

Thermal, Cardiac and Adrenergic Responses to Repeated Local Cooling

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Summary

The aim of this study was to ascertain whether repeated local cooling induces the same or different adaptational responses as repeated whole body cooling. Repeated cooling of the legs (immersion into 12 °C water up to the knees for 30 min, 20 times during 4 weeks = local cold adaptation – LCA) attenuated the initial increase in heart rate and blood pressure currently observed in control subjects immersed in cold water up to the knees. After LCA the initial skin temperature decrease tended to be lower, indicating reduced vasoconstriction. Heart rate and systolic blood pressure appeared to be generally lower during rest and during the time course of cooling in LCA humans, when compared to controls. All these changes seem to indicate attenuation of the sympathetic tone. In contrast, the sustained skin temperature in different areas of the body (finger, palm, forearm, thigh, chest) appeared to be generally lower in LCA subjects than in controls (except for temperatures on the forehead). Plasma levels of catecholamines (measured 20 and 40 min after the onset of cooling) were also not influenced by local cold adaptation. Locally cold adapted subjects, when exposed to whole body cold water immersion test, showed no change in the threshold temperature for induction of cold thermogenesis. This indicates that the hypothermic type of cold adaptation, typically occurring after systemic cold adaptation, does not appear after local cold adaptation of the intensity used. It is concluded that in humans the cold adaptation due to repeated local cooling of legs induces different physiological changes than systemic cold adaptation.

Key words

Local cold adaptation • Cardiovascular and metabolic responses • Man

Introduction

Our previous studies have shown that in humans the head out, hands out, cold water immersion (14 °C) (whole body cold test – WBCT) lowered average skin

and central body temperatures and increased metabolic rate (due to shivering and non-shivering thermogenesis), systolic blood pressure, heart rate and production of noradrenaline (Janský *et al.* 1996a,b, Vybíral *et al.* 2000). These data indicate a strong and sustained activation of

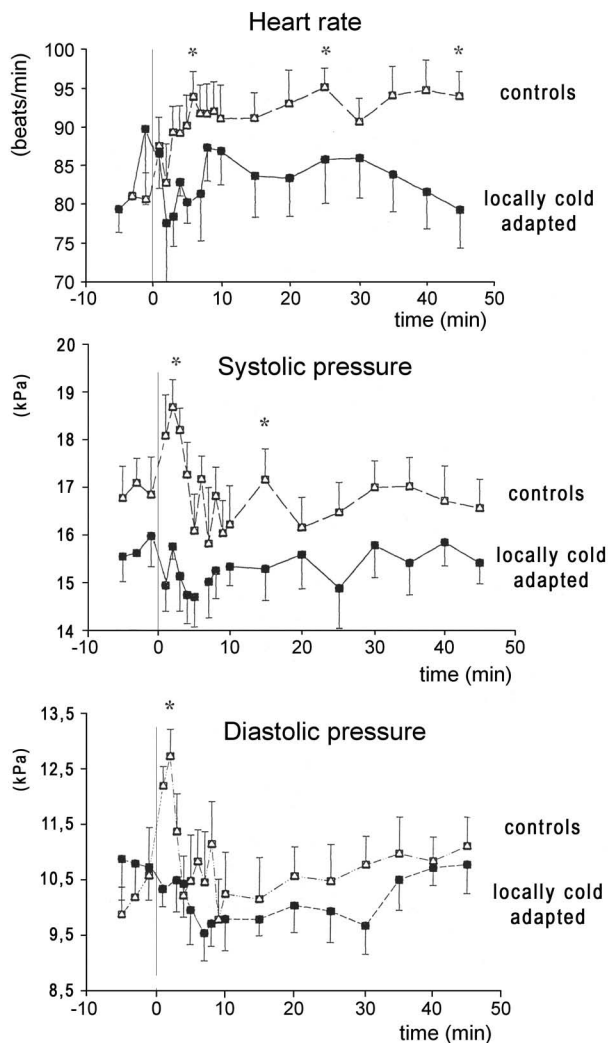


Fig. 1. Heart rate, mean systolic and diastolic blood pressures of control (open symbols) and locally cold-adapted (full symbols) human subjects during peripheral cooling of lower legs. (\pm S.D.). Asterisks denote significant differences ($p < 0.05$). Cooling starts at time zero.

the sympathetic nervous system during systemic cooling.

Repeated whole body cold water immersions (systemic cold adaptation – SCA) in the laboratory did not influence heart rate and blood pressure, but lowered average skin temperature (Janský *et al.* 1996a,b). In winter swimmers, adapted to long-term outdoor exposures to cold water throughout the year, a potentiated thermogenic effect of adrenaline (metabolic adaptation) and an increased efficiency of vasoconstriction (insulative adaptation) were observed (Lesná *et al.* 1999). Lowered heart rate was also found in winter swimmers during cold water immersion (Vybiral *et al.* 2000), although no change in plasma concentration of noradrenaline was observed after SCA. Additionally, it was found that SCA subjects show a lowered temperature threshold for the induction of cold thermogenesis

(hypothermic adaptation) (Janský *et al.* 1996a, Vybiral *et al.* 2000). Thus, metabolic, hypothermic and insulative types of adaptation can appear in SCA humans (Janský 1998, Janský *et al.* 2002).

In this study an attempt was made to ascertain whether or not repeated local peripheral cooling of lower legs (local cold adaptation – LCA) can induce habituation and thermoregulatory and cardiovascular responses similar to those observed after repeated whole body cooling (SCA). To our knowledge the data on this topic are sparse. Savourey *et al.* (1996) studied the relationship between local cooling and general cold adaptation symptoms. In his review on cold-induced vasodilatation Daanen (2003) also discussed local versus total body acclimatization. LeBlanc (1975) summarizing data on immersion of hands concluded that locally cold-adapted subjects (Eskimos, Gaspé fishermen), when compared to controls, show a lowered increase in the heart rate and blood pressure and higher skin temperatures on fingers immediately after immersion of a hand into cold water. He concluded that not only local cold adaptation but also ethnicity and selection may also play a role.

Methods

In our study cardiovascular responses of human subjects were continuously monitored before and after immersion into cold water up to the knees for 45 min. Data after the first immersion and after repeated immersions were compared to show the effect of local cold adaptation.

Six male subjects (21 ± 1 years, 67 ± 8 kg, 182 ± 1 cm) wearing trunks were used for the experiments, performed in morning hours of October. Control subjects (prior to local cold adaptation) were considered to be warm adapted, because they were not exposed to cold during the summer season. Prior to immersion they rested lying in thermo-neutral conditions under a blanket. Then, after 15 min of adaptation to the vertical position, standing subjects were immersed up to the knees into 12°C water for 45 min. Air temperature during the experiment was $29.9 \pm 0.4^\circ\text{C}$ (relative humidity $46.8 \pm 1.3\%$, air velocity 0.078 ± 0.01 m/s). During the time course of the experiment changes in skin temperatures (finger, palm, forearm, thigh, chest, forehead), the heart rate and blood pressure were measured. Skin temperatures were monitored by thermosensors (Analog Devices, U.S.A.) using a computerized data acquisition system. Thermosensors

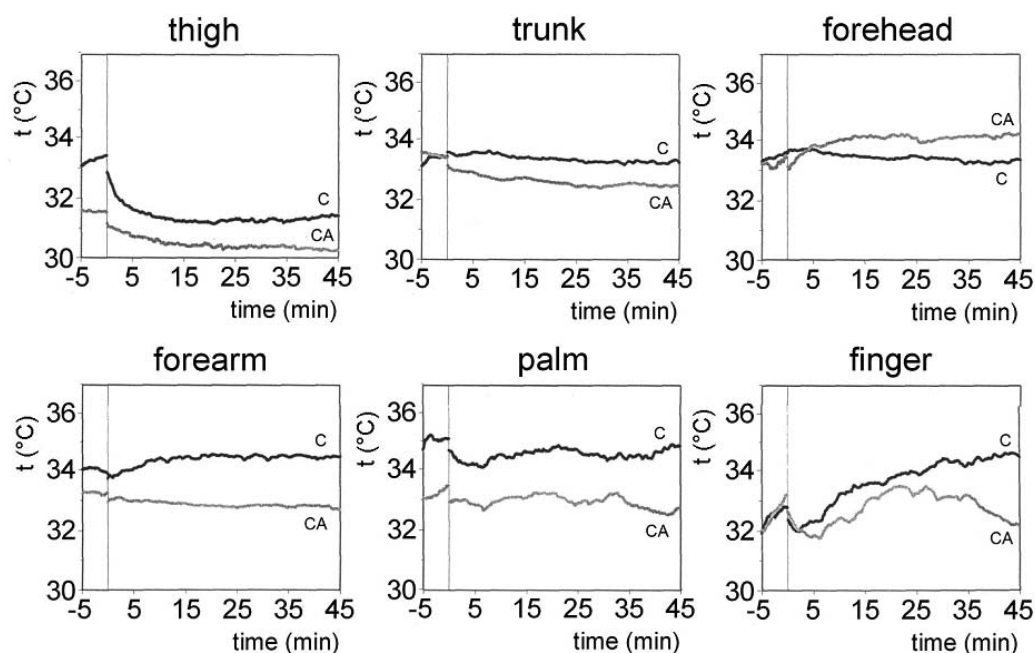


Fig. 2. Changes in average skin temperatures in different areas of the body during peripheral cooling of lower legs in control (dark lines) and locally cold adapted (light lines) human subjects. Cooling starts at time zero. C = controls, CA = locally cold-adapted. Measured by thermosensors.

were attached to the skin with tape. The heart rate, mean systolic and diastolic blood pressures were measured by the oscillometric blood pressure instrument Omron R3 (Germany).

To measure the temperature in selected skin areas (neck, trunk, arm, thigh) a thermovision camera AGA 570 was used (Agema Infrared System AB, Danderyd, Sweden). Value for reflectivity of the skin was 0.98 (for details see Janský *et al.* 2003).

Venous blood samples were taken prior to, 20 min and 40 min after the start of cooling and plasma catecholamine concentrations were measured using radioenzymatic kits (Catechola) by the RIA method (Immunotech, UVVR Prague, Czech Republic). Data obtained by the above mentioned methods served as control data and were compared with those obtained after cold adaptation. Control data were presented *in extenso* in our earlier publication (Janský *et al.* 2003).

Local adaptation to cold (LCA) was induced by immersing subjects of the same group ($n=6$) up to the knees into 12 °C water for 30 min, 5 days a week, for a period of 4 weeks. Total time spent in the cold water during the whole adaptational period was about 10 h. At the end of the adaptational procedure similar parameters were measured during cold immersion of lower legs as in control subjects prior to local cold adaptation.

In order to induce greater stimulation of

thermoregulatory responses, in a separate experiment controls and locally cold adapted subjects were immersed up to the armpit into 14 °C water for 45 min (whole body cold test – WBCT). Identical subjects as during local cooling were used for the experiments. The WBCT was performed one day before the first test (controls) and one day after local cold adaptation. Rectal temperature, tympanic temperature, and metabolic rate (oxygen consumption) were monitored during the WBCT. The metabolic rate was measured using a computerized paramagnetic oxygen analyzer (Dvořák, Czech Republic) at 1-min intervals.

Data are presented as means \pm SD. Statistical significance of data was estimated by two-way ANOVA and Student's paired *t*-test set at $p<0.05$ level.

Experiments were approved by the Ethics Committee at the Priesnitz Spa. Subjects gave informed consent with the experiments.

Results

In the controls, immersion of lower legs into the cold water induced a sustained increase in heart rate, while the systolic and diastolic blood pressure increased only temporarily within the first 8 min of the experiment. In locally cold-adapted subjects of the same group, heart rate and blood pressure values appeared to be generally

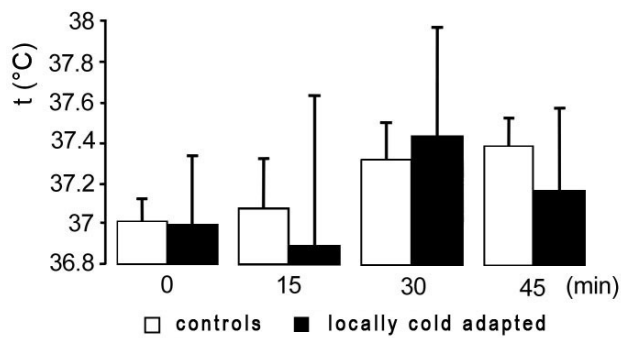


Fig. 3. Tympanic temperatures during peripheral cooling of lower legs (at time 0, 15, 30, 45 min after onset of cooling) in control (open columns) and locally cold-adapted (full columns) human subjects.

lower than in the controls (statistically significant at the 5th, 25th and 45th min of cold exposure) and the initial increase in blood pressure did not manifest (Fig. 1).

Skin temperature on cooled areas of legs decreased rapidly to reach the lowest temperature within 5 min (not shown here). Skin temperatures on non-cooled areas of the body declined slightly within the first 5 min and then showed distinct cycling (for details see Janský *et al.* 2003). Average skin temperatures on non-cooled areas of the body, either decreased (thigh), or remained unchanged (trunk, forehead), or, after the initial decrease, even increased (forearm, palm, finger) during local cooling (Fig. 2). Tympanic temperatures tended to increase (Fig. 3).

In LCA subjects, the average skin temperatures were found to be generally lower than those in the controls (except for temperatures on the forehead) (Fig. 2) and the initial decrease in skin temperatures, indicating cold induced vasoconstriction, appeared to be less prominent (Fig. 4). In several subjects the coinduced vasodilatation (CIVD) patterns in fingers showed greater fluctuations (Fig. 5). On the other hand, tympanic temperatures (Fig. 3) and blood levels of catecholamines (measured 20 and 40 min after the start of cooling) (Fig. 6) were neither influenced by local cooling, nor by LCA.

Locally cold-adapted subjects, when exposed to a head out cold water immersion, showed no significant changes in rectal and tympanic temperatures and no change in heat production compared to controls. When plotting data on metabolic rate against rectal temperature at given time intervals during the experiment, no changes in threshold temperature for induction of cold thermogenesis and in the thermosensitivity of the body temperature control were encountered (Fig. 7).

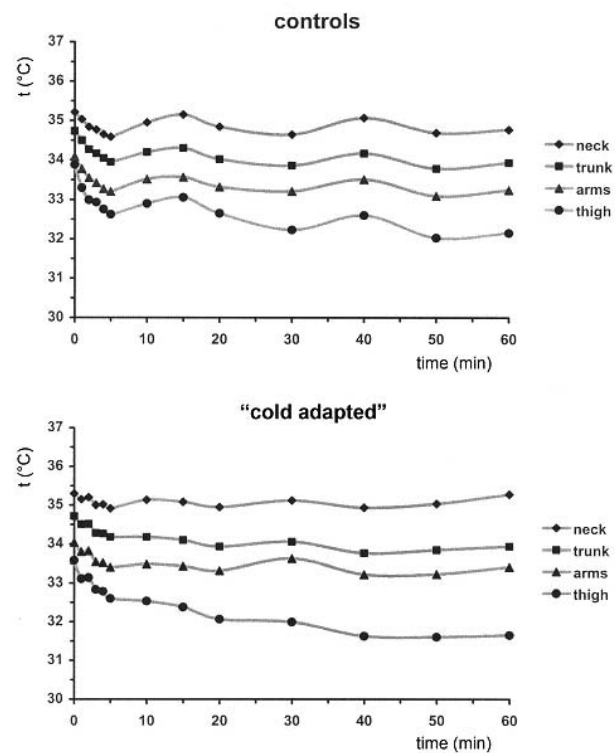


Fig. 4. Changes in average skin temperatures in different body areas during peripheral cooling of lower legs in controls (above) and locally cold-adapted (below) human subjects. Cooling starts at time zero. Measured by thermovision.

Discussion

In agreement with the data obtained by LeBlanc *et al.* (1960), LeBlanc (1975), and Savourey *et al.* (1996), our data show that the attenuation of „alarm reaction“, revealing as a smaller increase in heart rate and blood pressure immediately after cold immersion, develops after repeated cooling of lower legs. Thus, habituation of regulatory functions appears to be the most apparent phenomenon occurring after local cold adaptation.

Furthermore, our findings that skin temperatures of non-immersed parts of the body during local cooling of lower legs are lower in LCA subjects, while the tympanic temperature increases, seem to indicate that repeated cold water immersions of legs induce greater peripheral vasoconstriction and subsequent redistribution of the blood, resulting in warming of the body core and in attenuation of heat loss from non-cooled peripheral areas of the body. Our results are to a certain extent comparable to those published by Savourey *et al.* (1996), who also observed increased tympanic temperature during the cold foot test (CFT). In contrast to our results, Savourey *et al.* (1996) found a higher average skin temperature after LCA. Older data in the literature also indicate that

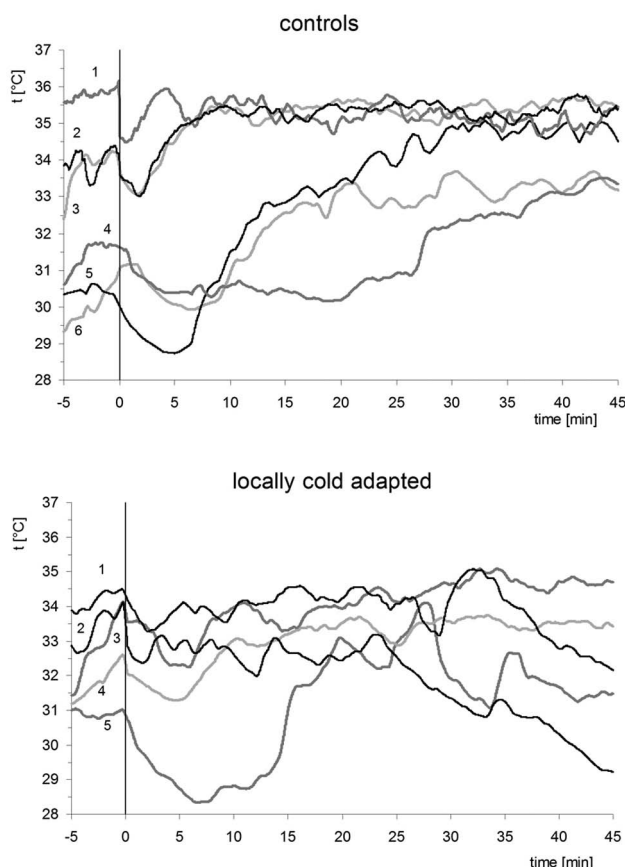


Fig. 5. Average skin temperatures in selected areas of the body during peripheral cooling of lower legs in controls (above) and locally cold-adapted human subjects (below). Cooling starts at time zero. Measured by thermovision. Numbers denote individual subjects.

repeated cold exposure of a hand or foot, without general body exposure to cold, can increase blood flow in cold exposed extremities. Higher skin temperature on hands and smaller increase in systolic and diastolic pressure during cooling of hands were observed in Gaspé fishermen (LeBlanc *et al.* 1960), Eskimos (LeBlanc 1975), Korean Ama (Paik *et al.* 1972) and Japanese Ainu (Itoh *et al.* 1970). These data are not fully comparable to our results because in most cases the above mentioned authors monitored skin temperatures from fingers of hands immersed into the cold water, while our data show changes in skin temperatures of non-immersed parts of the body after cooling of lower legs.

Our data indicate changes in CIVD pattern in fingers after local cold adaptation (see Fig. 5). Data in the literature suggest that the more effective CIVD may be responsible for the increased blood flow in extremities after local cold adaptation (e.g. Nelms and Soper 1962). Redistribution of blood flow between superficial and deeper tissues could also be involved in this phenomenon (Leftheriotis *et al.* 1990).

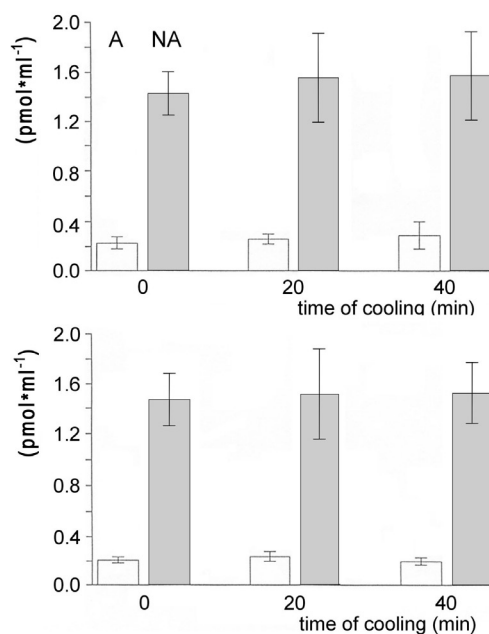


Fig. 6. Plasma levels of adrenaline (open columns) and noradrenaline (grey columns) during peripheral cooling of lower legs (at time 0, 20, 40 min after the start of cooling) in control (above) and locally cold-adapted (below) human subjects. (mean \pm S.D.)

Our measurements showing that the initial increases in heart rate and blood pressure occurring *immediately after cold exposure* are less pronounced in LCA subjects (similar results were obtained by other authors - see above), as well as the finding that the skin temperature decreases less, indicate that the initial sympathetically mediated reactions seem to be attenuated. In contrast to that, lower skin temperatures *during the cold test* seem to suggest that an increased activity of the sympathetic nervous system occurs in LCA subjects during local exposure to cold. The reason for this difference remains to be elucidated.

Only a few studies can be compared to our data on plasma levels of catecholamines. Winer and Carter (1977), LeBlanc *et al.* (1979) and Sendowski *et al.* (1990) studied the effect of local cold immersion (short-term immersion of hands into 0-5 °C water) and demonstrated a striking increase in plasma levels of catecholamines within 2 min of cold exposure. While adrenaline concentration returned to the original level immediately after cooling, the increased noradrenaline level persisted for at least 10 min after cold exposure. Savourey *et al.* (1996), Janský *et al.* (1996a, 1997) and Vybiral *et al.* (2000) studied the effect of previous cold adaptation on plasma catecholamine levels after the whole body cold exposure. While Savourey *et al.* (1996) observed a trend to increased catecholamine production in men exposed to

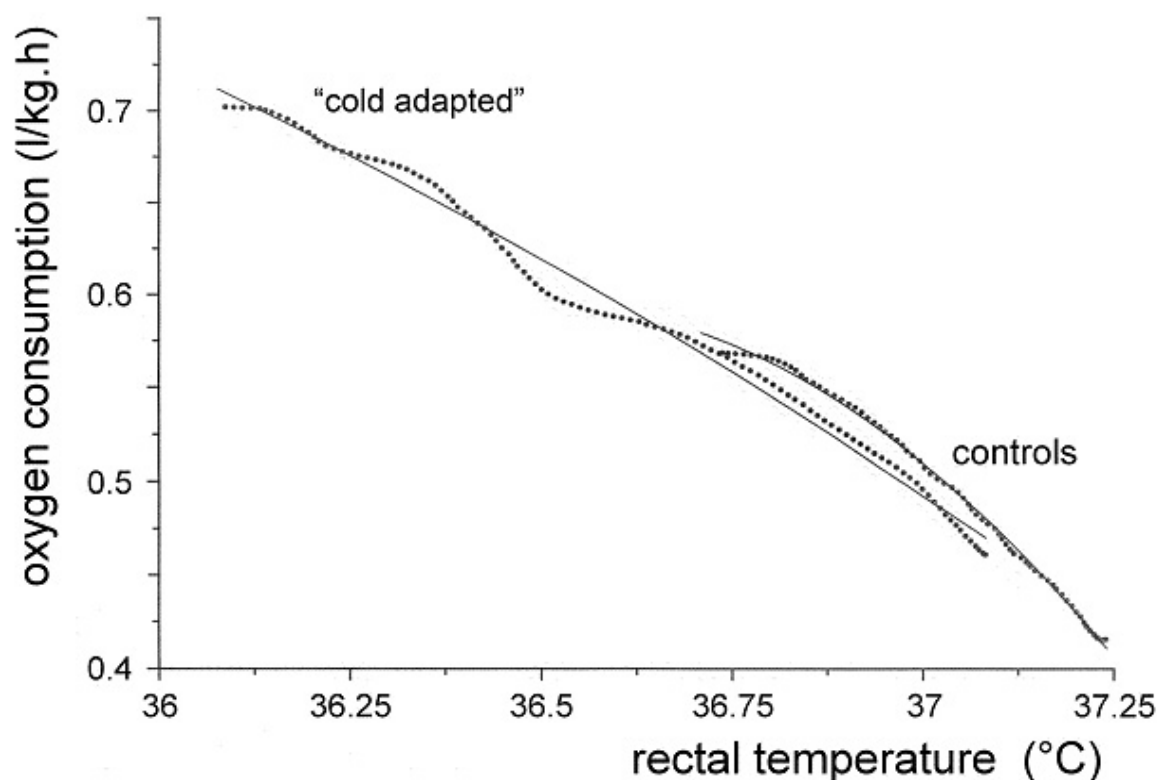


Fig. 7. Relationship between rectal temperature and metabolic rate during whole body cooling (WBCT) in controls and locally cold-adapted human subjects. Points indicate individual values. Lines denote extrapolation of data. Left: values obtained from locally cold adapted subject. Right: values obtained from controls.

cold air after LCA, our previous data showed a nonsignificant trend to a decreased production of adrenaline and noradrenaline (Janský *et al.* 1966b), or no changes in plasma levels of catecholamines in cold adapted subjects after the whole body cold exposure (Janský *et al.* 1996a, 1977, Vybíral *et al.* 2000). This may be due to fact that blood samples were taken after 20 or more minutes after the start of cooling.

Thus, data presented in this paper seem to suggest that repeated local cooling (LCA) induce changes in the sympathetic tone, which may be manifested differently during the course of local cooling. Our data also indicate that physiological responses induced by LCA differ from those occurring after repeated head-out cold water immersions (SCA). Systemic cold adaptation (SCA) in the laboratory not only increases sympathetic tone, which is manifested as increased vasoconstriction, but also lowers the temperature threshold for induction of cold thermogenesis. All these changes lead to energy preservation (Janský *et al.* 1996a,b, Lesná *et al.* 1999, Vybíral *et al.* 2000). At the same time the increased sympathetic tone after SCA induces activation of nonshivering thermogenesis. In contrast to these data, the

locally cold adapted subjects, when exposed to a head out cold water immersion, show nonsignificantly lower tympanic and rectal temperatures and no change in the threshold temperature for induction of cold thermogenesis. Savourey *et al.* (1996) also observed lower tympanic and rectal temperatures in LCA subjects during the whole body cold exposure (air -1°C).

Our previous findings indicate that metabolic, hypothermic and insulative types of adaptation appear in SCA humans (Janský 1998, Janský *et al.* 2002). While the SCA evidently increases chances for survival during a severe cold stress, the biological value of the LCA remains obscure. However, the findings that local cold adaptation induces attenuation of the sympathetic tone may explain the positive curing effect of Priessnitz and Kneipp procedures in patients suffering from hypertension and neurasthenia.

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Reprint requests

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