and Discussion

Figure 1 shows the thermal sensation votes, and skin temperatures on the forehead and hand of each category classified by exercise experiences during thermal neutrality of the examinees. Exercise experiences did not have a statistically significant relationship with thermal sensation. Skin temperatures did not show significant difference among the three groups. Furthermore, we did neither detect a statistically significant difference in thermal sensation votes and skin temperatures among the category of events of sports in schools (Fig. 2) nor did we detect a significant difference in them between the events of inside and outside sports.

The quantification method of the first type was conducted to explain the thermal sensation votes and skin temperatures on the forehead and hand, respectively, by swapping the explanatory variable of temperature listed in Fig. 3. The best results are respectively shown in Tables 1 and 2. Thermal sensation votes had statistically significant relationship between annual maximum temperature in the pre-school habitation (Matsuyama et al., 2006) as well as hand skin

Fig. 1. The average and standard deviation of (a) thermal sensation votes (T. S. V.), (b) skin temperatures on the forehead and hand, based on exercise experiences.

Fig. 2. Same as Fig. 1 but for the events of sports.

Fig. 3. Values of AIC obtained by the quantification method of the first type. Numbers in brackets are categories of temperature.

Table 1. Best results of the quantification method of the first type to explain thermal sensation votes.

Explanatory Variable	Partial Correlation Coefficient
Hand Skin Temperature	0.538**
Max. Temp. at Pre-school Habitation	0.522**
Gender	0.255
Exercise Experience	0.076
Multiple Correlation Coefficient	0.683*

Significance level: * $p < 0.05$, ** $p < 0.01$.

Table 2. Same as Table 1 but to explain skin temperatures.

Explanatory Variable	Forehead	Hand
Mean Temp. at High-school Habitation	0.623**	0.520**
Gender	0.762**	0.562**
Exercise Experience	0.337*	0.207
Multiple Correlation Coefficient	0.780**	0.686**

Significance level: * $p < 0.05$, ** $p < 0.01$.

temperatures. In this case, thermal sensation votes did not have a significant relationship with exercise experiences (Table 1). Skin temperatures on the forehead and hand showed a statistical significant relationship with annual mean temperature at high school and gender (Table 2). Similarly, each AIC value on both skin temperatures was smallest when annual mean temperature at high school was selected as the explanatory variable.

In the present study, teenage exercise experiences were not related to thermal sensation during thermal neutrality. In this respect, Erlandson et al. (2003) reported that the thermal sensation recorded using the ASHRAE seven-point scale in the air-conditioned office buildings of Australia, did not differ between non-exercising and heavily exercising persons. Indeed, during prolonged exercise, autonomic thermoregulation, such as sweating and active vasodilation, plays more important role to dissipate heat rather than behavioral thermoregulation. Taken together, previous exercise experiences and current exercising habit may not affect the determination of thermal sensation associated with behavioral thermoregulation in thermal neutrality.

Early study by Kenshalo (1970) clearly showed that thermal sensation and its expression may vary following the initial adapting skin temperature. Similarly, skin temperature on the hand, in the present study, showed a statistically significant relationship with thermal sensation in thermal neutrality. The levels of both skin temperatures, however, were independent of exercise experiences. On the other hand, we reported annual maximum temperature in the pre-school habitation also had the strongest relationship with thermal sensation (Matsuyama et al., 2006). It is well known that the number of sweat gland is determined by 2–3 years old (Kuno, 1956). Thus, the cli-

mate in this period is thought to be an important factor for this determinant. If this physiological adaptation in babyhood is adjusted to thermal sensation or comfort associated with behavioral thermoregulation which precedes the onset of sweating response, it may be a meaningful adaptation.

In conclusion, the results from this observational study indicate that the climate of pre-school habitation is strongly related to thermal sensation, during thermal neutrality, rather than teenaged exercise experiences.

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