Thermal Responses of 6- to 8-year-old Children during Immersion of Their Legs in a Hot Water Bath

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Abstract. Twenty-three children (12 boys and 11 girls) and 13 female students served as the subjects in summer. The children were from six to eight years old. The subjects were seated in a hot room of 30°C and their legs were immersed in bath water of 42°C for 30 minutes. Total sweat rate, local sweat rate on the back, rectal temperature, skin temperatures at eight sites, heart rate and blood pressure were measured during the experiments. Total sweat rate of both groups was similar, but local sweat rates of the children were significantly smaller than those of the students. Although the degree of increase in rectal temperature from immersion in the hot bath were similar, the increases of heart rate and skin temperatures on the thigh and forearm were greater in children. These results suggest that the thermoregulatory ability of children during heat exposure is similar to that of young female adults. However, it is found that for heat loss, children resort more to vasodilation than sweating during heat exposure as compared to adults. The children were divided into two groups according to whether the children were exposed to air cooling systems in summer in their infancy or not. There was no significant inter-group differences in physiological responses during immersion in the hot water bath. It is found that the ability of Japanese children to tolerate heat was not reduced distinctly by the frequent use of an air cooling system in infancy.


Keywords: children, sweat rate, rectal temperature, skin temperature, air cooling system

Introduction

The ability to tolerate heat is one of the important factors in maintaining health. There has been abundant research on temperature regulation of adults who were exposed to heat (e.g., Folk 1974). However, there have been relatively few scientific studies on thermal responses of children during rest (Kosuge 1939; Okayasu 1950; Kawahara 1960) and exercise (Araki et al. 1979; Araki et al. 1980; Davis 1981; Bar-Or 1989) in hot environments. Moreover, especially in these studies during rest, only sweat rate and rectal temperature were measured, and relatively small number of children served as the subjects. There is still a shortage of data measuring various physiological responses of children during heat exposures. Hence this study was undertaken to investigate thermal responses precisely in a large number of children during rest in a hot environment.

It is known that the number of active sweat glands is decided by the ambient temperature of one’s living environment for the first two years after birth (Kuno 1956). Namely, the babies who were born in a hot country have many active glands compared with the babies in a cool country. It is very hot in summer in Japan, e.g. the average highest day time temperature in Tokyo is 30.8°C. However, since air cooling systems have spread widely, some Japanese babies are growing up in cool temperatures even in summer. Therefore, it is supposed that if an infant was kept in an air conditioned room all day during these first years, they will not be able to tolerate stressful heat in summer during childhood. The second purpose of this experiment is to investigate whether frequent use of an air cooling system in infancy affects children’s heat tolerance or not.

Methods

Subjects

Twenty-three children (12 boys and 11 girls) and 13 female students served as the subjects. Their ages were from 6 to 8 years old in children, and 21 to 26 years old in students. The children were born in the Tokyo area, and the students have been living in there for at least four years. The characteristics of the subjects in both groups were given in Table 1. All values in the table were significantly different between the groups. The purpose and procedure of the experiment were explained and a written form of consent was signed by the students and the parents of all the children. The children wore only shorts and the students wore bikini swimsuits.

The children were divided into two groups: one was the group who did not use an air cooling system in their infancy (n=11), the other was the group who used an air
Table 1 Physical characteristics of the subjects. Values are means and standard errors.

<table>
<thead>
<tr>
<th>n</th>
<th>Age (yrs)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>BSA (m²)</th>
<th>BSA/Wt (cm²/kg)</th>
<th>Skinfold Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Chest</td>
</tr>
<tr>
<td>Children</td>
<td>23</td>
<td>7.8</td>
<td>129.1</td>
<td>27.9</td>
<td>0.97</td>
<td>355.1</td>
</tr>
<tr>
<td></td>
<td>0.1</td>
<td>1.6</td>
<td>1.3</td>
<td>0.03</td>
<td>6.7</td>
<td>1.4</td>
</tr>
<tr>
<td>Students</td>
<td>13</td>
<td>22.6</td>
<td>158.3</td>
<td>50.5</td>
<td>1.45</td>
<td>287.4</td>
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<td>1.3</td>
<td>1.3</td>
<td>0.02</td>
<td>3.8</td>
<td>1.1</td>
</tr>
</tbody>
</table>

BSA: Body surface area estimated from Fujimoto et al. (1968).

cooling system frequently in summer (n=12). In the latter group, two children used air cooling systems everyday in hot summer, seven children very often used them and three children often used them. There were no differences in age and sex between the groups.

Measurements
Rectal temperature and skin temperatures were measured with thermistor thermometers every minute. The rectal probe was inserted 12 cm and 10 cm past the anus of the students and children, respectively. The skin sites monitored were forehead (T₁), chest (T₂), abdomen (T₃), forearm (T₄), hand (T₅), thigh (T₆), leg (T₇) and foot (T₈). Mean skin temperature (Tsk) was calculated according to the following formula (Teichner, 1958).

\[
Tsk = 0.07T₁ + 0.35(T₂ + T₃) + 0.14T₄ + 0.05T₅ + 0.19T₆ + 0.13T₇ + 0.07T₈
\]

Heart rates were measured every minute by heart rate memories. Blood pressures were obtained on the left upper arm from an tonometer. Total sweat rate was determined by the measurements of body weight with a platform scale to within ±5 g at the beginning and the end of the heat exposure. Local sweat samples were collected every 10 minutes with a piece of filter paper (12.6 cm²) attached on the left side of the back, and the sodium content of local sweat was measured with a flame photometer. Local sweat rates on the right side of the back were measured by the method of sweat capsule using a resistance hygrometer. In brief, a capsule mounted on the skin was ventilated with air at a preset low humidity; changes in the humidity of the efferent air caused changes in the resistance of a hygrosensitive element (Kraning and Sturgeon, 1983).

Procedure
The subjects stayed in a pre-room of 28°C with 50% rh for more than 60 minutes. Thereafter they sat in a hot room of 30°C with 70% rh for 60 minutes, and for the last 30 minutes their legs were immersed up to the knees in bath water of 42°C (Osada et al. 1969; Mayuzumi et al. 1981). They were seated and entertained by video movies in order to keep them still during the experiments. Water loss was not replaced during the experiment. These experiments were carried out in July and August. All data are presented as mean ± standard error. Inter-group differences were compared using an analysis of t-test, and in statistical test a value of P<0.05 was accepted as indicating significance.

Results
Comparisons between the students and children
Since there were no distinct differences in physiological responses between the boys and girls during the experiments, the boys and girls were put together and grouped as children.

Sweating
The average (SE) total sweat rate was 128.2 (5.8) g/m²/hr for the children and 113.6 (11.8) g/m²/hr for the students which was not a significant difference. Figure 1 showed the time course of the changes in the average (SE) local sweat rate on the back. The local sweat rate increased rapidly with the leg immersion for both groups. The average time required for the onset of sweating after the immersion was 4.7(0.5) minutes for the children and 6.2 (0.6) minutes for the students. The children started sweating earlier than the students during the leg immersion, although this difference was not significant. The sweat rates of the children were significantly lower than those of the students after 19 minutes of immersion. The threshold rectal temperature when
the sweating began in the children and students were 37.58 (0.06)°C and 37.35 (0.05)°C, respectively. The threshold rectal temperature in the children was significantly higher than that in the students.

Average sodium concentration of the local sweat during the last 10 minutes of immersion in the children was 1030 (212) ppm and 1345 (236) ppm in the students; the difference was not significant.

**Body temperatures**

Figure 2 showed the time course of the changes in mean rectal (SE) temperature in both of the groups. Rectal temperatures of the children during the experiments were significantly higher than those of the students by 0.25°C. Average rectal temperature before the immersion was 37.60 (0.05)°C in the children, and 37.35 (0.04)°C in the students. Rectal temperatures decreased slightly from the leg immersion and then increased gradually for both groups. Earlier onsets of increasing rectal temperatures of the students were found. At the end of the immersion, rectal temperature of the children increased by 0.23°C on the average, and 0.27°C in the students. It was found that there was no significant difference in these values.

Table 2 showed the means (SE) of skin temperatures before and at the end of the immersion for the groups. There were no differences in skin temperatures on the trunks and immersed legs between the groups. However, there were distinct differences in the skin temperatures on the limbs between the groups. Figure 3 showed the time course of the changes in mean forearm skin temperature. Forearm skin temperatures of both groups were almost similar before the immersion. The forearm skin temperature of the children increased with the immersion. On the other hand, the skin temperature of the students decreased. There were significant differences between the groups during the immersion, and these differences were also found in the thigh skin temperatures. Namely, thigh skin temperatures in the students decreased slightly during the immersion, on the contrary, those in the children increased by 0.8°C on the average. Mean skin temperatures of the children during the experiment, especially during the immersion, remained at a higher level than those of the students.

**Heart rate and blood pressure**

The heart rates of the children were significantly higher than those of the students during the experiment (Figure 4). Average heart rate before the immersion in the children was 94.5 (2.7) beats/min, and in the students was 77.8 (4.1) beats/min. Average increase in the heart rate of the children at the end of the immersion (22 beats/min) was significantly higher than that of the students (14 beats/min).

Figure 5 showed the time course of the changes in mean systolic blood pressure in both of the groups. Systolic blood pressure increased slightly by the immersion for both groups. Although the changes in systolic pressure were greater in the students, there were no significant differences in systolic blood pressure between the groups.

**Differences in thermal responses among the children**

The children were divided into two groups: one was the group who did not use an air cooling system in infancy (n=11), and the other was the group who used an air cooling system frequently in summer (n=13). Table 3 showed differences in thermal responses between the two groups. There were no significant differences in thermal responses due to heat exposure between the groups.

**Discussion**

**Comparisons between the students and children**

Some Japanese researchers (Kosuge 1939; Okayasu 1950; Kawahara 1960) have reported that total sweat rates of children were higher than those of adults during rest in hot environments, but this study contradicted this result; there was no difference in total sweat rate between the groups. This inconsistency may be due to the facts that...
there were small age differences in the sweat rates in summer (Kosuge 1939; Okayasu 1950) and smaller sweat rates were observed in female adults compared to male adults (Kawahara 1960). Namely, this experiment was conducted in summer and female students served as the adult subjects.

Although local sweat rates on the back in the children were significantly lower than those in the students, there was no significant difference in total sweat rate between the groups. This discrepancy could be explained by a recent study of Shiraiishi and Araki (1990). In their study, four 4-year-old children and five male students were exposed to a condition in which the temperature increased from 20°C to 40°C in 25 minutes and stayed at 40°C for 20 minutes in summer and winter. They showed that there were regional differences in local sweat rate of children and adults. Local sweat rate on the back for the children was lower than that in the adults in summer. On the other hand, local sweat rate on the forearm in the children was greater than that in the adults.

Araki et al. (1979, 1980) reported several studies on thermal regulation in children during exercise in hot environments. They reported that increases in deep body temperature of adults were offset by a great increase in sweat rate; on the other hand, those of the children were offset by a greater increase in skin temperatures. Davies (1981) measured thermal responses to exercise in children and adults in a moderate thermal environment, and calculated their heat balance. Although heat loss via convection and radiation in the children was 44%, that in the adults was only 33%. In this experiment, although there were no significant differences in skin temperature on the trunks between the groups, skin temperature on the forearm (see Figure 3) and thighs in the children were significantly higher than those in the students. These results suggest that the cutaneous blood flow of the children, especially in the limbs, increases at a greater rate than the students. The greater increase in cutaneous blood flow of the children, mainly in the limbs, probably caused a lower venous return (Rowell 1977) which effected the greater increase in the heart rate during the immersion as shown in Figure 5.

Is there any influence of the physical characteristics of the children on thermal responses during the heat exposure? The children have a greater surface area-mass-ratio than the adults by 24% as shown in Table 1. This greater surface area-mass-ratio has an advantage in thermal regulation under this thermal condition. Namely, mean skin temperature (36°C) was higher than ambient temperature (30°C). On the other hand, the thinner fat layer of the children's legs (about half of the students) during the leg immersion in the hot water bath has a disadvantage compared with the students (Mayuzumi et al. 1981). Due to this counter effect, the physical characteristics of the children would have had no distinct effects on thermal responses in this experiment.

There is a discrepancy in the research on the difference in rectal temperature during heat exposures
between the children and adults. Kosuge (1939) reported that the rectal temperature decreased during heat exposure (33°C) in the children, and on the contrary, it increased in the adults. Shiraiishi and Araki (1990) reported that rectal temperature of both groups decreased under the hot condition (40°C), and the degree of decrease was greater for children than for adults. In this experiment, rectal temperature of both groups increased from the immersion, and the degree of the increase was the same. Namely, the children could thermoregulate their rectal temperatures as effectively as adults under this condition, though at a higher level. This discrepancy would be due to differences in the degree of the heat loads. The heat loads in the previous two experiments were relatively light; on the other hand, the heat load from the immersion was greater in this experiment. Further research on the age difference in thermal regulation is needed under various thermal conditions.

In summary, limited to these experimental conditions, the thermoregulatory ability of 6- to 8-year-old children during heat exposure is similar to that of young female adults. However, it is found that for heat loss, children resort more to vasodilation than sweating during heat exposure as compared to adults.

**Differences in thermal responses among the children**

It is known that physiological adaptability of humans to thermal environments is developed by appropriate thermal stimuli. Kuno (1956) reported that the number of active sweat glands is decided by the ambient temperature of the places where a person lived for the first two years after birth. In these years, the rate of use of air cooling systems in Japanese houses was only 1%. However, the using rate has increased year by year, and now this rate is over 70% (Economic Planning Agency 1992). Moreover, there are some houses where cooling systems are used all day long in summer, and the infants are kept inside. Hence, there are now residential thermal environments that are beyond our imagination 30 years ago; and children are growing up in such environments. However, even though the indoor thermal environments in Japanese houses have changed rapidly during the last 30 years, the hot humid summer in Japan have not changed.

Therefore, the intention of this study was to determined whether or not these artificial residential thermal environments affect children’s heat tolerance.

There were no significant differences between the groups in thermal responses during immersion in the hot water bath as shown in Table 3. Although it is difficult to resolve this question solely by this experiment, it was found that the ability of Japanese children to tolerate heat was not reduced distinctly by the frequent use of an air cooling system in infancy. There could be some reasons why the difference in thermal responses between the groups was not found. One reason is the fact that the increase in sweat rate due to repeated heat exposures or thermal adaptation for children are less than those for adults (Araki et al(114,133),(825,704)(102,133),(829,704). 1979). Another reason is that the children in this experiment were divided into two groups according to the use of air cooling system in their infancy or not. The children who were grouped as frequent users of air cooling systems may have played outside in summer in their 3- to 7-year-old period. This behaviour after the first two years would have improved the heat tolerance of the children.

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**References**


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**Table 3 Differences in thermal responses between the groups in the children. Values are means and SE.**

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>TSR (g/m²/hr)</th>
<th>LSR (mg/cm²/min)</th>
<th>OT (sec)</th>
<th>Na⁺ (ppm)</th>
<th>Tre (°C)</th>
<th>HR (beats/min)</th>
<th>SBP (mmHg)</th>
<th>DBP (mmHg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequent use of air cooling system</td>
<td>12</td>
<td>130.8</td>
<td>0.64</td>
<td>263</td>
<td>1251</td>
<td>37.82</td>
<td>115.7</td>
<td>106.5</td>
<td>67.8</td>
</tr>
<tr>
<td>Non-use of air cooling system</td>
<td>11</td>
<td>125.5</td>
<td>0.61</td>
<td>297</td>
<td>725</td>
<td>37.84</td>
<td>110.8</td>
<td>106.4</td>
<td>65.6</td>
</tr>
</tbody>
</table>

**Temperature Regulation:**

OT: Time required for the onset of sweating; Na⁺: Sodium concentration during the last 10 minutes immersion; Tre: Rectal temperature at the end of the immersion; HR: Heart rate during the last three minutes of the immersion; SBP: Systolic blood pressure at the end of the immersion; DBP: Diastolic blood pressure at the end of the immersion.
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