Chapter 5

Repeated cold exposures do not improve cooling efficiency and exercise performance

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Bogerd N, Cvetek N, Bogerd CP, Rossi RM & Daanen HAM Repeated cold exposures do not improve cooling efficiency and exercise performance

Abstract

Repeated cold exposures have been shown to lead to minor acclimation effects, including hypothermic adaptation. We hypothesized that such adaptation would potentially improve pre-cooling efficiency, reflected in improved subsequent exercise performance. Eight healthy males were exposed to cooling (ice-vest) for ten consecutive days while resting for 60 min in a climatic chamber at a temperature of 20.8 ± 0.6 °C and 47 ± 2% relative humidity. On the 1st, 5th and 10th day, cooling was followed by i) 30 min submaximal exercise with cycling at 65 % $\dot{V}O_{2peak}$ and ii) graded exercise test until exhaustion, performed at a temperature of 30.8 ± 0.3 °C and 72 ± 3 % relative humidity. We did not observe any effect of repetitive cooling on skin blood flow or any changes in intestinal or skin temperatures. Consequently, no changes in body heat storage were observed. Nevertheless, on 10th day the participants felt less cold and felt less thermally uncomfortable ($p < 0.05$) compared to the 1st day. For the graded exercise, time to exhaustion was similar for 1st (14:51 ± 05:25 min), 5th (15:32 ± 05:27 min) and 10th day (15:29 ± 05:21 min). It is concluded that although repeated cooling improves thermal sensation and thermal comfort, it does not have any effect on cooling efficiency and exercise performance. Thus, repeated use of an ice-vest does not lead to advantageous or disadvantageous effects on exercise performance in the heat.

5.1 Introduction

Cooling prior to exercise i.e. pre-cooling is shown to decrease heat strain during the exercise, resulting in increased exercise performance (Duffield, 2008; Marino, 2002). Effects of pre-cooling have been mainly investigated through single cold exposures prior to exercise (Bogerd *et al.,* 2010; Arngrimsson *et al.,* 2004). Nevertheless, in field settings, competitions can span over several days (e.g. cycling), thus pre-cooling may be provided repeatedly. The effects of repeated pre-cooling on cooling efficiency and exercise performance have been hardly investigated.

Thermoregulatory effects of repeated cold exposures have been previously studied in relation to cold adaptation. Cold adaptation was induced with repeated exposure to cold air or water immersion (Leppaluoto *et al.,* 2001; Marino *et al.,* 1998; Bruck *et al.,* 1976). Such cold exposures are reported to result in downward shifts in body core temperature (Marino *et al.,* 1998; Bruck *et al.,* 1976). For instance, Marino *et al.* (1998) observed that rectal temperature decreased to 36.5 °C after the first cold exposure, whereas it reached lower values of 36.2 °C for the second and of 36.1 °C for the third cold exposure. Previously, the improvements in exercise performance were shown to coincide with the degree of pre-cooling (Bogerd *et al.,* 2010). Since, repeated cooling is shown to lower body core temperature to greater degree than one-time cold exposure; it is likely that beneficial effects on subsequent exercise performance are magnified.

Repeated cold exposures are reported to lead to decreased skin vasoconstriction (Leppaluoto *et al.,* 2001; Mathew *et al.,* 1981). Presence of decreased skin vasoconstrictor response has been assumed from increased skin temperatures or from decreased noradrenalin concentrations (Leppaluoto *et al.,* 2001; Mathew *et al.,* 1981). The intensity of vasoconstrictor responses may be assessed using laser-Doppler flowmetery, providing information on skin blood flow. It is suggested that if repeated cold exposure decreases vasoconstrictor responses, an increase in skin blood flow would be observed. Such changes in skin blood flow would improve heat loss to the environment, thereby increasing the efficiency of cooling.

The aim of the present study was to investigate changes in body core and skin temperatures, and skin blood flow before and during exercise after 10 repeated mild cold exposures for one hour a day using an ice-vest. Furthermore, we investigated if these responses have an effect on subsequent exercise performance.

5.2 Methods

5.2.1 Participants

Eight healthy males (height 180 ± 8 cm, body mass 75.4 ± 9.3 kg, body fat percentage 15 ± 3%, age 25 ± 4 years and peak oxygen consumption ($\dot{V}O_{2peak}$) 57.6 ± 5.0 $ml \cdot min^{-1} \cdot kg^{-1}$) volunteered to participate in the study. During the study the participants were asked to maintain their regular diet. They were asked not to consume caffeine or alcohol 24 h before each trial, and to refrain from food 2 h before each trial. However, they were encouraged to drink water or other non-caffeinated/non-alcoholic beverages before the trials. Agreement with these requirements was verified prior to the trials and no violations were reported. The study was approved by Cantonal Ethical Committee of St. Gallen, Switzerland and written consent was obtained from all participants prior to the study.

5.2.2 Experimental design

The study consisted of i) one preliminary and ii) ten consecutive experimental trials. At least 48 h of rest was allowed between the preliminary and the first experimental trial. In the preliminary trial the participant's anthropometrical characteristics and $\dot{V}O_{2peak}$ were determined. In all experimental trials, upon arrival to the laboratory, the participants put on cycling pants, a cycling shirt, socks and shoes, and were exposed to 60 min of cooling. Cooling was provided with an ice-vest (Arctic Heat, Burleigh Heads, Australia) while sitting in a climatic chamber controlled at the temperature of 20.8 ± 0.6 °C and 47 ± 2% relative humidity. Whereas, in the 1st (T1), 5th (T5) and 10th (T10) experimental trial the participants were submitted to cooling only after being first instrumented. Furthermore, after the cooling, the participants entered another climatic chamber controlled at a temperature of 30.8 ± 0.3 °C and 72 ± 3 % relative humidity and performed i) 30 min submaximal cycling exercise and ii) graded exercise test until exhaustion. Specifically, submaximal exercises consisted of 5 min warm-up with cycling at 50% $\dot{V}O_{2peak}$, followed by 25 min cycling at 65% $\dot{V}O_{2peak}$. During the graded exercise test, workload was increased every 30 s for each participant individually (2 - 3 W) in order to reach 100% $\dot{V}O_{2peak}$ within 25 min. All experimental trials were performed at the same time of a day to minimize the influence of circadian rhythm.

5.2.3 Measurements

The anthropometrical characteristics measured were height (Hoechst Mass, Germany), body mass (ID5 Multi range, Mettler Toledo, Greifensee, Switzerland) and skin fold thicknesses. Skin fold thicknesses were measured at four body sites i.e. biceps brachii, triceps brachii, subscapular and suprailiac (Durnin & Womersley, 1974) using a skin caliper (Harpender Skinfold Caliper, Baty, British Indicators, UK). The $\dot{V}O_{2peak}$ was assessed during a graded exercise test on an electrically-braked cycling ergometer (Cyclus 2, RBM GmbH, Leipzig, Germany). Following 3 min cycling at a power output corresponding to 50 W, the power output was subsequently increased by 30 W every 2 min until volitional exhaustion. Expired air was collected breath-by-breath (Oxycon Alpha, Jaeger, Würzburg, Germany) and analysed in 30 s averages through the test to determine oxygen uptake. The highest value obtained was considered as $\dot{V}O_{2peak}$.

In the 1st, 5th and 10th experimental trial intestinal temperature (T_{in}) was monitored via a radio pill (CorTemp^{TM}, HQ Inc., Palmetto, USA) ingested 8 hours before the start of the experimental trials. Such procedure is suggested to allow the pill to reach the intestines and to avoid temperature fluctuations when passing the stomach (Lim *et al.,* 2008). To receive the signal emitted by a pill every 20 s, a receiver (HT150001, CorTemp^{TM}, HQ Inc., Palmetto, USA) was secured on the participant’s waist. Skin temperature thermistors (MSR B10012, Prospective Concepts, Glattbrugg, Switzerland) were attached according to the ISO 9866 standard (2004) on eight body sites (forehead, right scapula, left upper chest, right arm in upper location, left arm in lower location, left hand, right anterior thigh and left calf) using a breathable medical tape (Tegaderm, 3M Health Care, USA). Skin temperature was recorded every 10 s on a data-logger (MSR, Prospective Concepts, Glattbrugg, Switzerland). Heart rate was recorded every 5 s using a heart rate transmitter and the corresponding heart rate monitor (810i, Polar, Kempele, Finland). Skin blood flow was measured prior to and every 15 min during the cooling at the anterior forearm at the middle point between the elbow and the wrist (PF 5010, Perimed, Jarfalla, Sweden). A holder securing the laser-Doppler probe was fixed to the skin using adhesive ring (3M Double-Stick Discs, Health Care Products and Services Division, Canada). Laser-Doppler was calibrated preceding every trial using calibration kit provided by manufacturer (PF 1000 Calibration device, Perimed, Jarfalla, Sweden). Cycling exercise was performed on electrically-braked cycling ergometer (Cyclus 2, RBM GmbH, Leipzig, Germany). Sweating rate was estimated for the submaximal exercise and the graded exercise test via body mass difference (ID5 Multi range, Mettler Toledo, Greifensee, Switzerland) obtained prior to and after submaximal exercise, and after the graded exercise test. Blood lactate concentrations were determined using a hand-held lactate analyzer (Accutrend Lactate, Mannheim, Germany) prior to the start of submaximal exercise, after the warm-up, after the submaximal exercise and after the graded exercise test. Thermal comfort (TC) and thermal perception (TP) were rated according to the ISO 10551 standard (2001) using seven-point scale prior to cooling and at every 15th minute of cooling, prior to and at the end of the submaximal exercise and at the end of the graded exercise test. Rate of perceived exertion (RPE) was assessed using Borg scale (1982) at the end of the warm-up, at the end of the submaximal exercise, and at the end of the graded exercise test.

5.2.4 Calculations

The weighted mean skin temperature ($\overline{T}_{sk}$) was calculated according to ISO 9886 (2004). T_{in} and $\overline{T}_{sk}$ were used to calculate the body temperature according to Webb (1993) as:

$$\overline{T}_b\,(°C) = 0.75 \cdot T_{in} + 0.25 \cdot \overline{T}_{sk} \qquad \text{(Eq. 5.1)}$$

Body heat storage (S) was calculated according to Burton (1935) as:

$$S\,(W \cdot m^{-2}) = \Delta\,\overline{T}_b \cdot m \cdot CE \cdot AD^{-1} \cdot t^{-1} \qquad \text{(Eq. 5.2)}$$

$\Delta\,\overline{T}_b$: the difference in $\overline{T}_b$ between the start and the end of the cooling,

m (kg): participant's body mass,

CE ($kJ \cdot kg^{-1} \cdot °C^{-1}$): heat capacity (Webb, 1993),

AD (m^2): participant's body surface area (DuBois & DuBois, 1916),

t (s): duration of cooling.

5.2.5 Statistics

SPSS 14.0 for Windows (SPSS Inc. Chicago, Illinois, USA) was used for the statistical analysis. The statistical significance level was set at $p<0.05$. Analysis of variance for repeated measures was used to test for within participant differences among the conditions. If a significant difference was observed, a Bonferroni corrected t-test was used for post-hoc comparison. Additionally, a paired t-test was used to test the differences within the same condition. All values are reported as mean ± standard deviation.

5.3 Results

T_{in} measured at the beginning and at the end of cooling, submaximal exercise and graded exercise test on T5 and T10 did not differ significantly ($p>0.05$) from T1. The decrease in T_{in} during cooling amounted to 0.2 ± 0.2 °C ($p=0.06$), 0.1 ± 0.2 °C ($p=0.10$) and 0.1 ± 0.2 °C ($p=0.26$) for T1, T5 and T10, respectively. The increase in T_{in} during submaximal exercise reached 1.0 ± 0.5 °C ($p<0.001$), 0.9 ± 0.3 °C ($p<0.001$) and 0.8 ± 0.3 °C ($p<0.001$) for T1, T5 and T10, respectively. During the graded exercise test, T_{in} additionally increased for 0.5 ± 0.3 °C ($p=0.03$), 0.6 ± 0.3 °C ($p<0.01$) and 0.5 ± 0.4 °C ($p=0.04$) for T1, T5 and T10, respectively. Figure 5.1 shows the results for intestinal temperature. The time scale for the graded exercise test is limited to 5 minutes since all subjects cycled for at least this time interval.

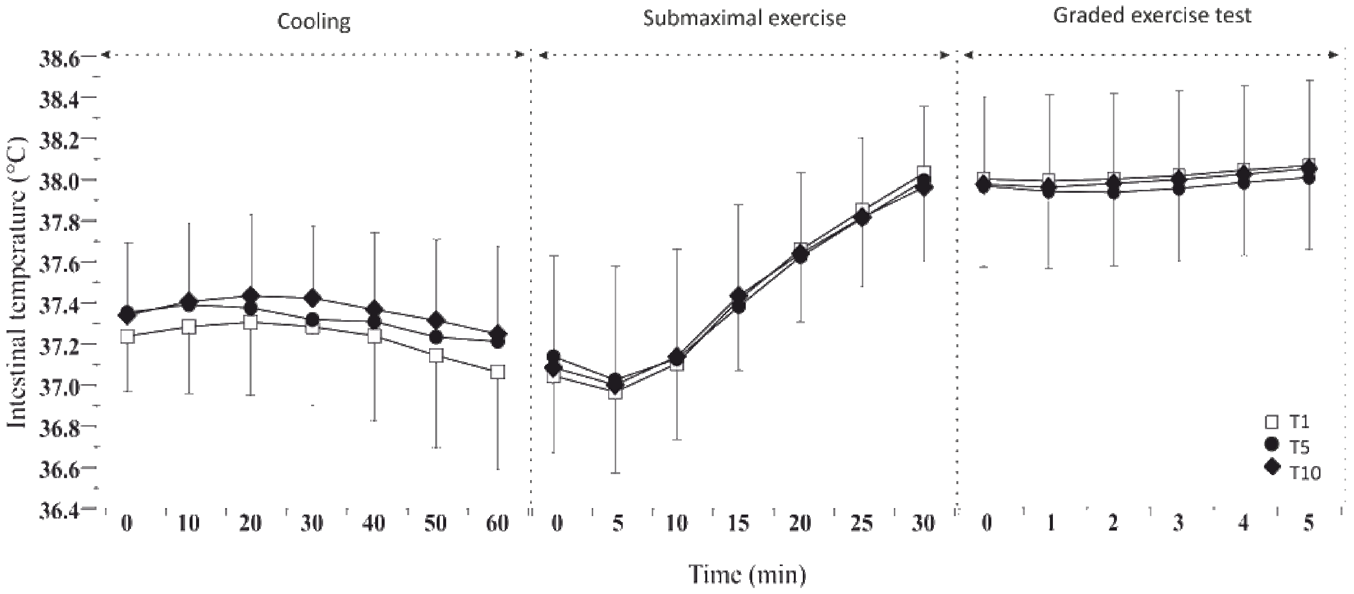

Fig. 5.1 *Intestinal temperature for cooling, submaximal exercise and graded exercise test for the 1st (T1), 5th (T5) and 10th (T10) experimental trial. Values are reported as mean ± standard deviation.*

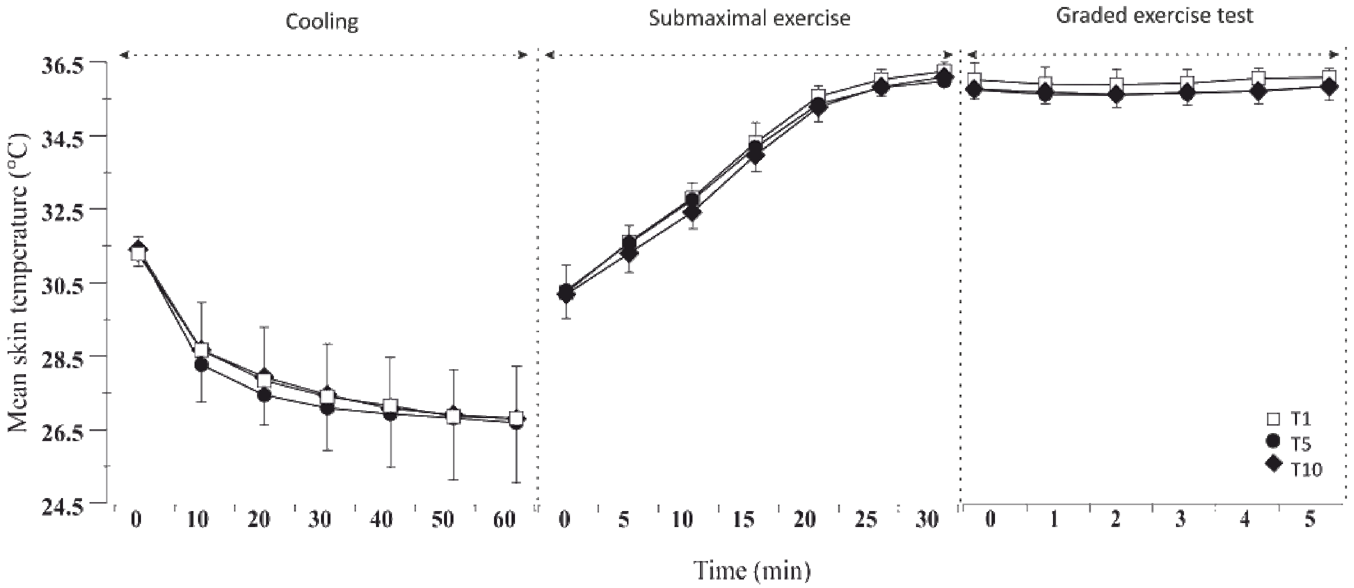

Fig. 5.2 *Mean skin temperature for cooling, submaximal exercise and graded exercise test for the 1st (T1), 5th (T5) and 10th (T10) experimental trial. Values are reported as mean ± standard deviation.*

As shown in Figure 5. 2, $\overline{T}_{sk}$ decreased through cooling ($p<0.001$) for 3.6 ± 1.3 °C, 4.0 ± 1.0 °C and 3.7 ± 1.1 °C in T1, T5 and T10 respectively. No differences were observed in $\overline{T}_{sk}$ at the beginning or at the end of cooling, submaximal exercise and graded exercise test between T1, T5 and T10. During submaximal exercise, $\overline{T}_{sk}$ increased with 5.6 ± 0.7 °C ($p<0.001$), 5.8 ± 0.7 °C ($p<0.001$) and 5.4 ± 0.8 °C ($p<0.001$) for T1, T5 and T10 respectively. During the graded exercise we did not observe an increase during T1 (0.5 ± 1.0 °C; $p=0.19$), whereas for T5 and T10 an increase of 0.9 ± 0.4 °C ($p<0.001$) and of 0.8 ± 0.4 °C ($p=0.001$) was observed, respectively. The time scale for the graded exercise test is limited to 5 minutes since all subjects cycled for at least this time interval. A similar decreases ($p>0.05$) in body heat storage was observed in all cases.

Skin blood flow decreased ($p<0.05$) through the course of cooling on all occasions (Figure 5.3). However, it was not affected ($p>0.05$) by repetitive cold exposure at any time point investigated.

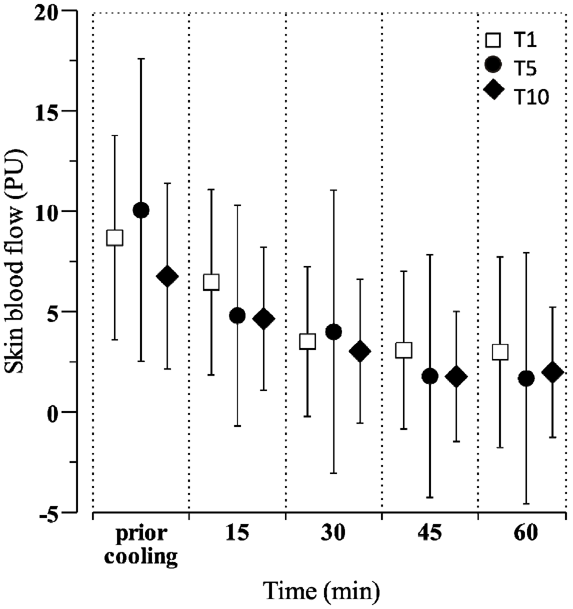

***Figure 5.3** Skin blood flow prior to and during the cooling for 1^{st} (T1), 5^{th} (T5) and 10^{th} (T10) experimental trial. Values are reported as mean ± standard deviation.*

No significant differences ($p>0.05$) in heart rate were observed prior to or post pre-cooling, submaximal exercise and graded exercise test for T1, T5 and T10. Lactate concentrations were also similar on in all cases prior to and post submaximal exercise. A higher (5.1 ± 0.8; $p=0.04$) lactate concentration was observed for T10 compared to T1 (4.3

± 0.6). There were no significant differences ($p<0.05$) in sweat rate during the submaximal exercise among T1 (4.9 ± 1.4 $g \cdot min^{-1} \cdot m^{-2}$), T5 (5.1 ± 1.2 $g \cdot min^{-1} \cdot m^{-2}$) and T10 (5.1 ± 0.8 $g \cdot min^{-1} \cdot m^{-2}$) as well as during the graded exercise test (T1: 12.0 ± 4.3 $g \cdot min^{-1} \cdot m^{-2}$; T5: 9.7 ± 2.7 $g \cdot min^{-1} \cdot m^{-2}$; T10: 9.5 ± 1.7 $g \cdot min^{-1} \cdot m^{-2}$). No significant differences ($p<0.05$) were observed in the time to exhaustion for T1 (14:51 ± 05:25 min), T5 (15:32 ± 05:27 min) and T10 (15:29 ± 05:21 min).

Thermal perception rated prior to cooling was different for T5 (0 ± 0; $p=0.04$) and T10 (0 ± 0; $p=0.02$) compared to T1 (-1 ± 0). Except for the minute 30 and 60, the participants rated the thermal perception as less cold ($p<0.05$) for T10 compared to T1. On the other hand, no differences ($p>0.05$) were observed between T1 and T5 except for the minute 30. No differences were observed in thermal perception during subsequent submaximal exercise and the graded exercise test. Participants felt more thermally comfortable ($p<0.05$) on minute 5 and 45 for T10 compared to T1, whereas no differences were observed between T1 and T5 on any time point investigated. No differences were observed in rating of perceived exertion on any time point investigated.

5.4 Discussion

In present study, one hour of cooling provided on 10 consecutive days, did not enhance a decrease in body core temperature. A similar experimental procedure was applied in previous studies, but unlike the present study, an enhancement of the body core temperature cooling was observed (Leppaluoto *et al.,* 2001; Bruck *et al.,* 1976). Bruck *et al.* (1976) exposed their participants to cold air (between + 5 °C and – 5 °C) for one hour, 4 to 7 times, within 10 - 14 days and observed a decrease in oesophageal temperature. One possible explanation of this discrepancy in the results is that in the study of Bruck *et al.* (1976) body core temperature was monitored in oesophagus. In contrast, in present study the body core temperature was monitored in the intestines. Since it was shown that intestinal and oesophageal temperature do not differ during cold exposure (O'Brien *et al.,* 1998) we, however do not expect the location of body core temperature measurement to have an effect.

Although Bruck *et al.* (1976) provided less exposures it is likely that their cooling intensity was higher. In contrast to the previous studies, where cooling was provided with cold air or water immersion (Leppaluoto *et al.,* 2001; Marino *et al.,*1998; Bruck *et al.,* 1976), in present study cooling was provided with an ice-vest. This was reflected also in relatively low change in body heat storage. Specifically, the change in body heat storage was reported to range from 6 to 13 $kJ \cdot kg^{-1}$ for cold air exposure and for the water immersions from 21 to 26 $kJ \cdot kg^{-1}$ (Leppaluoto *et al.,* 2001). The mean change in body heat storage upon cooling in present study amounted to 3.6 ± 1.2 $kJ \cdot kg^{-1}$. Thus, it is likely that the application of an ice-vest provided a too low cooling intensity to induce thermoregulatory adaptive responses.

Increased skin temperature and blunted noradrenalin concentrations have been considered as indices for decreased vasoconstrictor response (Leppaluoto *et al.,* 2001; Mathew *et al.,* 1981). In present study, changes in skin blood flow and thus possible effects of repeated cold exposures on vasoconstrictor response were investigated using laser-Doppler flowmetery. No effect of repetitive cold exposures on skin blood flow and therefore on vasoconstrictor response was observed. Hence, it is suggested that repetitive cooling failed to increase the exchange of heat between the body core and the environment through acclimation. The unaltered skin blood flow also explains that no differences were observed in intestinal temperature. Specifically, if repetitive cooling would increase the skin blood flow it would be expected that the exchange of heat would increase; thereby decreases in body core temperature would be observed (Kurz *et al.,* 1995). Furthermore, the absence of the change in skin temperature additionally confirms the absence of any effect of repetitive cooling on vasoconstrictor response.

Thermal perception improvements were generally observed prior to and during the last cold exposure compared to the first cold exposure. Thus, repetitive cooling caused habituation of thermal sensations, which is consistent with previous observations (Leppaluoto *et al.,* 2001; Bruck *et al.,* 1976). Leppaluoto *et al.* (2001) observed improvements in thermal sensation in hand, foot and in general thermal sensation (over all body) already after the first repetition of cold exposure and that of the face after the second cold exposure. However, in the present study complete habituation was observed on the 10th cooling day. Such a delay in habituation could be ascribed to the lower cooling intensity as suggested above. This is also supported by the study of Bruck *et al.* (1976), where a lower cooling intensity applied, induced improvements in thermal sensation only after the third day of cold exposure. It is thus concluded that although no evidence of cold habituation was observed for core and skin temperatures, and for skin blood flow, improvements were observed in thermal sensation. Thus, to some, albeit minor extend, the method of repetitive cooling used here did initiate habituation responses.

The absence of decrease in intestinal temperatures was also reflected in unaltered subsequent exercise performance. We, however, observed higher lactate concentrations on the tenth compared to the first day. The explanation for this observation remains unclear, as we did not observe any differences in time to exhaustion between the first and the tenth day.

In summary, in the present study cold habituation reflected in improved thermal sensation was observed. Nevertheless, the repeated application of an ice-vest did not the affect body core or skin temperature. Furthermore, no changes were observed in the skin blood flow. Accordingly, no improvements in subsequent exercise were observed. Thus, it is suggested that, besides decreasing the sensation of cold, the repeated use of an ice-vest does not have neither advantageous nor disadvantageous effects on exercise performance in the heat.

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