

Influence of pre-cooling intensity on vasomotor response and metabolic heat production

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INTRODUCTION

Cooling prior the exercise (pre-cooling) can counteract the negative effects of heat stress on endurance exercise performance (1). Among other methods, pre-cooling is provided by the application of cooling vests. Cooling vests, however, demonstrate some disadvantages. Firstly, they are generally not tailored to the participants, are bulky and heavy. The lack of optimal fit can result in decreased heat transfer efficiency between the body and the cooling garment. Furthermore, bulkiness and heaviness can increase the energy cost, during warming-up with a cooling vest. Secondly, the vests based on ice packs or frozen gels (ice-vests) are reported to cause thermal discomfort (2). To overcome these disadvantages a cooling-shirt was developed. The cooling-shirt compared to an ice-vest provides moderate intensity of pre-cooling.

An ice vest reported to cause skin vasoconstriction (3). It is likely that vasoconstriction reduces cooling efficiency, defined as the ratio between the body core cooling and cooling provided by a cooling garment. In principle, vasoconstriction will increase the skin insulation and prevent the exchange of heat between the body core and the cooling garment. Thus, we suggest that providing a moderate intensity of pre-cooling, such as with the cooling-shirt, could avoid vasoconstriction and promote the cooling efficiency. Furthermore, certain approaches of pre-cooling are reported to initiate thermogenesis (4). Nevertheless, the effect of wearing an ice-vest on thermogenesis has not yet been studied. We assume if pre-cooling with an ice-vest initiates thermogenesis, this effect should be avoided with application of moderate intensity of pre-cooling.

The present study thus aimed at investigating whether moderate intensity of pre-cooling avoids cutaneous vasoconstriction and possible thermogenesis. Specifically, two cooling systems i) a cooling-shirt providing moderate pre-cooling and ii) an ice-vest providing strong pre-cooling are being investigated. Furthermore, we evaluated the effect of these two intensities of pre-cooling on subsequent exercise performance in hot and humid conditions.

METHODS

Eight healthy males participated in the present study (age 27 ± 4 years, height 171.4 ± 4.3 cm, body mass 72.5 ± 5.2 kg and peak oxygen consumption 57.1 ± 4.7 mL·min⁻¹·kg⁻¹). The experimental procedures were verbally explained, and written informed consent was obtained from all participants prior to the study. The Ethical Cantonal Committee of St. Gallen, Switzerland approved the study.

A repeated measures design in which the participant served as his own control was applied. In two of three experimental trials, pre-cooling was applied during the pre-exercise session with i) a prototype cooling-shirt providing moderate pre-cooling (MC) and, ii) an ice-vest providing strong pre-cooling (SC). In the third experimental trial, the participants wore a conventional sport shirt, which served as a control condition (CON). Each experimental trial was divided into two consecutive sessions; a pre-exercise and an exercise session. The pre-exercise session lasted 45 min. Whereas, the exercise session was terminated when one of the following criteria was met i) cycling for 60 min, ii) a rectal temperature exceeding 40.0 °C or, iii) participants voluntarily terminating the exercise.

The cooling power of the cooling-shirt and ice-vest was 19.0 ± 4.5 W/m² and 48.2 ± 9.0 W/m², respectively (5). Specifically, the prototype cooling-shirt was designed in a shape of a vest and was tailored to fit each participant individually.

In all experimental trials, the participants were first asked to insert a rectal probe. After putting on cycling shorts, shoes and socks the skin temperature thermistors were placed on eight body sites according to ISO 9886 standard (6). An additional thermistor was placed on the finger tip of a right middle finger. Skin blood flow was measured with laser-Doppler on the nine locations contra-laterally to the skin temperature sensors. Dependently on the experimental trial, during the pre-exercise session the participants wore a sport shirt or the cooling garment. During the exercise session the participants on all conditions wore the sport shirt. The exercise was performed in climatic chamber (29.3 ± 0.2 °C; $79.7 \pm 3.4\%$) and consisted out of i) 5 min warm-up, during which the subject cycled at a power output corresponding to 50% peak oxygen consumption and ii) subsequent submaximal cycling at 65%.

The rectal temperature (T_{re}) was recorded every second. The rate of increase of T_{re} during the exercise session was determined from each data-set individually through an iterative procedure. Skin temperatures, obtained from eight body locations every second, were used to calculate weighted mean skin temperature (T_{sk}) (6). The T_{re} and T_{sk} were furthermore used to calculate the mean body temperature (T_b) (7). The change in the heat storage (S) during the pre-exercise and exercise sessions was calculated according to Burton (8) as $S(\text{Wm}^{-2}) = \Delta T_b \cdot m \cdot CE \cdot AD^{-1} \cdot t^{-1}$. Where, ΔT_b (°C) represents the difference in T_b between the start and the end of either the pre-exercise or exercise session. Metabolic heat production (M) was calculated for the pre-exercise session according to the ISO8996 (9) as $M(\text{Wm}^{-2}) = EE \cdot VO_2 \cdot AD^{-1}$. Skin blood flow was measured during two periods, at the start and end of the pre-exercise session. The skin blood flow value prior to the pre-exercise session was considered as a baseline and set to 100%, while the later skin blood flow value was expressed as the difference.

For the statistical analysis, SPSS 14.0 for Windows was used, and the statistical significance level was set at $p < 0.05$. All values are reported as averages \pm one standard deviation.

RESULTS

Application of MC and SC showed significant effects on the skin blood flow when compared to CON. However, the effect of MC and SC was in general not significantly different. In more detail, when compared with CON, the application of MC and SC significantly reduced skin blood flow on the back, the chest and the finger. SC in addition decreased the skin blood flow at the shoulder.

A decrease in T_{sk} of 1.49 ± 0.25 °C ($p < 0.001$) was observed over the 45 min in MC and of 2.70 ± 0.65 °C ($p < 0.001$) in SC. As presented in Fig. 1 the decrease in MC and SC differed significantly from each other from the 25th min onward. For CON, no significant decrease in T_{sk} was observed. Furthermore, as presented in Fig. 2 T_{re} decreased significantly ($p < 0.001$) with 0.21 ± 0.06 °C over the 45 min during CON. Conversely, no significant changes for MC (0.05 ± 0.14 °C) or SC (0.14 ± 0.17 °C) were observed through the pre-exercise session.

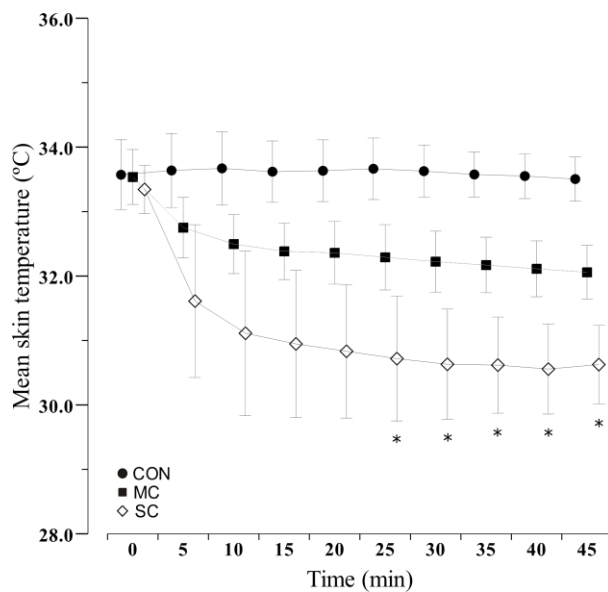


Fig. 1. Weighted mean skin temperature (T_{sk}) for no pre-cooling (CON), moderate pre-cooling (MC), and strong pre-cooling (SC) during the pre-exercise session. An asterisk (*) denotes a significant difference between MC and SC.

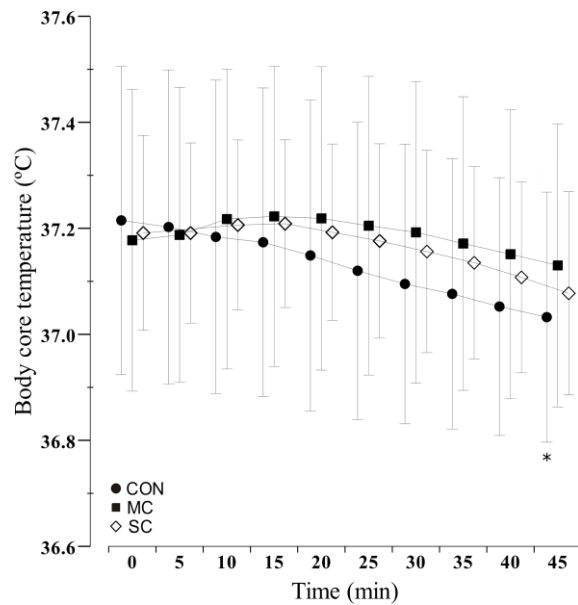


Fig. 2. Rectal temperature (T_{re}) for no pre-cooling (CON), moderate pre-cooling (MC), and strong pre-cooling (SC) during the pre-exercise session. An asterisk (*) denotes a significantly decreased T_{re} between the beginning and the end of the CON trial.

Application of the cooling garments coincided with a decrease in heat storage by 8.42 ± 5.93 $W \cdot m^{-2}$ ($p = 0.006$) in MC and by 25.51 ± 8.48 $W \cdot m^{-2}$ ($p < 0.001$) in SC. The decrease differed significantly between MC and SC. In contrast, heat storage in CON did not change significantly.

Oxygen consumption was during the pre-exercise session with 33 ± 17 $ml \cdot min^{-1}$ ($p = 0.001$) in MC and with 56 ± 13 $ml \cdot min^{-1}$ ($p < 0.001$) in SC significantly higher than in CON. Similarly, carbon dioxide production was in MC significantly higher by 43 ± 11 $ml \cdot min^{-1}$ ($p < 0.001$) and in SC by 61 ± 8 $ml \cdot min^{-1}$ ($p < 0.001$) than in CON. Increased oxygen consumption and carbon dioxide production in MC and SC coincided with higher metabolic heat production when

compared with CON. In particular, this amounted to $5.82 \pm 2.76 \text{ W/m}^2$ ($p=0.056$) higher metabolic heat production in MC and to $6.38 \pm 2.68 \text{ W/m}^2$ ($p=0.009$) in SC.

At the start of exercise session T_{re} did not differ significantly among the conditions. During the session T_{re} increased with $2.17 \pm 0.53 \text{ }^\circ\text{C}$ in CON, with $2.20 \pm 0.64 \text{ }^\circ\text{C}$ in MC and with $2.26 \pm 0.64 \text{ }^\circ\text{C}$ in SC, this increase did not differ significantly among the conditions. However, when taking into account the duration of the exercise, the rate of increase in T_{re} was in SC the lowest among the conditions. T_{re} at the end of the exercise was similar ($p>0.05$) among the conditions.

Only two participants managed to perform 60 min cycling in all conditions. Two other participants managed to complete the full 60 min exercise in SC, but not in CON and MC. With the two latter conditions, their exercise time was $46:26 \pm 04:12 \text{ min}$ and $53:10 \pm 02:10 \text{ min}$, respectively. The remaining four participants cycled for $36:44 \pm 09:20 \text{ min}$, $39:16 \pm 06:02 \text{ min}$ and $41:15 \pm 07:02 \text{ min}$, respectively for CON, MC and SC.

DISCUSSION AND CONCLUSION

Similar decreases in $SkBF$ were observed for MC, compared to SC. This indicates that application of moderate intensity of pre-cooling, similar to strong intensity, caused vasoconstriction. Such response furthermore explains the lack of difference in cooling efficiency between the MC and SC. Namely, heat extracted from the body divided by the cooling power of the cooling-shirt accounted for $44 \pm 28\%$, whereas for the ice-vest $55 \pm 18\%$, which was not significantly different. Hence, application of the cooling-shirt and thereby moderate pre-cooling did not promote the cooling efficiency. It thus appears that the efficiency of the heat exchange between the body core and the cooling garment is not likely to be promoted with decreased cooling intensity, as long as vasoconstriction is provoked.

Significant increase in metabolic energy production of 6% in SC ($6.4 \pm 2.7 \text{ W}\cdot\text{m}^{-2}$) and the tendency towards a significant increase of 4% in MC ($5.8 \pm 2.8 \text{ W}\cdot\text{m}^{-2}$; $p=0.056$), compared to CON was observed. Nevertheless, despite heat production evidently increased during SC, this did not exceed the amount of heat extracted. Specifically, when taking into consideration the heat produced during the pre-exercise session, heat storage decreased by $5.7 \pm 94 \text{ W}\cdot\text{m}^{-2}$ for MC, and by $23.2 \pm 10.9 \text{ W}\cdot\text{m}^{-2}$ for SC compared to CON. Therefore, application of both MC and SC, achieved pre-cooling, as the amount of heat extracted exceeds the amount of heat produced. Moreover, SC represented an advantageous means of pre-cooling, as evident in larger decrease of the body heat content, even though it initiated metabolic heat production.

During the exercise session 6 out of 8 participants, thus excluding the two who cycled 60 min on all occasions, exercised longer in MC and SC than in CON. And in 5 out of these 6 participants, longer exercising times were observed in SC than in MC. In particular, 6% longer exercise time was observed for MC ($p=0.046$) and 11% for SC ($p=0.028$) compared to CON. Furthermore, prolonged time to exhaustion after application of the ice-vest coincided with significant decrease in rate of T_{re} . It therefore appears that our pre-cooling method created a heat sink that persisted through the exercise and affected the rate of T_{re} increase.

In conclusion, the goal of the present study was to investigate whether moderate pre-cooling avoids vasoconstriction and promote cooling efficiency. The results showed that decreasing the intensity of pre-cooling does not avoid vasoconstriction. In fact, moderate pre-cooling similarly as strong pre-cooling cause vasoconstriction, whereas strong pre-cooling in addition initiate metabolic heat production. Nevertheless, the initiated metabolic heat production did not fully counteract the heat extracted by the pre-cooling. Strong pre-cooling compared with no or

moderate pre-cooling created the largest heat sink and decreased the rate of body core temperature increase during the exercise. This resulted in the greatest improvement in time to exhaustion.

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