Assessment of Local Cold Tolerance of Individuals by using Conventional and Unconventional Methods Based on Observation of CIVD Reactivity

Shin-ichi Sawada, Dr.Med.Sc.
Chief of International Research Exchange and Information Center
National Institute of Industrial Health
Nagao 6-21-1, Tama-ku, Kawasaki
JAPAN
Tel: +81-44-865-6111, Fax: +81-44-865-6124
E-mail: sawada@niih.go.jp

ABSTRACT

Cold-induced vasodilatation (CIVD), which occurs in fingers and toes exposed to extreme cold, is a defensive reaction of protecting the extremities against frostbite. Yoshimura and Iida (1950) developed a practical method, based on observation of CIVD reactivity, for assessing peripheral resistance against frostbite (local cold tolerance). Thereafter, many studies using this test method to clarify the factors affecting the local cold tolerance, such as occupation, gender, race, environmental temperature, clothing, ambient pressure and cold acclimatization have been conducted. Recent Japanese clinical studies have suggested that this local cold tolerance test is also useful for evaluating the sympathetic skin vasomotor function and a peripheral sensory nerve disturbance. These tests have, however, consisted of a 30-min immersion of fingers in ice water (0 °C). Under these test conditions, most of the participants have tended to feel much pain and distress, and some have either fainted or had to withdraw prematurely from the experiment as a result. This means that vulnerable individuals, such as older persons or children, cannot participate in this stressful test. Consequently we proposed a simplified and less painful test for assessing the local cold tolerance (1983, 1984), as a substitute for the conventional test. Here I review some Japanese pioneering studies on factors governing the individual difference of the local cold tolerance which Yoshimura and Iida conducted by using their original method (conventional method). Also I refer to a study on applicability of our modified method (unconventional method) for assessing the local cold tolerance and summarize some of our recent findings on the factors affecting the local cold tolerance obtained by using the unconventional method.

1. CLASSICAL DATA BY CONVENTIONAL METHOD

The response of cold-induced vasodilatation (CIVD), which Lewis[1)] first described as "hunting reaction", has been found to be related to the severity of cold injuries, those with a higher response are less susceptible to frostbite and vice versa. Yoshimura and Iida[2)] developed a practical method, based on observation of CIVD reactivity, for assessing the peripheral resistance against frostbite (local cold tolerance). Thereafter, many studies using this test method to clarify the factors affecting the local cold tolerance, such as occupation, gender, race, environmental temperature, clothing, ambient pressure and cold acclimatization have been conducted.

Sawada, S. (2005) Assessment of Local Cold Tolerance of Individuals by using Conventional and Unconventional Methods Based on Observation of CIVD Reactivity. In *Prevention of Cold Injuries* (pp. 12-1 – 12-6). Meeting Proceedings RTO-MP-HFM-126, Paper 12. Neuilly-sur-Seine, France: RTO. Available from: http://www.rto.nato.int/abstracts.asp.

1.1 A Point Test on the Resistance against Frostbite [2)]

A practical and useful method was devised to determine the individual difference of the vascular hunting reaction to cold (CIVD) by dipping the middle finger of the subject in ice water for 30 minutes and measuring its skin temperature, and to compare the reactivity of the subject with one another by evaluating the so-called "resistance index of frostbite" from the temperature curve thus determined. The method was called "a point test of the resistance against frostbite". The resistance index estimated by the method was fairly reproducible as far as the experimental conditions were constant. A marked seasonal change was found in the temperature reaction of one and the same subjects, which increased in summer, and decreased in winter. The change was found to be mainly due to the change of room temperature. Even at the same room temperature, however, the reaction differed a little in summer and winter, i.e. is accelerated in the former when compared with the latter. The difference is probably due to an acclimatization of the vasomotor centre, in which the tonus changes to dilation of the skin vessels of extremities in summer, and constriction in winter. Influences of environmental temperature were examined in detail and it was found that the reactivity was accelerated by rise in room temperature in proportion with the magnitude of the reactivity itself. This fact can be explained by the fact that the reactivity of vessels is controlled by the tonus of the vasomotor, especially of the vasodilator, which changes with the environmental temperature. Effects of humidity on the temperature reaction was proved to exist, but not so marked as those of room temperature. Making use of the above experimental results, a method was devised to eliminate the errors in the temperature reaction due to the change of room temperature, and to evaluate the resistance index at the standard temperature of 20°C from measurements at other temperatures. It was found that 81%-94% of values thus corrected coincided with those actually measured at 20°C within the scope of experimental error, when the room temperature was between 15°C to 25°C.

1.2 Factors Governing the Individual Difference of the Resistance against Frostbite [3)]

Factors governing individual differences of temperature hunting reaction to cold found by Lewis[1)] were studied by the point test for frostbite resistance mentioned above. Main results obtained were as follows: The reaction was found even a few days after birth and developed rapidly with lapse of days. The high reactivity in childhood was lessened in puberty and again it rose in young adult, after which it decreased gradually with the progress of age. A female adult seemed to show a little lower reactivity than a male. Native countries and racial specificity were proved to have an intimate relation with the reactivity and a main factor of the influences was deduced to be the effect of training to cold. The Orochons were found to have the highest reactivity among all nations in Manchuria, and thus protecting themselves from frostbite, adapted to their nomadic life in a cold country. The reactivity of Japanese adults who recently came to Manchuria was the lowest of all the natives, while that of Japanese children was about the same with those of the native (the Mongols and the Chinese) children. A validity of training effect reported by Takahashi was ascertained, and it was proved that the effect was more remarkable on the youth than on the adult. Subjects of low reactivity were proved to show frequently high sympathetic tonus. Thus the tonus of autonomic nervous system had an intimate bearing with the reactivity. Main internal factors causing individual differences of the reaction were presumed to be differences of the following three: the morphological constitution, especially of blood vessels, the nervous control (activity) and other physiological properties of the skin. The experimental results mentioned above were explained from this point of view.

1.3 Effects of Diets on the Reactivity of Skin Vessels to Cold [4)]

By measuring the reaction index mentioned above, the influences of dietary constitution on the temperature reaction of the finger to cold were investigated and following results were obtained. The daily intake of excessive dietary protein (150-200g/day) accelerated the CIVD after about a week and the high reactivity was maintained thereafter, while a well defined influence could not be detected even after two weeks of low protein diet (25g/day). Intake of excessive salt (over about 45g. NaCL in daily diet) increased the reactivity after about a week, while salt lacking decreased it. These changes of the reactivity of cutaneous vessels to cold were explained by influences of diet on metabolism which were to affect the function of the thermoregulatory centre. It was pointed out that either high protein or high salt diet might be suitable for protection against frostbite in cold countries.

2. NEW DATA BY UNCONVENTIONAL METHOD

As mentioned above, Yoshimura and Iida [2] developed a local cold tolerance test on the basis of the CIVD observed in human fingers. The test has, however, consisted of a 30-min immersion of fingers in ice water (0 °C). Under this test condition, most of the participants had tended to feel much pain and distress, and some had either fainted or had to withdraw prematurely from the experiment as a result. This means that vulnerable individuals, such as older persons or children, cannot participate in this stressful test. Consequently we proposed a simplified and less painful test for assessing the local cold tolerance as a substitute for the conventional test. By using this unconventional method, we have studied the several factors relating to the reactivity of CIVD such as aging, season, physical exercise and repeated cooling.

2.1 Development of Unconventional Method [5),6)]

Cold-induced vasodilatation (CIVD) and systemic cardiovascular responses due to local finger cooling were studied in 10 healthy subjects at different room (22 and 30°C), water (0, 5, and 10°C) temperatures and immersion times (5 to 30 min). The skin temperature of the immersed finger, blood pressure, and heart rate were measured before and during the experiments. Marked CIVD comparable to that at the 0°C test could be obtained even at a water temperature of 5 or 10°C by a rise in room temperature. Under such room and water temperature conditions where marked CIVD appeared, the order of the degree of CIVD in the individuals was almost the same, although the CIVD response was influenced by changes in the room and water temperatures. Furthermore, the order of the mean skin temperature (MSTi) calculated by shortening the immersion time every 1 min remained extremely stable ($r>0.90$) even by more than a 20-min reduced immersion time, especially at a water temperature of 5°C. During several minutes after the start of immersion, maximal changes in blood pressure and discomfort due to cold were observed. The degree of these systemic loads in the subjects was reduced with rise in the water temperature. It is concluded that the current local cold tolerance test for 30 min at 0°C can be substituted sufficiently by a 5°C test for 10 to 15 min, and partly even by the 10°C test with the limitation that only MSTi and AT are available as an indicator of the local cold tolerance at higher environmental temperatures.

2.2 Effect of Aging [7)]

The primary objective of this study was to examine the age-related change of cold-induced vasodilatation (CIVD) and the associated skin temperature responses in older persons by using a modified local cold tolerance test. The secondary objective was to confirm whether the modified test condition is acceptable for older people. The test consisted of a 10-min immersion of the left middle finger in cold water at 10°C, and was substituted for a conventional test (30-min immersion in ice water at 0°C). The finger skin temperature responses before, during and after the immersion of six older men (62-70 years) were compared with those of seven younger men (20-29 years). CIVD occurred significantly later in the older group, and the magnitude of their response was significantly lower during the immersion. No vasodilatation occurred in two of the older men. The finger skin temperature after the immersion did not recover quickly to the pre-immersion level in most of the older men unlike the young men. The finger skin temperature before the immersion was not significantly different between the two age groups. Therefore, the depressed CIVD reactivity and slow recovery rate of the finger skin temperature after the immersion in the older men were thought to reflect the age-related changes of peripheral vascular reactivity to a local cold stimulus. Considering the fact that no subjects complained a great deal of cold pain during the immersion, our modified local cold tolerance test seems to be a useful and sensitive method for detecting the age-related degradation of local cold tolerance and peripheral vascular reactivity in older workers.

2.3 Seasonal Difference [8)]

To elucidate the seasonal effect on local cold tolerance, the cold defence responses to finger cooling were studied in the same subjects during summer and winter. Nine Japanese men between the ages of 21 and 30 participated in the finger cooling test. Prior to the test, each subject wore only shorts and rested on a chair in a comfortably warm room with an ambient temperature of 30°C and relative humidity of 40% for more than 40 minutes, to stabilize the pre-exposure thermal state of the subjects. In the finger cooling test, each subject immersed his left middle finger in cold water of 5°C for 10 minutes, during which time the skin temperature of the immersed finger was recorded for evaluation of cold-induced vasodilatation (CIVD) reactivity. During the finger cooling, CIVD occurred in eight of the nine subjects, regardless of the season. The mean time of the onset of CIVD (±se) was 4.32±0.53 minutes in summer and 4.45±0.61 minutes in winter, which represents a statistically insignificant difference. The magnitude of CIVD during cold-water immersion also showed no seasonal differences. The mean finger temperature before the immersion (BST), which was higher than 35°C in both summer and winter, showed no significant seasonal differences. The variation in CIVD reactivity showed a greater correlation with BST than with the season. These results suggested that the CIVD reactivity shows no significant seasonal differences if the finger skin temperature prior to finger cooling can be kept higher than 35°C under comfortably warm test conditions.

2.4 Physical Exercise [9)]

To investigate whether physical exercise improves cold defense responses caused by finger cooling, cold-induced vasodilatation (CIVD) and subjective pain and thermal sensations were observed both after and during light and moderate exercises in a moderate cold environment. Healthy young subjects consisting of fourteen men and two women aged 21 to 25 years immersed their fingers into stirred cold water of 10°C for 10 minutes in an ambient temperature condition of 10°C. Ten of them exercised for 10 minutes on a bicycle ergometer at 40 and 80 W immediately before the cold water immersion (Experiment I). Six of them exercised at the same level as Experiment I during the immersion (Experiment II). Through the experiments, skin temperature of the immersed finger tip was continuously measured for assessing the CIVD reactivity. Pain and cold sensations of the immersed fingers were also reported every one minutes as indices of subjective thermal strain. In the experiment I where the exercise was carried out before the cold water immersion, marked CIVD response occurred even in an ambient temperature condition of 10°C whereas little CIVD was observed without the exercise before the immersion. The CIVD response was significantly greater in the exercise of 80W than in that of 40W. Subjective thermal strain such as pain and cold sensations was less with the exercise than without the exercise. Also in the experiment II where the exercise was carried out during the cold water immersion, CIVD reactivity increased in proportion to the increase in exercise level (from 40W to 80W) and subjective pain and cold sensations was mitigated. This study clearly shows that moderate exercise (80W) before and during finger cooling improves CIVD reactivity in a moderate cold environment and that cold-induced pain and cold sensation is mitigated. Therefore, peripheral overcooling and subjective cold strain at work in moderate cold environments could be mitigated by moderate exercises before or during the work.

2.5 Repeated Cooling

In workers in cold environments such as refrigerated warehouses, food processing facilities and outdoors in cold weather, excessive cooling of fingers and toes have been frequently reported. In such cold work places, the workers are likely to handle frozen materials through cotton gloves or cold protective-gloves they wear, or touch a frozen fish or meat directly with their hands, or immerse their fingers in cold-water. In almost all cases, their fingers and hands are repeatedly and intermittently cooled, with rests and pauses in between. However, there have been so far only a few studies on the effects of repeated or intermittent peripheral cooling.

2.5.1 Effect of Ambient Temperature [10)]

To examine how repeated finger cooling with rest affects cold-induced vasodilatation (CIVD), pain, and cold sensation of finger, six healthy men aged 21 to 23 years immersed their left index fingers six times in stirred water at 10°C for 10 minutes. Each cold-water immersion was followed by a 5-minute rest. This repeated cold-water immersion experiment was carried out under three ambient temperature conditions: warm (30°C), thermoneutral (25°C), and cool (20°C). At the ambient temperatures of 30°C and 25°C, marked CIVD response occurred and the CIVD reactivity did not significantly change upon repetition of cold-water immersion. The finger skin temperature during each post-immersion rest also tended to recover quickly to the pre-immersion level. At the ambient temperature of 20°C, however, the CIVD response weakened continuously upon repetition of immersion and almost disappeared during the final immersion. The recovery of finger temperature during each post-immersion rest delayed continuously upon repetition of immersion. At every ambient temperature, finger pain and cold sensations induced by each cold water immersion significantly decreased upon repetition of immersion, and they completely disappeared during each post-immersion rest period. Oral temperature during the experiment showed no significant change at the ambient temperatures of 25°C and 30°C, whereas it decreased significantly at the ambient temperature of 20°C. These results suggest that in cool environments where the body core temperature is liable to decrease, repeated finger cooling may weaken CIVD reactivity and delay the recovery of finger temperature during post-immersion rest periods. In such cool environments, subjective judgements such as the decrease of finger pain and cold sensations during repeated finger cooling and the absence of them during post-immersion rest may not be reliable indicators for predicting the risk of progressive finger cooling and frostbite.

2.5.2 Effect of Clothing [11)]

The objective of this study was to investigate how repeated and intermittent finger cooling affects cold-induced vasodilatation (CIVD) response and finger pain and thermal sensations under different clothing conditions. Seven young men aged 23 to 24 years immersed their right index fingers in stirred water at 10°C for 10 minutes. This immersion procedure was repeated five times under ambient temperature of 20°C and relative humidity of 50%. Each cold-water immersion was followed by a 5-minute rest under the same climatic condition. This repeated cold-water immersion experiment was carried out on different days under three clothing conditions: light (pants, T-shirt, shorts and socks), medium (light clothing plus shirt and trousers) and heavy clothing (medium clothing plus jacket). Under the heavy clothing condition, marked CIVD response occurred and the CIVD reactivity did not significantly change upon repetition of cold-water immersion. The finger skin temperature during each post-immersion rest also tended to recover quickly to the pre-immersion level. Under the light clothing condition, however, the CIVD response weakened continuously upon repetition of immersion and the response in some subjects almost disappeared during the final immersion. The recovery rate of finger temperature during each post-immersion rest tended to decrease continuously upon repetition of immersion. Under every clothing condition, finger pain sensation rapidly increased during each immersion, but it completely disappeared during each post-immersion rest period. Finger cold sensation also rapidly increased during each immersion, but it was replaced by a warm or slightly warm sensation during each rest period. These subjective sensations during the immersion and post-immersion periods had no significant differences between clothing conditions. The present study suggests that light clothing in a cool environment may weaken CIVD reactivity during repeated finger cooling and delay the recovery of finger temperature during post-immersion rest periods. It also suggests that under such conditions, subjective judgments such as absence of finger pain and occurrence of warm sensations during post-immersion rest may not be reliable indicators of the risk of progressive finger cooling and frostbite formation.

3. CONCLUSION

Our unconventional method (5 or 10°C water immersion for 10 minutes) for assessing local cold tolerance of individuals is more useful than the conventional method (0°C ice water immersion for 30 minutes) in terms of an ethical and safe approach. Further research by using this unconventional method will provide us with more information on peripheral cooling effects on humans in the field of occupational health and clinical diagnosis.

4. REFERENCES

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