Hand Skin Temperature: A Usability for Health Care Services

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***Abstract*—This study was focused on the applicability of hand skin temperature measurements for evaluation of the individual health. Quantitative estimation of skin temperature related to cold-induced vasomotor reactions has a potential diagnostic value for health assessment and it is usable in personalized health care services. The aim of this study was to evaluate the dynamics of hand skin temperature after the local cooling in persons with different susceptibility to cold (n=74, 32 men, 42 women, age range 17-23 years). Skin temperature of distal parts of the arms was measured during the local cold test and throughout re-warming period. Additionally blood pressure and heart rate were monitored and cold tolerance was estimated. The dynamics of hand skin temperature was shown to correlate with the susceptibility to cold. High susceptibility to cold characterized by the aggravated cold-induced vasoconstriction appeared as non-re-warming by the end of 15 minutes examination. In contrast to temperature measurements the monitoring of blood pressure and heart rate after the local cooling did not show significant dynamics. The results of thermography corresponded well with cardiovascular reactivity. So, the diagnostics of the aggravated cold-induced vasoconstriction can be used for detection of premorbid state of the organism in addition to conventional methods. Thus, skin vasomotor reactions were found to be closely related to the autonomic regulation both under physiological and pathological conditions. It might be promising for individual self-diagnostics of the health problems and also for monitoring of the physiological state in humans either under extreme conditions or sport training.**

I. Introduction

The vascular system of the skin of the human body has regional heterogeneity in the structure and functional organization that forms complex interwoven “body carpet”. The skin blood flow is known to change in a wide range mostly according to the thermal state of the organism [1], [2], [3]. Thus, skin blood flow increases during heat elimination and it significantly decreases during heat conservation. Vessels of the most distal parts of the body, such as fingers, toes and tips of the nose and ears, are supplied by unique structural and functional features that prevent their from total blood flow abruption in order to maintain nutritional perfusion [3]. The control of the thermoregulatory vasomotor reactions includes manifold factors such as neuro-humoral and endothelial ones that interplay with other homeostatic mechanisms. Whole-body cooling during exposure to cold environment increases sympathetic adrenergic outflow to skin vessels that induces the vasoconstriction effect [1], [3]. Local cooling of the skin directly amplifies sympathetically mediated vasoconstriction because of up-regulation of α_2-adrenoreceptor expression [1], [3].

The exaggerated vasoconstriction of the cutaneous vascular system in response to cold exposure is manifested as Raynaud phenomenon [3]. It appears as a result of impaired vasomotor control and utilizes some features of premorbid state of the organism. The mechanisms underlying the Raynaud phenomenon are also common for other different signs of cold intolerance (for example, cold urticarial, cold asthma, pain) that is characteristic of impaired adaptation of the organism or/and early stage of illness [4], [5]. Cold-related symptoms are considered to have both local effect that results in tissue dysfunction and reflection effect on different systems possibly causing cardiac arrhythmias, pain, dyspnea and other discomfort [4], [5], [6]. All of above-mentioned features could be regarded as signs of a premorbid state or early stage of illness.

In the previous studies the increased incidence of Raynaud phenomenon in persons during acclimatization to cold climate, as well as in patients with chronic diseases has been shown [5]. Further more, changes of the autonomic regulation that are common for reduced adaptability of the organism have been documented in persons with exaggerated cold-induced vasoconstriction [7]. The similar sings of cold intolerance followed by autonomic dysregulation has been observed in patients recovered after stroke [8], [9].

Both the sympathetically mediated autonomic regulation and the sensitivity of vascular structures to catecholamines have great effect on thermoregulatory vasomotor function [3]. The same mechanisms are involved into, so-called, stress-induced regulation that arises in the organism exposed to severe hazardous environment or non-healthy lifestyle. As far as the chronic stress is known to increase the cardiovascular morbidity and mortality, the early diagnostic of disadaptation and premorbid state of the organism is of great importance. In the nordic regions the prevention of cardiovascular morbidity becomes even more essential due to interaction of environmental and social stressful conditions [6], [10], [11], [12], and mobile health care services based on individual self-control approaches significantly contribute to public health improvement.

Thus, the quantitative estimation of skin temperature related to cold-induced vasomotor reactions has a potential diagnostic value for health assessment and it is usable in personalized health care services. The aim of this study was to evaluate the dynamics of hand skin temperature after the local cooling in persons with different susceptibility to cold.

II. SUBJECTS AND METHODS

Seventy four healthy young people (32 men, 42 women, age range 17-23 years, mean age 19,2±1,2 years) volunteered to participate in this study on their informed consent. All the participants were involved from the students of Petrozavodsk State University. They were divided in three groups according to their tolerance to cold. The first group (I) included persons with high susceptibility to cold (n=30), the second group (II) consisted of persons with normal susceptibility to cold (a reference group, n=32), and the third group (III) – persons with high tolerance to cold (winter swimmers, n=12). Subjects from groups I and II had ordinary physical activity whereas subjects from group III were self-motivated to take winter swimming for 1-2 years. So, subjects of group III were physically trained and adapted to cold by short-term repetitive cold water immersions. By the time of examination winter swimmers had weekly total body immersions in the ice water lasting 45-60 sec in average. As such, they were considered to have high cold tolerance.

All measurements were performed under laboratory conditions (the room air temperature 22-24°C, the humidity 50-60%, air flow velocity less than 0,1 m/s) after subjects wearing light comfortable clothing stood for 30 minutes in order to stabilize the body temperature.

All the participants had normal nutritional state; anthropometric parameters of different groups of subjects were similar. These are presented in Table I.

Cold-induced vasoconstriction was studied before and after the local cold test caused by dipping of the hand into cold water mixed with melting ice (mean water temperature 3,1±1,7 °C) for 3 minutes long. This method is well known as a convenient procedure for diagnostics of autonomic regulation and cardiovascular reactivity [13].

In group I and II the skin temperature was measured with the help of digital medical thermometer DT 633 (A&D Company LTd, Japan), temperature measurements in group III has been done by means of the infrared thermograph device «Testo 882» (Testo, Germany). The last technique of temperature detection has proven to be promising as a research tool for identifying surface skin temperature in different states of the organism [14], [15].

The temperature was acquired in both arms at rest conditions, right after the cooling and then every 3 minutes within further 15 minutes of the re-warming period. The places of the skin temperature registration are presented on Fig. 1. The thermometry was performed on the symmetrical parts of both arms in the middle of the back of the hand (1), in the middle of the forearm (2) and on the external surface of elbow (3).

The systolic and diastolic arterial blood pressure (SAD and DAD, respectively) and heart rate (HR) were registered using digital blood pressure monitor UA-705 (A&D Company LTd, Japan). Hemodynamic parameters were controlled at rest conditions, right after the cooling and then in 15 minutes throughout the re-warming period.

The tolerance to cold was estimated with the help of questionnaire on cold-related complaints, including Raynaud phenomenon, cold urticaria, cold asthma, pains or other discomfort signs that appear during cold exposure [4], [5], [6]. The diagnostics of Raynaud phenomenon as the most typical appearance of cold intolerance was of great importance. It was recognized as exaggerated cold-induced vasoconstriction by symmetrical episodes of vasospasms that were usually followed by typical color changers (white fingers), ischemic pain and/or edema [3]. Cold perception was evaluated on the base of a digital-analogous scale from 1 to 6 points that ranged from “high susceptibility” to “high tolerance to cold”.

The data obtained in this study were processed by statistical analysis using ANOVA and non-parametric criteria. The software «Statistica for Windows» 6.0. was used.

TABLE I. ANTHROPOMETRIC CHARACTERISTICS OF PARTICIPANTS (MEAN±SD)

Gender, number	Body mass, kg	Length, sm	Body mass index
Men, n=32	72,5±13,5	177,3±7,0	22,9±3,3
Women, n=42	60,1±9,6	166,8±6,1	21,6±3,1

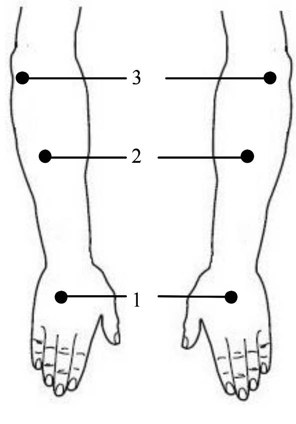

Fig. 1. The places of skin temperature measurements

III. RESULTS AND DISCUSSION

A. *Skin temperature measurements*

The main study was performed on the group of young people with ordinary lifestyle and moderate physical activity (group I and II). At rest conditions the hand skin temperature in the investigated groups was 30,4±0,5°C, on the middle of the forearm – 31,4±0,4°C, around elbow – 31,8±0,3°C in average. After the local cooling, hand skin temperature of the cooled arm decreased to 26,7±0,9°C in average. At the end of examination on the 15^{th} minute it was 28,6±0,5°C in average.

In women the decrease of hand skin temperature right after cooling was greater than in men, it decreased by 23% of the rest parameters and 16%, respectively ($p<0,05$). By the end of re-warming period the hand skin temperature in women was still lower than in men. So, women were suggested to be more predisposed to aggravated cold-induced vasoconstriction as well as to develop the Raynaud phenomenon [3].

According to temperature values by the end of 15 minutes after the local cold test, the general group was divided on two different ones. Persons who had hand skin temperature as much as 27°C were included into group I (n=30, 8 men, 22 women), others were included into group II (n=32, 16 men, 16 women). The skin temperature around elbow did not show any significant changes on neither cooling nor contralateral arm through the period of examination, while in the distal parts of arms (on the hand and forearm) the dynamics of the skin temperature was different in the investigated groups I and II. The results of temperature measurements are presented on Fig. 2 and Tables II and III.

Group II was characterized by the physiological vasomotor reaction to local cooling that caused temporary inhibition of endothelium-derived vasodilation mechanisms combined with the sympathetically mediated vasoconstriction [1], [3]. The decrease of skin temperature was observed only in the cooled hand. No changes of skin temperature on the forearm as well as on the contralateral arm were noticed (see Fig. 2, Tables II and III). Lowered hand skin temperature persisted only for 6 minutes of examination, after it did not differ from the rest conditions.

Group I demonstrated aggravated cold-induced vasoconstriction (see Fig. 2, Tables II and III). Subjects of group I had lower hand skin temperature at rest conditions, a more decreased temperature after the local cooling and a “non-re-warming” through the following 15 minutes of examination. The lowered temperature was documented not only in the cooled hand but also in the contralateral one and forearms. So, in group I the local cooling induced a spread-out vasoconstriction effect in a form of “gloves” that persisted longer than physiological thermoregulatory vasomotor reaction in group II. This kind of response on local cooling corresponds to mechanisms of Raynaud phenomenon [3]. It is presumably evolved due to high sensitivity of vascular structures to adrenergic mediators, and it has potential diagnostic value as a sign of cardiovascular diseases [3], [4], [5], [6]. In addition, the decreased adaptability in persons with high cold susceptibility has been reported in heart rate variability study where the decrease of time- and frequency domain characteristics of heart rate variability was demonstrated [7].

In our previous study of the thermoregulatory vasomotor reactions in post-stroke patients we have reported on the aggravated cold-induced vasoconstriction in them [8], [9]. The local cold test performed both on paretic and intact hand provoked a spread out cold-induced vasoconstriction in post-stroke patients. The dynamics of the hand skin temperature during the local test is presented on Fig. 3 [9]. The impaired local thermoregulatory response in the investigated group was combined with the peripheral autonomic dysfunction that evidenced the major role of the increased sensitivity of skin vessels to catecholamines in the cold-induced vasospasm [8], [9]. The similar mechanisms supposed to be involved in the Raynaud phenomenon [3]. The pathologically decreased time- and frequency domain characteristics of heart rate variability were found to characterize the impaired cardiovascular reactivity in those patients [8], [9].

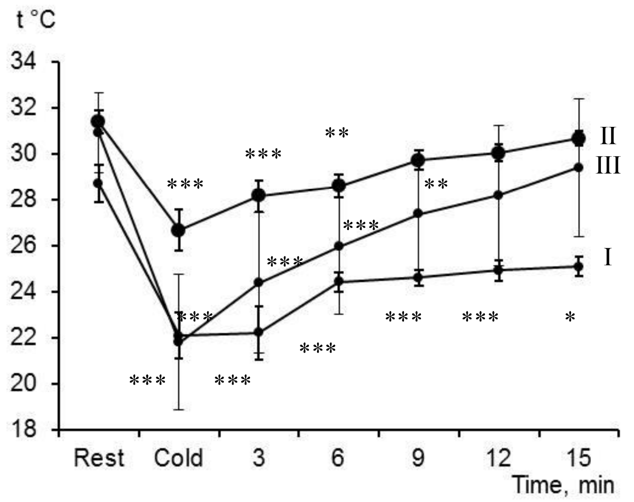

Fig. 2. The dynamic of the skin temperature on the cooled hand in persons with normal cold tolerance (II), high cold susceptibility (I) and high cold tolerance (III).
The significance of differences from the rest conditions * - p<0,05, ** - p<0,01, *** - p<0,001.

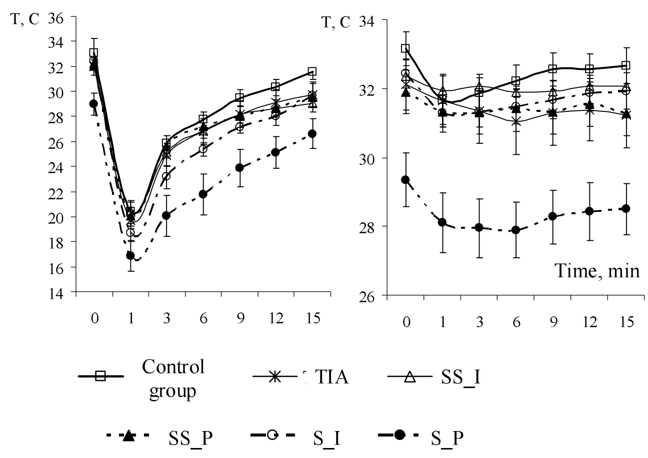

Fig. 3. The skin temperature of cooled (left graph) and contralateral (right graph) hand along with local cold test [9]. TIA – transient ischemic attack, SS – small stroke, S – stroke, I – intact hand, P – paretic hand.

The significance of differences from the rest conditions * - p<0,05.

Temperature measurements in group III showed a more or less physiological cold-induced vasomotor reaction (see Fig. 2, tables II and III). Vasoconstriction induced by local cooling was observed in the cooled hand, while no changes in the forearm as well as in the contralateral arm was noticed (see Fig. 2, Tables II and III). Re-warming by the end of examination was observed in most subjects. Winter swimmers represent a unique small number group of persons affected by short-term repetitive ice water immersions. Most probably, group III has some inter-

TABLE II. THE SKIN TEMPERATURE (° C) ON THE BACK OF THE HANDS THROUGH THE LOCAL COLD TEST IN GROUPS WITH DIFFERENT SUSCEPTIBILITY TO COLD (MEAN±SD)

Time	Cooled arm			Contralateral arm		
	Group I	Group II	Group III	Group I	Group II	Group III
Rest	28,68±0,82 ##	31,37±0,49	31,06±1,67	28,76±0,78 ##	31,09±0,51	30,96±1,68
Cold	22,09±1,00 *** ###	26,66±0,89 ***	20,42±3,09 ***	27,69±0,86 ##	30,57±0,54	31,09±1,55
3'	22,21±1,15 *** ###	28,15±0,68 ***	24,18±2,84 ***	26,54±0,67 * ###	30,31±0,51	31,13±1,61
6'	24,41±0,42 *** ###	28,59±0,50 **	26,23±2,51 ***	28,18±0,69 ###	31,11±0,46	31,28±1,79
9'	24,62±0,34 *** ###	29,70±0,43	27,72±2,60 **	27,65±0,66 ###	31,73±0,36	31,54±1,88
12'	24,92±0,43 *** ###	30,04±0,36	29,03±2,51 *	28,05±0,65 ###	31,84±0,34	31,65±1,86
15'	25,08±0,43 * ###	30,65±0,31	30,17±2,41	28,07±0,66 ###	31,92±0,31	31,72±1,94

The significance of differences from the rest condition * - p<0,05, ** - p<0,01, *** - p<0,001, from the parameter of group II # - p<0,05, ## - p<0,01, ### - p<0,001.

TABLE III. THE SKIN TEMPERATURE (° C) IN THE FOREARMS THROUGH THE LOCAL COLD TEST IN GROUPS WITH DIFFERENT SUSCEPTIBILITY TO COLD (MEAN±SD)

Time	Cooled arm			Contralateral arm		
	Group I	Group II	Group III	Group I	Group II	Group III
Rest	29,83±0,79 #	31,42±0,39	31,17±1,26	30,23±0,80	31,46±0,39	31,48±1,08
Cold	29,01±0,83 #	30,48±0,43	31,21±0,80	29,54±0,83 #	31,29±0,40	31,59±0,67
3'	27,49±0,69 ** ##	30,09±0,49	30,94±1,06	28,23±0,81 * ###	30,88±0,42	31,61±0,73
6'	28,94±0,7	29,90±0,49	30,46±1,60 #	29,74±0,75 #	31,43±0,36	31,46±1,09
9'	28,52±0,66#	30,65±0,27	30,49±1,54	29,54±0,70 #	31,34±0,39	31,41±1,11
12'	28,41±0,62##	30,89±0,24	30,51±1,29 ##	29,57±0,68 ##	31,76±0,28	31,44±1,23
15'	28,49±0,61##	30,92±0,25	30,80±1,21 ##	29,51±0,67 #	31,7±0,28	31,67±1,49

The significance of differences from the rest condition * - p<0,05, ** - p<0,01, from the parameter of group II # - p<0,05, ## - p<0,01, ### - p<0,001.

cold tolerance that explains big dispersion of temperature data measured during the local cold test.

B. Blood pressure and heart rate monitoring

Local cooling is often used tor investigate cardiovascular reactivity [13]. At rest condition SAD and DAD as well as HR were in within limits of normal values in all investigated groups. The results of monitoring of hemodynamic parameters are presented in Table IV. No much change of the controlled parameters was noticed except of increased HR in subjects of group I as they are sensitive to cold persons. As all the participants of the study were living in Karelia for a long time and were climatically adapted, these results were expectable. The decreased cardiovascular response on the local cooling in persons adapted to cold or physically trained has already been reported [7], [16].

Thus, in contrast to temperature measurements the monitoring of blood pressure and HR after the local cooling did not show significant dynamics. Therefore, it is difficult to identify the functional state of the organism according to blood pressure measurements.

C. Cold tolerance estimation

The ability of man to stay in cold environment keeping working or being physically active depends on the physiological state of the organism and on the cold tolerance [4], [5]. The analysis of complaints related to cold exposure revealed that persons from group I usually suffer from cold-induced discomfort.

TABLE IV. THE MONITORING OF HEMODYNAMIC PARAMETERS IN THE INVESTIGATED GROUPS (MEAN±SD)

Parameter	Time	Group I	Group II	Group III
SAD, mm Hg	Rest	108±8	114±11	118±9
	Cold	112±12	123±13	119±14
	15'	108±11	113±11	115±11
DAD, mm Hg	Rest	66±5	69±7	71±9
	Cold	73±6	76±7	74±5
	15'	69±6	68±9	72±5
HR, min^{-1}	Rest	78±8	68±5	67±5
	Cold	73±9 *	67±6	67±5
	15'	70±8 *	65±5	67±4

The significance of differences from group II * - p<0,05

High susceptibility to cold was associated with a number of so-called "cold-related symptoms" [4], [5], [6]. The average number of these in group I was 3-5 signs that corresponds to high susceptibility to cold. This was observed in humans with inadequate cold adaptation or in chronic disease patients, especially those who have cardiovascular and neuromuscular health problems [5], [6]. Subjects of group II and III pointed only 1-2 symptoms or no one.

Raynaud phenomenon was recognized in 16 subjects with the help of questionnaire by the typical pale color transformation of fingers and following pain and/or edema on the base of self-reporting symptoms. The rate of Raynaud phenomenon was found to consist 21% of examined subjects. It is closely corresponds to the rate of Raynaud phenomenon in the population according to the literature data [3], [4]. The most subjects with Raynaud phenomenon (n=11) belonged to group I, they had low skin temperature and other features of aggravated cold-induced vasoconstriction.

According to temperature measurements, Raynaud phenomenon significantly correlated with low hand skin temperature by the end of examination ($p<0,05$). Group II had only 5 subjects with self-reported Raynaud phenomenon, while group III did not have persons with high susceptibility to cold at all. Other frequently mentioned complaints were cold rhinitis, cold paresthesia or numbness, and dyspnea.

The analysis of cold perception revealed association of the number of cold-related symptoms and presence of Raynaud phenomenon with the negative subjective attitude to cold. because of appeared discomfort. Group I had the lowest tolerance to cold. Subjects of this group reported on inability to make any activity in cold environment, and on avoidance of any cold exposure. Group II was characterized by the ordinary physical activity including winter sport and working outdoors; the self-limitation for cold exposures in this subjects was not strict. Group III had no limitations concerning cold environment and it was characterized by high tolerance to cold.

Thus, our study found that physiological state of the organism and thermoregulatory vasomotor reactions have close relation to cold tolerance as an important inherency of the organism. The results of temperature measurements are in a good accordance with the data of self-reported cold tolerance estimation.

IV. Conclusion

This study was aimed to access applicability of hand skin temperature for the evaluation of the individual health. Skin vasomotor reactions are closely related to the autonomic regulation both under physiological and pathological conditions. The results of laboratory temperature measurements are in a good accordance with the subjective estimation of the functional state of the organism in relation to cold exposure. The hand skin temperature correlates well with physiological state of the organism, and it was shown to be a sensitive marker of impaired adaptation. As both the cold-induced reactivity and stress regulation utilize the common pathways, the diagnostics of the aggravated cold-induced vasoconstriction can be used for detection of premorbid state of the organism in addition to traditionally used methods, such as blood pressure and heart rate monitoring. So, it might be also a useful method for individual self-diagnostics of the health problems and also for monitoring of the physiological state in humans under extreme conditions or sport training. It is so technically easy to measure temperature on skin. Combining temperature measurement with mobile medicine services may expand awareness of a human about his state of health. Therefore, thermal measuring could be a perspective and promising solution for health detecting services.

The development of personalized health care services benefits from smart spaces. Elaboration of applications for smartphone detecting the skin hand temperature in relation to the functional rest or different temperature exposures and physical activity can be useful and promising feature in addition to the available mobile medicine services.

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