

BLOOD PRESSURE AND HEART RATE RESPONSES IN MEN EXPOSED TO ARM AND LEG COLD PRESSOR TESTS AND WHOLE-BODY COLD EXPOSURE

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ABSTRACT

Objectives. Comparison of the effects of different types of cold exposure on blood pressure and heart rate.

Study design. Controlled laboratory study.

Methods. Twenty healthy men were exposed to three different types of cold exposure: cold pressor tests for hands and feet, and a 2-h cold air exposure at an ambient temperature of +10 °C.

Results. All types of cold exposure caused a rise in systolic and diastolic blood pressures. Heart rate increased in the foot cold pressor test. In the cold chamber test, heart rate fell, causing a decrease in the rate:pressure product. No statistically significant correlations were found between the blood pressure responses to cold pressor and cold chamber tests. The increased rate:pressure product observed in the cold pressor tests is indicative of an increased oxygen consumption in the heart muscle.

Conclusions. The measured cardiovascular responses indicate that a sudden local exposure to severe cold would be more stressful than a long lasting, milder exposure to cold, even when the latter is applied to the whole body

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Keywords: local cold exposure, whole-body cold exposure, cold pressor test, blood pressure, heart rate

INTRODUCTION

Both systolic and diastolic blood pressures rise in response to cold exposure. This is due to an activation of the sympathetic nervous system and the consequent cutaneous vasoconstriction. The rate by which the blood pressure rises depends on the individual physiological reaction, as well as the type and duration of the cold exposure (cold water or air, whole body or extremities) (1). A common method employed for investigating the responses of the blood pressure and heart rate to local cooling is to immerse one or both hands in ice-water for 1 minute. This allows to identify individuals whose blood pressure responses are greater than normal. In addition to blood pressure increases, increased heart rates are also associated with the so-called cold pressor test (2). Factors affecting the rise in blood pressure include an increased sympathetic nervous activity, vasoconstriction (2), and pain experienced during the cold exposure (3).

A whole-body exposure to moderately cold air has been used to investigate the physiological reactions, and especially adaptation, to cold. During these exposures, the subjects have usually been lightly clothed and have been exposed to air temperatures between +5 °C and +10 °C for periods ranging from 30 to 120 minutes (4-13). The investigated parameters have been systolic and diastolic blood pressures, heart rate, skin temperatures, core temperature, metabolism, shivering, hormonal reactions and thermal sensations. We sought to compare the effects of different types of cold exposure tests, performed on the same subjects, on blood pressure and heart rate. In this study, we exposed 20 lightly clothed volunteers to hand and foot cold pressor tests,

and to a whole-body cold air exposure test lasting for 120 min at an ambient temperature of +10 °C.

METHODS

Twenty healthy male volunteers gave their informed consent to participate in this study. Age, weight, height, body fat (as measured from the skinfolds) and maximal oxygen consumption (VO_{2max}) (means \pm SD) were 25.0 ± 3.2 years, 76.0 ± 1.3 kg, 176.0 ± 5.3 cm, 18.7 ± 5.6 %, 3.0 ± 0.8 ml/min/kg, respectively. Physical training and intake of alcohol were not allowed during the two days preceding the test. The subjects were submitted to a medical examination, in order to confirm that they were healthy. The subjects were familiarized with the experimental procedures before the tests. The experimental protocol was accepted by the Ethics Review Board of the Medical Faculty, University of Oulu.

Experimental protocol

A supper was taken at 5-6 p.m. of the evening preceding the tests. On the test day, the subjects woke up at 7 a.m., had a light breakfast and arrived at the laboratory at 9 a.m. The hand and foot cold pressor tests were carried out on the first test day. For this procedure, the subjects, dressed in shorts, lay on an examination bed and rested for 10 min before the cold exposure. The resting values for blood pressures and heart rate as well as skin temperatures were then measured. During the hand cold pressor test, both hands were immersed up to the wrists in ice-water (temperature +2°C) for 1 min. During the foot cold pressor test,

both feet were immersed up to the ankles in ice-water for 1 min. Blood pressure, heart rate and skin temperature readings were recorded at the end of the immersions. The subjects then rested on the examination bed and the same measurements were performed again at 2, 4 and 8 min after immersion. Blood pressures and heart rates were always registered by the same physician. Skin temperatures of both middle fingers (1 cm distally from nail) and big toes (1 cm distally from nail) were recorded using YSI-thermodes (YSI Yellow Springs, Ohio, USA), which were held in place with adhesive tape.

In the whole-body cold exposure test the subjects, clothed in shorts, were first exposed to an ambient temperature of +28 °C for 30 min, followed by a 120-min exposure to +10 °C (range 9.5-11.2 °C). Air velocity was less than 0.2 m/s and the humidity was 2-4 g/m. The subjects sat on a netted chair during the entire test procedure. Skin temperatures and blood pressures were measured by the same methods employed in the cold pressor tests. Heart rate was recorded continuously by radiotelemetry (MEDINIK), using EKG electrodes (S&W, Healthcare Corporation Brooksville, FL). The cold chamber tests and the cold pressor tests were carried out on different days.

Statistical analyses

For the cold chamber test, comparisons of the blood pressure, heart rate, rate:pressure product and skin temperatures measured at 28°C and 10°C were made using the paired t-test. For the cold pressor tests, the same variables measured at 28 °C (value after 10 min at rest) and immediately after (1 min), and 2, 4 and 8 min after the cold immersion test, were compared using paired t-tests. To control for multiple comparisons, the observed p-values were adjusted using

the Bonferroni method. Pearsons correlation coefficients were calculated to examine the association. The rate of change in the physiological parameters obtained between the beginning and end of the exposure during the cold chamber and pressor tests were calculated. Pearsons correlation analyses were conducted to examine the association between the different types of cold exposure on the change in physiological parameters. Significance was set at $p < 0.05$.

RESULTS

In the hand cold pressor test, the mean increases of the systolic and diastolic blood pressures were 24 mmHg and 25 mmHg ($p < 0.01$), respectively (Table I).

In the foot cold pressor test, the mean increases in systolic and diastolic blood pressures were 25 mmHg ($p < 0.01$) and 23 mmHg ($p < 0.01$), respectively (Table II). At the same time, heart rates increased by an average of 16 beats/min ($p < 0.01$, Table II). Both cold pressor tests caused a marked increase in the rate:pressure product (systolic blood pressure x heart rate) (Tables I and II).

At 28 °C, before the whole-body cold exposure test, the mean resting values of the systolic and diastolic blood pressures were 126 mmHg and 83 mmHg, respectively. After 120 min at +10 °C, the values were increased to 145 and 100 mmHg, respectively (Table III). At the end of the cold exposure, the mean increases in systolic and diastolic blood pressures, relative to the values at 28 °C, were 16 ± 20.5 mmHg and in 16 ± 7.0 mmHg, respectively (Table III). At the same time, the mean decrease in heart rate was 12 ± 8.2 beats/min, thus lowering the rate:pressure product by 668 (Table III).

Table I. Systolic and diastolic blood pressures (mmHg), heart rate (beats/min), rate:pressure product (systolic blood pressure x heart rate) and middle finger skin temperature (°C) during the cold pressor test to hands. Values are mean \pm SD (n = 20). * p < 0.05, **p < 0.01. Comparisons were made relative to the resting values registered after 10 min at 28 °C (the last value before the cold exposure).

Time (min)	Blood pressure (mmHg)		Heart rate (beats/min)	Rate: pressure product	T _{finger} (°C)
	systolic	diastolic			
0	136 \pm 12	84 \pm 10	65 \pm 12	9239 \pm 2555	not measured
5	136 \pm 13	86 \pm 9	63 \pm 11	8590 \pm 2111	30 \pm 4
10	135 \pm 19	85 \pm 10	63 \pm 11	8509 \pm 2067	29 \pm 4
Immersion of hands in ice-water					
11	158 \pm 18**	110 \pm 13**	71 \pm 16	11408 \pm 3417*	15 \pm 3**
12	142 \pm 16	93 \pm 10	59 \pm 11	8501 \pm 2431	17 \pm 2**
14	134 \pm 13	86 \pm 11	61 \pm 10	8227 \pm 1931	19 \pm 4**
18	134 \pm 12	85 \pm 9	59 \pm 9	8018 \pm 1658	20 \pm 5**

Table II. Systolic and diastolic blood pressures (mmHg), heart rate (beats/min), rate:pressure product (systolic blood pressure x heart rate) and big toe skin temperature (°C) during the cold pressor test to feet. See further explanation in table I.

Time (min)	Blood pressure (mmHg)		Heart rate (beats/min)	Rate: pressure product	T _{toe} (°C)
	systolic	diastolic			
0	132 \pm 11	80 \pm 8	58 \pm 6	8546 \pm 1574	not measured
5	131 \pm 10	79 \pm 8	56 \pm 7	7308 \pm 1064	25 \pm 2
10	130 \pm 10	79 \pm 8	58 \pm 8	7531 \pm 1169	24 \pm 2
Immersion of feet in ice-water					
11	156 \pm 19**	102 \pm 16**	73 \pm 17**	11529 \pm 3554**	15 \pm 3**
12	141 \pm 11*	89 \pm 9**	59 \pm 9	8061 \pm 881	17 \pm 2**
14	133 \pm 4	84 \pm 6	56 \pm 9	6393 \pm 2820	17 \pm 1**
18	131 \pm 11	80 \pm 8	56 \pm 8	7269 \pm 927	18 \pm 1**

Table III. Systolic and diastolic blood pressures (mmHg), heart rate (beats/min), rate:pressure product (systolic blood pressure x heart rate), middle finger (T_{finger}) and big toe (T_{toe}) skin temperatures (°C) during the cold chamber test at thermoneutral temperature (+28 °C) and after 120 min at +10 °C. Values are mean \pm SD (n = 20).

	28 °C	After 120 min at 10 °C
Systolic BP (mmHg)	126 \pm 18	145 \pm 23**
Diastolic BP (mmHg)	83 \pm 16	100 \pm 17**
Heart rate (beats/min)	72 \pm 16	59 \pm 22*
Rate:pressure product	9400 \pm 3600	8520 \pm 1480*
T _{finger} (°C)	30 \pm 4	16 \pm 3***
T _{toe} (°C)	28 \pm 3	14 \pm 3***

The variation of the mean blood pressure and heart rate with time during the cold chamber test are presented in Figure 1.

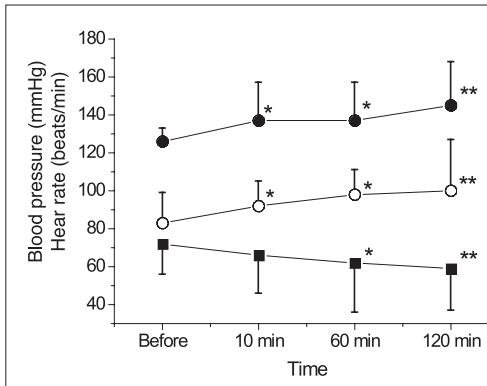


Figure 1. Mean systolic (closed circles) and diastolic (open circles) blood pressures (mmHg) and heart rate (beats/min-closed squares) during the whole-body cold exposure test. Values are means \pm SD ($n = 20$) measured at thermoneutral temperature and after 10, 60 and 120 min in the cold. * $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$.

There were no statistically significant differences between the rates of changes of either the systolic, or the diastolic blood pressures observed in the cold pressor and whole-body cold exposure tests. The mean decreases in big toe skin temperature were 9 ± 2.6 °C in the cold pressor test and 15 ± 3.2 °C in the whole-body cold exposure test. The mean decreases of the skin temperature of the middle finger were 14 ± 3.2 °C in the cold pressor test and 18 ± 2.8 °C in the cold chamber test.

DISCUSSION

Cardiovascular responses of lightly clothed men exposed to cold air have been extensively described previously (4-6, 14, 15), as have the effects of local cold exposure (2, 3, 16-18). In this study, both local and whole-

body cooling tests were carried out on the same individuals. This makes it possible to compare the cardiovascular effects of these different test types. In order to minimize the effects of individual variation, we recruited 20 volunteers for our study.

At the end of the 120-min whole-body cold exposure test at 10 °C, both systolic and the diastolic blood pressures increased by 16 mmHg, relative to the values measured at 28 °C. The increased blood pressure results in a higher work load on the heart, but this is dampened by a reflex mechanism, mediated by baroreceptors, which decreases the heart rate. This decrease in the heart rate occurred both in our study and in some earlier studies (4,6,14), while other studies (5,15) observed no changes in heart rate. The cold, as a stressor, increases sympathetic nervous activity which has a strong effect on the heart rate, possibly leading to these responses. We have also noticed a lowered heart rate response in the case of repeated exposures to an ambient temperature of +10 °C (7). It has been reported that cooling of the facial skin also has an effect on the bradycardia reaction (19). The lowered heart rate response observed in this study led to a diminished rate:pressure product, which is generally accepted as an indicator of the work load of the heart. In both cold pressor tests, a marked rise in systolic and diastolic blood pressures was found at the end of the 1-min cold pressor test. The systolic blood pressure was increased at the end of the hand cold pressor test by an average of 28 mmHg, which is greater than the increase observed in normoreactive subjects during a one-hand cold pressor test (10-20 mmHg) (16). This is probably due to the larger cold exposure area and to a more intensive cold

pain effect in this study, resulting in a more intensive sympathetic nervous activation and vasoconstriction, which would in turn lead to an increased resistance to the blood flow in the peripheral vessels. Plasma endothelin is a bioactive peptide which has a vasoconstrictive effect and, thus, causes blood pressure to increase. Increases in plasma endothelin levels have been described during cold pressor tests (20). However, the plasma endothelin level did not increase in a cold room test similar to that used in this study, (21).

When comparing the rate of changes in blood pressures during the cold pressor and cold chamber tests, we found no statistically significant correlation. Some individuals had a greater increase in their blood pressure at the end of the cold room exposure than in cold pressor tests, whereas other individuals had a greater blood pressure increase in the cold pressor tests. There were no statistically significant differences between the foot and hand cold pressor tests. In the cold pressor and whole-body cold exposure tests, the mechanisms mediating the increasing blood pressure are partly same: increased sympathetic nervous activity and vasoconstriction. This is also seen in the form of an increased catecholamine secretion (8, 17, 22). During the cold pressor tests, however, most of the subjects had sensations of pain, which was not experienced in the whole-body cold exposure test (subjective observation). There are considerable inter-individual differences in how people experience pain, and pain is a strong stimulus for raising the blood pressure. This might partly explain the different individual blood pressure reactions between these types of exposure. Furthermore, the

sites of application of the cold stimuli differ in the cold pressor and whole-body cold exposure tests. The increased rate:pressure product observed in the cold pressor tests is indicative of a higher O_2 consumption in the heart during the cold exposure. Therefore, a sudden local exposure to cold, especially when it also causes pain, seems to be more stressful for the heart in terms of work load, than a longer, mild cold exposure, even when the latter is applied to the whole body. People suffering from heart disease should therefore take particular care to avoid this type of cold exposure. Further studies are needed to qualify the role of cold-induced pain on blood pressure responses.

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