PHYSIOLOGICAL RESPONSES TO WHOLE BODY BATH AND HOT AIR EXPOSURE WITH SPECIAL REFERENCE TO ASSESSMENT OF HEAT TOLERANCE

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Abstract In studies of heat tolerance in man, a hot bath has been sometimes used as heat stress. Sweating under water is not used for dissipation of heat, thus, assessment of heat tolerance with hot water bath methods is expected to be considerably different from that with the hot air method. Applying our indices methods for assessment of heat tolerance, therefore, the hot water bath method as a heat tolerance test was compared with that of exposure to hot air. The physiological responses to heat and heat tolerance were examined in 8 male college students in a hot air environment and in hot water at 39°C and 39.5°C. After staying for 30 min in a climatic chamber with a temperature of 30°C D.B. with 70% relative humidity, sweating in air was produced by immersion of both legs to just below the knees into a 42°C water bath with stirring. Each subject was then immersed into a hot water bath of 39°C or 39.5°C up to the neck for 30 min after 30 minutes' rest. Experiments on another group of 6 male students were made with hot bath of 38°C. Sweat rate and sweat Na concentration in an air environment were fairly well correlated with those in hot baths, while increase in rectal temperature was poorly correlated with that in hot baths. When assessed with our indices method, heat tolerance evaluated in an air environment did not always run parallel with that in hot baths. Such a discrepancy in heat tolerance assessed in hot air and in hot water appears to be explained chiefly by unusefulness of sweat produced under water for cooling the body in hot baths.

In studies on heat tolerance in man, a hot bath has been sometimes used as heat stress. Under the International Biological Programme (IBP), Belding and Hertig (1967) recommended also the use of a hot water bath for the study of...
heat tolerance for field work to collect large quantities of data on heat tolerance of different groups. One of the advantages of the hot water bath method is that control of bath water temperature is relatively easy, whereas exposure to hot air environments necessitates the control of air temperature, humidity and air flow velocity as well as radiation with some accuracy.

With the hot water bath method, however, there are some points that must be taken into careful consideration: sweating under water is not used for dissipation of heat (Hertig et al., 1961) but it still induces some disturbances in metabolism of salt and water just as that occurring under exposure to hot air, while uptake of water from the bath by the corneum might reduce the sweat volume (Randall and Peiss, 1957; Collins and Weiner, 1962; Brebner and Kerslake, 1963). Moreover, the great uniformity of skin temperature produced by high thermal conductivity of water (Burton and Bazett, 1936) may modify patterns of physiological strain in the body induced by the heat load. Thus the assessment of heat tolerance by the hot water bath method is expected to be considerably different from that with the hot air method. In the present study, therefore, comparison of hot water bath method as heat tolerance testing with that by exposure to hot air was attempted.

MATERIALS AND METHODS

In an air-conditioned room (air temperature 30±0.5°C, relative humidity 70±5%), two series of experiments, A and B, were made on 8 male college students in winter. In the series A, Ohara's sweating test (Ohara, 1968) was loaded as heat stress; as described in our previous paper (Hori et al., 1974), the test was made by immersion of both legs up to the knees into a hot water bath of 42°C for 90 min. In the series B, a subject wearing shorts only was immersed up to his neck in a hot water bath set up in the air-conditioned room for 30 min. In the hot water bath, the subject sat on a perforated board and the temperature of bath water was maintained at 39°C (series B39) or at 39.5°C (series B39.5).

In both series of experiments, each subject, wearing shorts only, sat on a chair in the air-conditioned room for 30 min prior to application of the heat load, while observations made during this period served as reference for those after loading heat stress. In the series B, the subject sat on a chair in the climatic chamber for 30 min after the bath, recovery process at 30°C with about 70% R.H. being followed up.

Similar observations were made on another group of 6 male medical students in spring. In this case, a 38°C hot water bath was applied, while collection of local sweat samples was omitted (series A' and B' 38).

Body weight was measured prior to and immediately after loading heat stress with the accuracy of ±5 g, the net body weight being obtained by subtracting the weight of dry or wet shorts. The total amount of sweat produced by the heat load was estimated from the decrease in the net body weight without correction.
for weight loss through respiration.

Using Ohara's filter paper method (Ohara, 1966), sweat samples were collected at each 15 min interval from the chest and back in series A and from the forehead in series B as described previously (Hori et al., 1974a). The Na and Cl concentration in the sweat was determined using eluates with distilled water from the filter papers by flame photometry and silver chloride titration, respectively.

Rectal temperature was measured by a thermocouple (copper-constantan) method throughout the experiments with the accuracy of ±0.02°C. Heart rate was estimated from the electrocardiogram.

As described previously (Inouye et al., 1972; Hori et al., 1974a, b), computation of the indices I and S based on relative increase in rectal temperature, relative water and salt loss induced by heat load was made as follows.

\[
I = (A^2 + B^2 + C^2)^{1/2} \quad S = B/(A^2 + C^2)^{1/2}
\]

where

\[
A = \Delta W/(0.07 \times W) \quad B = \Delta T/(40.6 - T_i) \quad C = \Delta Q/(0.75 \times W)
\]

and

\[
W = \text{Body weight before the experiment (kg)} \\
\Delta W = \text{Weight loss at the end of heat exposure (kg)} \\
T_i = \text{Rectal temperature before the experiment (°C)} \\
\Delta T = \text{Increase in rectal temperature at the end of heat exposure (°C)} \\
\Delta Q = \text{Salt loss (g)}
\]

RESULTS

1. Responses as a whole

A typical example of the results is illustrated in Fig. 1. In series B, the rise in rectal temperature (ΔT), rate of sweating (V) and salt concentration in sweat (C) may have not yet reached a steady level at the end of the loading bath test for 30 min, whereas those in series A had already attained an almost steady level about
Table 1. Body weight, weight loss, increase in rectal temperature and maximum Na concentration under three different conditions.

<table>
<thead>
<tr>
<th>Condition</th>
<th>W (kg)</th>
<th>ΔW (kg)</th>
<th>ΔT (°C)</th>
<th>Cm (mEq/liter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>60.9±5.3</td>
<td>0.62±0.09</td>
<td>0.63±0.09</td>
<td>69.3±9.9</td>
</tr>
<tr>
<td>B 39</td>
<td>60.2±5.3</td>
<td>0.66±0.08</td>
<td>0.67±0.15</td>
<td>66.3±6.5</td>
</tr>
<tr>
<td>B 39.5</td>
<td>60.2±5.1</td>
<td>0.85±0.17</td>
<td>1.14±0.15</td>
<td>69.9±6.9</td>
</tr>
<tr>
<td>A'</td>
<td>66.5±2.5</td>
<td>0.63±0.04</td>
<td>0.61±0.18</td>
<td>—</td>
</tr>
<tr>
<td>B' 38</td>
<td>66.5±2.5</td>
<td>0.53±0.15</td>
<td>0.41±0.12</td>
<td>—</td>
</tr>
</tbody>
</table>

A = air condition  
B 39 = in hot water bath of 39°C  
B 39.5 = in hot water bath of 39.5°C  
A' = air condition  
B' 38 = in hot water bath of 38°C  
W = initial body weight  
ΔW = weight loss  
ΔT = increase in rectal temperature  
Cm = maximum Na concentration  

Mean values are given with their standard deviation.

15–30 min before the end of the 90 min test. As summarized in Table 1, however, the magnitude of physiological responses as a whole observed in series A appears nearly the same as those in series B39, but significantly smaller than those in series B39.5. In an additional series A' and B'38, it was observed that the increase in rectal temperature (ΔT) and total sweat volume estimated as ΔW were a little lower in A' than in B'38. Despite a significant difference in the duration of loading heat stress and so in the time course of physiological responses, therefore, a whole body bath of 39°C for 30 min as heat stress might be nearly equivalent to Ohara’s sweating test.

2. Sweating reaction

Irrespective of the temperature of the hot water, the weight loss (ΔW) observed in each subject in series B is almost proportional to the ΔW observed in series A, the latter being nearly in the same magnitude as that in B39, smaller than that in B39.5 but greater than that in B38. On the other hand, the weight loss observed in the bath of 39°C showed a fairly good correlation with that in the bath of 39.5°C (r=0.89).

Figure 2 shows a close correlation of the peak salt concentration in sweat (Cm) collected from the forehead in series B39 and B39.5 with that obtained in series A as the average of the chest and back samples. Moreover, as seen in Fig. 2, the peak sweat rate (Vm) in the series B also runs nearly parallel with that observed in the sweating test (the average of the rate obtained at the chest and back).

These results suggest that, despite the greater part of sweating in the bath might be ineffective in dissipating heat by evaporation. The sweating reaction itself is quite similar to that worked in Ohara’s sweating test in a hot air environ-
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Fig. 2. Relationship between local peak sweat rate and peak Na concentration in local sweat. $V_m$: peak sweat rate, $C_m$: peak Na concentration, $\Delta$: air environment, $\bigcirc$: hot bath (39°C), $\bigtriangleup$: hot bath (39.5°C). The results obtained on one and the same subject are indicated by connecting these three marks with the broken and straight lines.

As already pointed out by OHARA (1968), therefore, his sweating type ($C_m - V_m$ plot), and so our modified sweating type too (HORI et al., 1974a), appear to be independent on the sort of heat stress applied, reflecting a characteristic of individual thermal sweating responses.

3. Changes in the rectal temperature

Concerning the increase in rectal temperature ($\Delta T$), positive correlation was

Fig. 3. Correlations of the increase in rectal temperature observed in series A with that in series B. $\Delta T(A)$: increase in rectal temperature in an air environment, $\Delta T(B)$: increase in rectal temperature in water environments. $\Delta$: hot bath (38°C), $\bigcirc$: hot bath (39°C), $\bigtriangleup$: hot bath (39.5°C).
not observed between both series, A and B, as shown in Fig. 3. The figure suggests rather a trend of negative correlation between both series ($\Delta T_A$ and $\Delta T_B$). On the other hand, $\Delta T$’s observed in series B39.5 showed a positive correlation ($r=0.68$) with those in series B39 (Fig. 4).

The level of $\Delta T_A$ could be regarded, as a rough approximation, to reflect a result of effectiveness of sweating in preventing a rise in the body temperature, so that the difference, $\Delta T_B - \Delta T_A$, especially that in series B39.5 might largely, if not solely, reflect the effect of dropping out of a greater part of evaporative heat dissipation in the bath; the more effective evaporative heat loss is in series A, the lower is $\Delta T_A$ at a given level of sweating. On the other hand, the total sweating

![Graph](image-url)

**Fig. 4.** Correlation between increase in rectal temperature in hot bath of 39°C and that in hot bath of 39.5°C. $\Delta T$: increase in rectal temperature.

![Graph](image-url)

**Fig. 5.** Correlations of weight loss observed in series A and B. $\Delta W(A)$: Weight loss in an air environment, $\Delta W(B)$: weight loss in water environments. ○: hot bath (39°C), ○: hot bath (39.5°C).
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Fig. 6. Relationship of difference in the rectal temperature increase between series A and B to that of weight loss. $\Delta T$: increase in rectal temperature, $\Delta W$: weight loss, A: Ohara's sweating test (series A), B: hot water bath experiments (series B), ○: hot bath (39°C), ●: hot bath (39.5°C).

in both series, $\Delta W_A$ and $\Delta W_B$, shows a positive correlation to each other as shown in Fig. 5. Thus, some correlation between $\Delta W_B - \Delta W_A$ and $\Delta T_B - \Delta T_A$ is to be expected. Figure 6 clearly shows such a tendency for $\Delta W_B - \Delta W_A$ to positively correlate with $\Delta T_B - \Delta T_A$.

Profuse sweating still continued a little while after the bath and so the decrease in the rectal temperature after the bath largely depends on evaporative heat loss by sweating. Thus, decline of the rectal temperature after the whole body

Fig. 7. Correlation between the increase in rectal temperature during heat exposure observed in series A and the decrease in rectal temperature during recovery in series B. $\Delta T$: increase in rectal temperature, $\frac{dt}{dT}$: reciprocal of rate of decrease in rectal temperature at rectal temperature of 38.5°C.

$y = 0.0193x + 0.101$
$r = 0.94$
bath, $dI_T/dt$, is expected to have some correlation with $I_T$. Indeed, as seen in Fig. 7, the reciprocal of this rate, $(dt/dI_T)$ measured at $T_n=38.5^\circ C$, shows a fairly good correlation with $I_T$.

4. Changes in the heart rate

Through both series of experiments, A (or $A'$) and B (or $B'$), the increase in the heart rate ($H$) with heat load did not show any significant correlation with $W$ as well as with the salt concentration in sweat. As naturally expected, a positive correlation ($r=0.48$) of $H$ with $T$ was observed but it was not so conclusive. Correlation of heart rate with $T$ is not so much improved by using the term $H/H_1$ instead of $H$, where $H_1$ is the initial heart rate prior to loading heat stress.

5. Indices $I$ and $S$

The mean value of the indices calculated from Eq. (1) for each series is presented in Table 2 with its standard deviation. As described previously (INOUYE et al., 1972; HORI et al., 1974a, b), Index $I$ is considered to reflect physiological strain resulting from heat stress loaded. From such a point of view, therefore, the present results indicate that the whole body bath in water of $39^\circ C$ for 30 min as heat stress is nearly the same as Ohara’s sweating test, the bath of $39.5^\circ C$ for 30 min (B39.5) being far more severe. Concerning the values of $S$, however, no statistically

<table>
<thead>
<tr>
<th>Series</th>
<th>Index $I$</th>
<th>Index $S$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.25±0.034</td>
<td>1.24±0.25</td>
</tr>
<tr>
<td>B 39</td>
<td>0.25±0.038</td>
<td>1.14±0.23</td>
</tr>
<tr>
<td>B 39.5</td>
<td>0.37±0.063</td>
<td>1.53±0.26</td>
</tr>
</tbody>
</table>

Fig. 8. Correlation of index $I$ in series A and B. $I_A$: Index $I$ obtained in Ohara’s sweating test (A), $I_B$: Index $I$ obtained in hot water bath test (B), $\bigcirc$: hot bath (39°C), $\bigcirc$: hot bath (39.5°C).
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Fig. 9. Correlation between Index I in hot bath of 39°C and that in hot bath of 39.5°C.

significant difference is observed among these three series.

Correlation of the index I among these series, are presented in Figs. 8 and 9. As seen in Fig. 8, IA shows rather a trend of negative correlation with IB but the regression line for 39.5°C is far steeper, while IB at 39.5°C runs parallel with that at 39°C and its correlation coefficient was 0.81 (Fig. 9).

DISCUSSION

Already in 1924, Bazett noted that loss of water by sweating in a hot bath occurred as freely as in a hot room. Since then, many investigators (Randall and Peiss, 1957; Collins and Weiner, 1962; Brebner and Kerslake, 1963) reported that uptake of water by the corneum always resulted in a decrease in sweating in a fresh water bath, regardless of the level of thermal stress. Moreover, rather homogeneous skin temperature resulted from hot water bath (Burton and Bazett, 1936) is expected to affect sweating reactions, as far as thermal sweating is affected not only by temperature changes in hypothalamus (core temperature) but also by afferent impulses from the temperature receptors in the skin (regional pattern of skin temperature).

The results presented above demonstrated, however, that under the conditions used in the present study at least, the sweating reactions observed in series A were fairly well correlated with those in series B: the sweat rate and Na concentration in sweat observed in hot air environment showed a fairly good correlation with those in whole body hot baths as seen in Fig. 2, a finding which proves that Ohara's sweating type is regarded as inherent for each individual, and independent on the sort of heat stress loaded in so far as the stress is not too severe. Thus, the difference in sweating responses between exposure to hot air and hot water bath might be said to be only quantitative, but not qualitative.

It should be noted here, however, that severe underwater sweating is not used
for cooling the body (HERTIG et al., 1961) but causes loss of water and salt just as that in hot air exposure, resulting in disturbance in water and salt metabolism.

In a water bath warmer than the body temperature, net heat transfer through the shell into the core occurs, resulting in a rise in the rectal temperature, $\Delta T_B$, while the rate of heat transfer largely depends on the insulative power of the shell; the lower the insulative capacity is, the higher the $\Delta T_B$ is. In Ohara’s sweating test, in which sweating chiefly occurs in air of $30^\circ$C, a greater part of metabolic heat is transferred from the core to the shell and dissipated by evaporation; the lower the insulative capacity of the shell is, the greater the efficiency of evaporative heat loss and so the lower the value of $\Delta T_A$ is. The results presented in Fig. 3 suggests that $\Delta T_A$ reflects such an effectiveness of heat dissipation by sweating. Thus, it does not seem so improbable that, as seen in Fig. 3, a tendency of $\Delta T_B$ being inversely correlated with $\Delta T_A$ appears. As seen in Fig. 5, the sweat volume observed in the series A and B ($\Delta W_A$ and $\Delta W_B$) runs parallel with each other and not so greatly different in its magnitude. Along the line of the above-mentioned reasoning, therefore, it is expected, of course as a rough approximation, that $(\Delta T_B - \Delta T_A) \times W$ reflects the amount of heat which could be dissipated in hot air environment by sweating. Indeed, as seen in Fig. 6, $\Delta W_B - \Delta W_A$ shows a fairly good correlation with $\Delta T_B - \Delta T_A$. On the other hand, both in the hot water bath of $39^\circ$C and $39.5^\circ$C, the factors concerning insulation and evaporative heat loss act in the same sense, so that a positive correlation between $\Delta T_B$ at $39^\circ$C and $39.5^\circ$C illustrated in Fig. 4 appears quite natural.

It has been well documented that the increase in heart rate under the influence of heat ($\Delta H$) was closely related to rise in the body temperature ($\Delta T$). Contribution to the magnitude of Index I of $\Delta T$ was largest but no significant correlation of $\Delta H$ (or $\Delta H/H_i$) with $\Delta W$ or with the salt concentration in sweat was observed. Thus it does not seem so unreasonable that $\Delta H$ (or $\Delta H/H_i$) shows only a poor correlation with the value of the Index I.

As seen in Fig. 3, $\Delta T_B$ shows a tendency of inversely correlating with $\Delta T_A$, but $\Delta W_B$ is, as seen in Fig. 5, nearly proportional to $\Delta W_A$. So far as the contribution of $\Delta T$ as the factor B to the magnitude of Index I is much greater than that of the other two factors, (cf. HORI et al., 1974a), an inverse correlation of $I_B$ with $I_A$ shown in Fig. 8 is easily understandable.

Because $I_B$ shows a trend of inverse correlation with $I_A$, it is apparent that our method of evaluating heat tolerance with the magnitude of Index I depends on the sort of heat stress loaded, and is not directly applicable to testing with a whole body hot bath. Now the question arises which is better as the heat load for heat tolerance testing, a heat load with hot air such as in Ohara’s sweating test or with a hot bath? Our results suggested that Ohara’s sweating type is conserved irrespective of which of the two sorts of stress is applied. So long as the so-called sweating pattern based on sweat samples collected locally is used as a criterion for heat tolerance as in OHARA’s method (1968) or in its modified method
(INOUYE et al., 1972; HORI et al., 1974a), the assessment of heat tolerance by the hot bath method might not be so different from that by hot air method. Such a method might be said to rest on “qualitative” aspects of thermal sweating reactions. From the viewpoint of heat balance of human body, however, “quantitative” aspects of sweating is of great importance; heat stress faced in our daily life is usually exposure to heat in air environments and individual differences in capacity of heat dissipation by sweating as well as of tolerating disturbances in water and salt metabolism are the main, if not sole, factors in determining difference in heat tolerance. In a hot bath, such an individual difference in capacity of heat dissipation by sweating is minimized. In this respect, loading heat stress in air environments is more reasonable than that in a whole body hot bath.

REFERENCES