Influence of Food Intake on Cold-Induced Vasodilatation of Finger

Nariko TAKANO and Michiyô KOTANI*

Physiology Laboratory, Department of School Health, Faculty of Education, Kanazawa University, Kanazawa, 920 Japan
* Hokuriku Gakuin Women’s College, Kanazawa, 920 Japan

Abstract When the finger is immersed in ice water, a sharp fall of the skin temperature is followed by its gradual rise due to the cold-induced vasodilatation (CIVD). The present study was attempted to examine whether the CIVD is affected by a small increase in internal heat load due to the dietary thermogenesis. A 10-min immersion of the left middle finger in ice water was performed at room temperature of 25–26 °C on 12 female subjects 60 min before, and 30 and 90 min after ingestion of a meal containing 700 kcal. Skin temperature of the finger and O₂ consumption were continuously measured before, during, and after the immersion. A CIVD index was measured using the data of the rising phase of skin temperature during the immersion. The CIVD index, a newly developed parameter in the present study, could reflect both the rapidity and the magnitude of CIVD response during the immersion. Compared with pre-prandial values, the O₂ consumption and the CIVD index significantly increased by 15 and 69%, respectively, at 30 min and by 15 and 50% at 90 min of the post-prandial period. Esophageal temperature was studied on another 5 subjects (1 male and 4 females) and it rose by 0.27 °C during the 90-min post-prandial period. The results, in support of the involvement of the central nervous system control in CIVD, suggest that the central process is so sensitive as to operate in a 15% increase in heat load into the body.

Key words: hunting reaction, cold-induced vasodilatation, finger skin vessel, food intake.

Lewis (1930) first described that when the finger was immersed in ice water, the finger skin temperature fell sharply to a certain level and was followed by irregular rises and falls, this temperature oscillation being called the hunting reaction. Similar reaction was observed in other parts of the extremities of men and animals (cf. Brown and Baust (1980)). The hunting reaction has been accounted for by
an intermittent interruption of cold-induced vasoconstriction by cold-induced vasodilatation (CIVD) of arterioles and arteriovenous anastomoses of the skin (WERNER, 1977). It has been suggested that the CIVD occurs through locally mediated processes such as an axon reflex of the sensory nerve (LEWIS, 1930), release of some vasodilatory substances (LEWIS, 1930), the reduced vasomotor tone, the decreased sensitivity of blood vessels to adrenergic stimulation (KEATINGE, 1964) and reduction of noradrenaline release from the sympathetic nerve (MEYER and WEBSTER, 1971).

Apart from the local control of the CIVD, an involvement of the central nervous system in CIVD has also been suggested. For instance, when an extremity was unilaterally cooled, a small fluctuation of skin temperature was observed contralaterally which was synchronous to that of the cooled side (LEWIS, 1930; BROWN and BAUST, 1980; KUNIMOTO, 1987). Furthermore, when the body was exposed to a higher ambient temperature while a finger was locally cooled, the CIVD started at a higher level of the finger skin temperature during its cold-induced fall (YOSHIMURA and IIDA, 1950; WERNER, 1977; KUNIMOTO, 1987). These findings indicate that the thermoregulatory conditions of the whole body may override the locally determined CIVD (WERNER, 1977). Thus, a hypothesis has been put forward that a central process controlling the sympathetic nervous system may be involved in the regulation of the hunting response (MEYER and WEBSTER, 1971; WERNER, 1977; BROWN and BAUST, 1980; KUNIMOTO, 1987).

Recent studies on the dietary thermogenesis have shown that the thermic effect of a meal continues over several hours in man, during which the metabolic rate increases by 10–30% (FELIG et al., 1983; LEBLANC and BRONDEL, 1985; NIELSEN, 1987) and the rectal temperature rises by 0.3°C (NIELSEN, 1987). The present study was performed to examine whether small internal heat load due to the dietary thermogenesis may modulate the CIVD of the finger, as has been demonstrated during external heat load (YOSHIMURA and IIDA, 1950; WERNER, 1977; KUNIMOTO, 1987).

METHODS

Twelve female students (age, 19–21 year; height, 154–165 cm; weight, 45–68 kg) volunteered for the experiment, giving informed consent. The experiment started at 9:00 A.M. after an overnight fast. During the experiment, room temperature was kept at 25–26°C and relative humidity at 55–60%; the subjects wore clothing in accordance with their comfort. The subjects underwent the experiment in a sitting position. After a 1-h rest, they were asked to immerse the left middle finger up to the middle phalanx in crushed ice water for 10 min. Temperature of the palmar surface of the finger tip was continuously measured using a copper-constantan thermocouple and recorded over a period of 16 min: 3 min of pre-immersion, 10 min of immersion, and 3 min of post-immersion. This procedure over 16 min was designated as a finger-cooling test. About 40 min later, the subjects were fed a meal.
containing 700 kcal with 36% carbohydrates, 48% fats, and 16% proteins, which had been kept at the room temperature. Thirty minutes after the beginning of the meal that lasted about 10 min, the second finger-cooling test was carried out, which was followed by the 3rd test 1 h after the second.

During each finger-cooling test, some metabolic parameters were measured. The subjects wore a face mask which was fitted with a hot-wire flowmeter for continuous measurement of respiratory flow. Respiratory gas was sampled continuously at the nose and introduced to a gas analyzer (medical gas analyzer, MG-360, Minato Med. Sci. Co.) for measurement of O₂ and CO₂ contents (by a zirconium reaction and an infrared absorption, respectively). Signals from the flowmeter and gas analyzer were fed to a minicomputer (respiromonitor, RM-200, Minato Med. Sci. Co.), which was capable of computing O₂ consumption (\( \dot{V}_{O_2} \)), CO₂ excretion (\( \dot{V}_{CO_2} \)), and RQ, on a breath-by-breath basis. Average values of these metabolic parameters before, during, and after immersion of the finger in ice water were calculated using the breath-by-breath data obtained during the last 2 min of the 3-min pre-immersion period, the last 8 min of the 10-min immersion period, and the last 2 min of the 3-min post-immersion period, respectively. All the metabolic parameters were found to have reached the steady state during these periods.

As mentioned above, the finger-cooling test was carried out three times within 2.5 h. The effect of repeated immersion of the finger in ice water on the hunting reaction was examined in another series of experiments, in which three runs of the finger-cooling test were performed in the same time interval but without a meal. Four of the 12 subjects participated in this experiment on a separate day.

The magnitude and the rapidity of CIVD response were estimated using a trapezoid method, as shown in Fig. 1. Figure 1 shows a record of the finger temperature change during a finger-cooling test. Over the period of time from the onset of rise in finger temperature to the end of cold exposure, the area between the temperature curve and the base line of 0°C was measured by a planimeter. It can be indicated that the greater the area, the earlier and the greater the rise in finger temperature due to CIVD. The area thus obtained was designated as a CIVD index in the present study.

In a separate experiment, the effect of food intake on esophageal temperature was studied in another 5 subjects (one male weighing 65 kg and 4 females, 48–52 kg). A thermocouple probe was inserted into the esophagus via the nose down to the level of left atrium. After output of the thermocouple that was continuously recorded reached the stable state, measurements of esophageal temperature and metabolic variables were carried out on the identical time schedule to that in the experiment with the finger-cooling test. The subjects were fed a meal (800 kcal for the male and 700 kcal for the females) at 60 min after the start of measurements.

The results were analyzed by paired Student's t-test, in which significance level was considered to be \( p < 0.05 \). Data were given as the means ± S.E.
RESULTS

Figure 2 shows the mean changes in $\dot{V}_{O_2}$ of 12 subjects during the finger-cooling test performed before and after food intake. Although $\dot{V}_{O_2}$ remained virtually unchanged over the periods before and during cold exposure of the finger, it significantly decreased during the post-cooling period. These $\dot{V}_{O_2}$ changes during the finger-cooling test were independent of food intake. However, the post-prandial levels of $\dot{V}_{O_2}$ all over the test periods were higher than the pre-prandial level. The post-cooling decrease in $\dot{V}_{O_2}$, to our knowledge, is a new finding. However, the mechanisms for this are not clarified at present.

Shown in Fig. 3 are changes in the finger skin temperature during finger-cooling tests performed on a subject before and after food intake. The skin temperature during cold exposure tended to rise earlier and stay at higher levels in the post-prandial period than in the pre-prandial period. The mean values of the CIVD index, skin temperature, and $\dot{V}_{O_2}$ (the latter two being the pre-cooling values in the finger-cooling test) for 12 subjects are shown in Fig. 4. Compared with the pre-prandial values, $\dot{V}_{O_2}$ significantly increased by 15% both at 30 and 90 min of the post-prandial period. The CIVD index significantly increased from $5.4 \pm 1.4$ (S.E.) in the pre-prandial period to $9.1 \pm 2.2$ at 30 min and $8.1 \pm 1.6$ at 90 min of the post-prandial period, corresponding to 69 and 50% increases, respectively. The finger skin temperature before cold exposure rose from $33.0 \pm 1.1 ^\circ C$ in the pre-prandial period to $33.8 \pm 1.1 ^\circ C$ at 30 min and $34.2 \pm 0.8 ^\circ C$ at 90 min of the post-prandial period, but the increments were not statistically significant ($p > 0.05$).

*Japanese Journal of Physiology*
It has been reported that the excessive changes in vasomotor tone of finger skin vessels before cooling, such as complete vasodilatation or complete vasoconstriction, suppress the hunting reaction (Lewis, 1930; Keatinge, 1957;
The present result of the finger skin temperature before cooling indicates that the vasomotor tone of the finger skin vessel before cooling would not have been in such an extreme change but in the optimum condition in terms of the vasoreactivity (Thoresen and Walløe, 1980).

Figure 5 shows the results of three runs of the finger-cooling tests performed at the intervals of 1-1.5 h with and without a meal on 4 of 12 subjects. The $V_O_2$ (the pre-cooling value in the finger-cooling test) remained unchanged in the three consecutive runs without a meal, while it increased in the post-prandial runs. The pre-cooling level of finger skin temperature remained unchanged in three consecutive runs with and without a meal. The CIVD index did not significantly change in the three runs without a meal, while it significantly increased in the post-prandial run. This indicates that the frequent exposure of a finger to cold by itself in the present study exerts little influence on the CIVD response of the finger and thus suggests that the post-prandial changes in the CIVD response is brought about by the effect of food intake.

Fig. 4. $O_2$ consumption ($V_O_2$) and finger skin temperature before immersion of the finger in ice water, and CIVD index of the finger. The measurements were performed at 60 min before and 30 and 90 min after ingestion of 700 kcal. Values are means ± S.E. of 12 subjects. *Significant difference from the pre-prandial value ($p<0.05$).
Table 1 summarizes changes in esophageal temperatures and $V_{O_2}$ measured on another 5 subjects (1 male and 4 females) before and after food ingestion without the finger-cooling test. The esophageal temperature in all the subjects irregularly

Table 1. Esophageal temperature and $O_2$ consumption before and after food ingestion without the finger-cooling test.

<table>
<thead>
<tr>
<th></th>
<th>Before ingestion</th>
<th>After ingestion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>60 min</td>
<td>0 min</td>
</tr>
<tr>
<td>$T_e$ ($^\circ$C)</td>
<td>36.75 $\pm$ 0.15</td>
<td>36.88 $\pm$ 0.13</td>
</tr>
<tr>
<td>$V_{O_2}$ (ml/min)</td>
<td>183 $\pm$ 13</td>
<td>$-$</td>
</tr>
</tbody>
</table>

Values are means $\pm$ S.E. of 5 subjects. A meal of 800 kcal was fed to a male subject and a meal of 700 kcal, to 4 female subjects. $T_e$, esophageal temperature; $V_{O_2}$, $O_2$ consumption. * Significant difference from the pre-prandial value ($p<0.05$).

Table 1 summarizes changes in esophageal temperatures and $V_{O_2}$ measured on another 5 subjects (1 male and 4 females) before and after food ingestion without the finger-cooling test. The esophageal temperature in all the subjects irregularly
fell to around 35°C during the ingestion (the data are not shown), probably because the food had been kept at room temperature. After the ingestion, esophageal temperature gradually returned to the pre-prandial level, which was followed by further increases by 0–0.4°C among subjects (0.27°C in average) over the 90-min post-prandial period. The post-prandial increase in $\dot{V}_O_2$ was 15% at 30 min and 18% at 90 min relative to the pre-prandial value, the increments being similar to those in 12 subjects who underwent the finger-cooling test (Fig. 4).

**DISCUSSION**

*Effect of repeated cooling test on the CIVD response.* After a 10-min immersion of a finger in cold water, redness and throb of the finger at room temperature have generally been recognized. This after-effect has been ascribed to a vasodilatation (LEWIS, 1930). Consequently, any changes in vasomotor tones of the finger that could be produced by a preceding finger-cooling test might alter the CIVD response in the successive cooling tests. We examined this possibility by repeating the finger-cooling tests without a meal (Fig. 5). The finger temperature of the pre-cooling period tended to become higher with repetition of the test, but the change was not significant. In fact, the value of CIVD index of the finger did not significantly change with repeating the tests. These observations may justify the present experimental procedure for CIVD responses consecutively measured at the intervals of 1–1.5 h. YOSHIMURA and IIDA (1950), however, observed an after-effect of cooling on the hunting reaction, for which the second immersion of the finger in ice water was performed 1 h following the first immersion lasting for 30 min, while it lasted only 10 min in the present study. A longer immersion in the study of YOSHIMURA and IIDA (1950) seems to have exerted greater influence on the hunting reaction in the successive immersion.

*The CIVD index.* YOSHIMURA and IIDA (1950) have estimated a reactivity of the hunting reaction in terms of three parameters: TTR, the time of the first temperature rise of an extremity after the start of its immersion in ice water; TFR, the skin temperature at TTR; and MST, the mean skin temperature over the period from the 5th min to the end of immersion. It follows that the greater the hunting reaction, the shorter the TTR and the higher the TFR and MST. In the present study, a 10-min immersion method was applied in order to minimize the after-effect of immersion on the hunting reaction. The 10-min immersion was not long enough to observe a full response of the hunting reaction and its repetition that are requisites for application of the above-mentioned Yoshimura and Iida method (YOSHIMURA and IIDA, 1950). Therefore, a new method with measurement of the CIVD index has been developed in present study, by which a reactivity of the hunting reaction could be estimated in terms of a single parameter.

Yoshimura and Iida's three parameters (YOSHIMURA and IIDA, 1950) were tentatively measured using our data of skin temperature obtained during the finger-cooling test. The results are shown in Table 2. Although differences between

*Japanese Journal of Physiology*
COLD-INDUCED VASODILATATION

The pre- and the post-prandial values in all parameters did not reach the significance level, all the parameters tended to change toward the direction of enhancement of the hunting response after food intake. On the other hand, in terms of the CIVD index of our own parameter, the increase in the hunting response after food intake has been shown to be statistically significant (Fig. 4). As the CIVD index can include the whole continuous change of skin temperature after the onset of CIVD, it seems to be a more sensitive parameter in detecting small changes in the hunting reaction as occurring after food intake, compared to Yoshimura and Iida's parameters.

CIVD response after food intake. After ingestion of a 700 kcal meal, $V_O_2$ increased by 30 ml/min (15% of the pre-prandial value) at 30 and 90 min (Fig. 4). If this increment had been held over the 90-min period studied, the calorific increment during this period would have been about 13.5 kcal, which is comparable with the result in the study of LeBlanc and Brondel (1985) with a 710 kcal feeding. In a separate experiment without the finger-cooling test, we observed that food intake of 700–800 kcal resulted in almost the same extent of increase in $V_O_2$, as mentioned above, accompanied with a rise in esophageal temperature of 0.27°C (Table 1). Nielsen (1987) has observed similar increases in rectal temperature after ingestion of a 885 kcal meal. It follows from this that such a small increase in heat content of the body could be accompanied with an enhancement of the CIVD response of the finger (Fig. 4).

Meyer and Webster (1971) hypothesized that the hunting reaction results from the fluctuation of the balance between the vasoconstriction and the vasodilatation during cold exposure, both of which are locally and centrally controlled. An enhanced CIVD response following food ingestion may be due to a shift of the balance toward vasodilatation. And, the balance may be so sensitive as to be changeable with a small increase in vasodilatory stimuli that would have been produced by only a 15% increase in the internal heat load due to the dietary thermogenesis. Post-prandial decreases in vasomotor tones of the skin vessels have

Table 2. Profile of finger skin temperature during immersion of the finger in ice water and the effect of food ingestion.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>After ingestion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-60 min</td>
</tr>
<tr>
<td>TTR (min)</td>
<td>6.92 ± 0.35</td>
</tr>
<tr>
<td>TFR (°C)</td>
<td>0.76 ± 0.09</td>
</tr>
<tr>
<td>MST (°C)</td>
<td>2.00 ± 0.31</td>
</tr>
</tbody>
</table>

Values are means ± S.E. of 12 subjects. A meal of 700 kcal was fed to the subjects. TTR, time of first temperature rise after the start of immersion; TFR, skin temperature at TTR; MST, mean skin temperature during the period of the time from TTR to the end of immersion.
been suggested from the results of increased skin temperature following food intake (Nielsen, 1987; Hirai et al., 1989).

In the present study, the hunting reaction has been studied on female subjects. The menstrual cycle for each subject, however, has not been identified. As the menstrual cycle has been shown to affect the vasoreactivity of the skin (Haslag and Hertzman, 1965; Murakami et al., 1973; Hirata et al., 1986) and the hunting reaction (Murakami et al., 1973), it may also exert some influences on the post-prandial hunting response. However, to our knowledge, no study of this point has been documented.

In conclusion, only a 15% increase in the internal heat load due to the dietary thermogenesis can accelerate the CIVD response, indicating that the thermal state of the whole body is a sensitive mediator of the hunting reaction.

REFERENCES


Thoresen, M. and Walløe, L. (1980) Skin blood flow in humans as a function of
