Chapter 4

The effect of pre-cooling intensity on cooling efficiency and exercise performance

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Abstract

Although pre-cooling is known to enhance exercise performance, the optimal cooling intensity is essentially unknown. We hypothesized that mild cooling opposed to strong cooling circumvents skin vasoconstriction and thermogenesis, and thus improves cooling efficiency reflected in improved time to exhaustion. Eight males undertook three randomized trials, consisting of a pre-cooling and an exercise session. During the pre-cooling, performed in a room of 24.6 ± 0.4 °C and 24 ± 6% relative humidity, participants received either 45 min of mild cooling using an evaporative cooling-shirt or strong cooling using an ice-vest. A no-cooling condition was added as a control. Subsequent cycling exercise was performed at 65% $\text{VO}_{2\text{peak}}$ in a climatic chamber of 29.3 ± 0.2 °C and 80 ± 3% relative humidity. During pre-cooling session, mild and strong cooling opposed to control decreased the skin blood flow. However, no differences were observed between mild and strong cooling. No thermogenesis was observed in any conditions investigated. The reduction of body heat storage was after pre-cooling session two times larger with strong cooling (39.5 ± 8.4 W·m$^{-2}$) opposed to mild cooling (21.2 ± 5.1 W·m$^{-2}$). This resulted in greatest improvement in time to exhaustion for strong cooling. We conclude that the investigated cooling intensities had a similar effect on cooling efficiency (vasoconstriction and thermogenesis) and that the improved performance after strong cooling is attributable to the greater decrease in body heat storage.
4.1 **Introduction**

Heat exposure is known to cause a decrease in endurance exercise performance (Maughan & Shirreffs, 2004). When the athlete is cooled prior to exercise (pre-cooling) the performance decrement can be counteracted (Duffield, 2008). In field settings, pre-cooling is mainly achieved with the application of cooling vests. However, cooling vests are associated with potential disadvantages. Firstly, they are not tailored to the participants, which may reduce the heat transfer efficiency. Secondly, they are usually bulky and heavy, possibly resulting in increased energy cost of the warm-up procedure (Hunter et al., 2006; Arngrimsson et al., 2004). Thirdly, cooling vests based on frozen gels or ice packs (ice-vests) are likely to cause thermal discomfort (Duffield et al., 2003). Thus, a lightweight evaporative cooling-shirt was developed to aim at reducing these disadvantages and providing only mild cooling to the body.

The application of an ice-vest is reported to cause significant decreases in skin temperatures, which can result in skin vasoconstriction (Cotter et al., 2001). Vasoconstriction will decrease skin blood flow and thus reduce the exchange of heat between the body and the cooling garment (Cheuvront et al., 2003). Since skin temperature (from 23 to 36 °C) is in linear relationship with the skin blood flow (Nilsson, 1987) it is expected that cooling intensity (cooling power provided by the cooling garment) becomes of importance when cooling of the same surface area and duration is provided. Specifically, strong cooling opposed to mild cooling is expected to decrease cooling efficiency. Such a decrease in cooling efficiency, defined as the ratio between the total cooling provided by a cooling garment and the body cooling, may be reflected in attenuated body core temperature decrease during pre-cooling. Furthermore, pre-cooling in cold air (5 ± 1 °C) is known to initiate thermogenesis (Lee & Haymes, 1995). Although cooling in cold air might be more intense than ice-vest cooling, it is not unlikely that the latter also results in thermogenic effects. As such an ice-vest with its associated relatively strong intensity of cooling may not be optimal for decreasing the body heat storage during a pre-cooling intervention. The effect of pre-cooling, using an ice-vest, on thermogenesis has not been yet reported. It is hypothesized that providing a mild intensity of pre-cooling that does not initiate vasoconstriction and/or thermogenesis may enhance cooling efficiency. Therefore, the aim of the present study was to investigate the vasoconstrictive and thermogenic effects of mild and strong pre-cooling and to determine whether the evaporative cooling-shirt circumvents vasoconstriction and thermogenesis, and promotes cooling efficiency.

To investigate the vasoconstrictive effect and thermogenesis of mild and relatively strong cooling, participants were first exposed to 45 min of pre-cooling. Additionally, a no-cooling condition was added as a control. Immediately after pre-cooling, the participants performed submaximal exercise in the heat until exhaustion.
4.2 Methods

4.2.1 Participants

Eight healthy males (age 27 ± 4 years, height 181 ± 4 cm, body mass 72.5 ± 5.2 kg, and peak oxygen consumption (\( VO_{2\text{peak}} \) 57.1 ± 4.7 \( \text{ml}\cdot\text{min}^{-1}\cdot\text{kg}^{-1} \)) participated in the study. The experimental procedures were verbally explained, and written informed consent was obtained from all participants prior to the study. For a period of 48 h before each trial, the participants were instructed to refrain from strenuous exercise. Furthermore, the participants 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 Cantonal Ethical Committee of St. Gallen, Switzerland approved the study.

4.2.2 Experimental design

A repeated measures design in which the participant served as his own control was applied. Participants performed one preliminary trial to determine the aerobic capacity, and thereafter three randomly assigned experimental trials. The preliminary trial was conducted on a separate occasion at least two, but not more than seven days prior to the experimental trials. In two of the experimental trials, cooling was applied during the pre-cooling session with i) an evaporative cooling-shirt providing mild cooling and ii) an ice-vest providing strong cooling. In a third experimental trial, the participants wore a conventional sport shirt, which served as a control condition. The experimental trials were conducted at the same time of a day and at least five days apart in order to minimize the influence of circadian rhythm and heat acclimation. Each experimental trial was divided into two consecutive sessions; a pre-cooling and an exercise session. The pre-cooling session lasted 45 min and took place in a room controlled at a temperature of 24.6 ± 0.4 °C and 24 ± 6% relative humidity. The exercise session was terminated when one of the following criteria was met i) participants voluntarily terminating the exercise, ii) a rectal temperature exceeding 40.0 °C or iii) cycling for 60 min. The chosen protocol was based on that previously used by Wilson \textit{et al.} (2002) and Hessemer \textit{et al.} (1984). The exercise session took place in a climatic chamber controlled at a temperature of 29.3 ± 0.2 °C and 80 ± 3% relative humidity.

4.2.3 Cooling garments

The cooling power of the evaporative cooling-shirt and the ice-vest were determined using a thermal manikin and as described by Kocjan and Rossi (2008). The cooling power amounted to 27.3 ± 1.1 W·m\(^{-2}\) and 49.2 ± 9.0 W·m\(^{-2}\) for the cooling-shirt and ice-vest,
respectively. The evaporative cooling-shirt (Unico, Alpnachstad, Switzerland) was designed in a shape of a vest and was tailored to fit each participant individually. As described elsewhere the cooling-shirt induces cooling via the process of water evaporation (Kocjan & Rothmaier, 2007). Briefly, the vest is made from a three-layer laminate; two waterproof, but water vapour permeable, outer membranes enclose a hydrophilic fabric, which acts as a water reservoir and distributor. The membranes are sealed to each other on all edges. Cooling was initiated by adding 160 ml of water adjusted to room temperature, leaving the hydrophilic fabric fully wetted. The water started to evaporate thereby cooling the shirt and underlying skin. The weight of the activated cooling-shirt was ~ 310 g. The ice-vest (Arctic Heat, Burleigh Heads, Australia) contains pockets, distributed over the front and back sides of the torso, filled with a hydrophilic material. The ice-vest was activated by water immersion for approximately 10 min and its subsequent storage for a minimum of 6 hours in a conventional freezer. After water immersion and freezing, the weight of the ice-vest amounted to ~ 1650 g.

4.2.4 Experimental procedure

In the preliminary trial, participant’s height (Hoechst Mass, Germany), body mass (ID5 Multi range, Mettler Toledo, Greifensee, Switzerland) and \( \text{VO}_{2 \text{peak}} \) were assessed. The \( \text{VO}_{2 \text{peak}} \) was assessed during a graded exercise test on an electrically-braked cycling ergometer (Cyclus 2, RBM GmbH, Leipzig, Germany). Preceding the study, the producer of cycling ergometer (RBM GmbH, Leipzig, Germany) calibrated the ergometer. 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. During the exercise participants were given verbal encouragement. Expired air was collected breath-by-breath and analysed in 30 s averages through the test to determine oxygen uptake. The highest value obtained was considered as \( \text{VO}_{2 \text{peak}} \). The graded exercise was performed in a climatic chamber controlled at the temperature of 20.6 ± 0.4 °C and 54 ± 5% relative humidity.

In the three experimental trials, participants were asked to self insert a rectal probe (MSR B10014, Prospective Concepts, Glattbrugg, Switzerland) 10 cm beyond the anal sphincter. Skin temperature thermistors (MSR B10012, Prospective Concepts, Glattbrugg, Switzerland) were attached 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) according to the ISO 9886 standard (2004b) using a breathable medical tape (Tegaderm, 3M Health Care, USA). A chest strap and the corresponding heart rate monitor were secured to measure the heart rate (810i, Polar, Kempele, Finland). Participants put on a conventional sport shirt (NikeFit Dry, Nike, The Netherlands), cycling pants, socks and shoes. Thereafter, resting oxygen consumption (\( \text{VO}_2 \)) and carbon dioxide production (\( \text{VCO}_2 \)) were determined (Oxycon Alpha, Jaeger, Würzburg, Germany). Skin blood flow was measured on eight locations contra-laterally to the skin temperature thermistors using
laser-Doppler flowmetry (PF 5010, Perimed, Jarfalla, Sweden). Additionally, skin blood flow was measured on the finger pad of the right middle finger. Holders securing the laser-Doppler probe at each measurement site were fixed to the skin using adhesive rings (Double-Stick Discs, 3M Health Care, Canada). Laser-Doppler was calibrated preceding every trial using calibration kit provided by manufacturer (PF 1000 Calibration device, Perimed, Jarfalla, Sweden). Following these baseline measures and depending on the cooling intervention, the participants either removed the sport shirt and put on the evaporative cooling-shirt or the ice-vest, or kept wearing the sport shirt, for the duration of the pre-cooling session. After the pre-cooling session, participants removed the facial mask and the cooling garment (if applied) and put on the sport shirt. The participants then entered the climatic chamber and mounted the cycling ergometer. The facial mask was again secured and the participants performed the exercise session consisting of i) 5 min warm-up, during which the participant cycled at a power output corresponding to 50% \( \dot{V}O_2^{peak} \), followed by ii) cycling at 65% \( \dot{V}O_2^{peak} \) until one of the termination criteria was met. During exercise, room temperature water was provided ad libitum and the consumed amount recorded. To ingest the water the participants were allowed to remove the mask.

### 4.2.5 Measurements and calculations

To monitor the body core temperature, the rectal temperature (\( T_{re} \)) was recorded. During the exercise session, the slope of \( T_{re} \) (\( \Delta T_{re} \; (^{\circ}\text{C}\cdot\text{h}^{-1}) \)) was determined from each data-set individually through an iterative procedure. When the Pearson's correlation coefficient of moving time frame started to drop below 0.99, the iteration process was terminated and the slope of the linear regression was obtained. This procedure was carried out in Matlab 14 for Windows. Rectal and skin temperatures were recorded every second and are reported as minute averages. Weighted mean skin temperature (\( T_{sk} \)) was calculated according to ISO 9886 (2004b). \( T_{re} \) and \( T_{sk} \) were used to calculate the mean body temperature (\( T_b \)) according to Jay et al. (2006). The change in the body heat storage during the pre-cooling session was calculated according to Burton (1935) as:

\[
S (\text{W} \cdot \text{m}^{-2}) = \Delta T_b \cdot m \cdot CE \cdot AD^{-1} \cdot t^{-1}
\]

(Eq. 4.1)

\( \Delta T_b \) (°C): the difference in \( T_b \) between the start and the end of the pre-cooling or exercise session

\( m \) (kg): participant’s body mass

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

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

\( t \) (s): duration of the pre-cooling or exercise session.
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Metabolic heat production during the pre-cooling session was calculated according to ISO 8996 (2004a) as:

\[ M (W \cdot m^{-2}) = EE \cdot \dot{V}O_2 \cdot AD \]

(Eq. 4.2)

\( EE (W \cdot h \cdot l^{-1} O_2) \): the energetic equivalent and is calculated as 
\( (0.23 \cdot RER + 0.77) \cdot 5.88 \), with 
\( RER = \dot{V}CO_2 / \dot{V}O_2 \).

Skin blood flow was measured during two periods, prior to the start and at the end of the pre-cooling session. The first 20 s measurement at each location was allowed for the signal to stabilize and following 15 s of the signal was analysed. The skin blood flow values prior to the pre-cooling session were considered as a baseline and set to 100%. The following skin blood flow values were expressed as the difference. Heart rate was recorded every five seconds during pre-cooling and exercise session. The sweat rate was estimated via the participant’s body mass difference prior to and post exercise, corrected for the amount of fluid consumed and the weight difference of the clothing. Thermal perception was rated according to ISO 10551 (2001) prior to each blood flow measurement during the pre-cooling session and after the initial 5 min and each subsequent 15 min during the exercise session. At the same time intervals during the exercise session, perceived exertion was rated according to Borg (1982).

4.2.6 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. A non-parametric Wilcoxon test was applied to determine the difference in time to exhaustion among the conditions investigated. A non-parametric test was selected as the comparison of the time to exhaustion was performed only on six participants who stopped exercising at or before 60 min cut-off. All values are reported as mean ± standard deviation.

4.3 Results

4.3.1 Pre-cooling session

Application of mild cooling and strong cooling caused a decrease of the skin blood flow when compared to control \( (p<0.05) \). As shown in Figure 4.1, skin blood flow was
reduced at the back, the chest and the finger for both conditions. Strong cooling, in addition, caused a decrease of the skin blood flow at the shoulder. The observed decreases in skin blood flow did not differ between mild and strong cooling.

**Figure 4.1** Skin blood flow at the end of the pre-cooling session. CON represents no cooling, MC mild cooling and SC strong cooling. 100% indicate starting values, values higher than 100% indicate an increase in skin blood flow, whereas values lower than 100% represent a decrease. Values are reported as mean ± standard deviation. An asterisk (*) denotes a difference from CON (p<0.05).

During pre-cooling $\overline{T}_{sk}$ decreased by $1.5 \pm 0.3$ °C (p<0.001) and $2.7 \pm 0.7$ °C (p<0.001) in mild and strong cooling, respectively. As presented in Figure 4.2, the observed decrease differed between the conditions from the 25th min onward. No decrease in $\overline{T}_{sk}$ was observed for control. However, in control a decrease in $T_{re}$ of $0.2 \pm 0.1$ °C (p<0.01) was observed (Figure 4.3). The decrease in $T_{re}$ of $0.1 \pm 0.1$ °C in mild cooling and of $0.1 \pm 0.2$ °C in strong cooling was not significant.
Figure 4.2 Mean skin temperature ($T_{sk}$) for no cooling (CON), mild cooling (MC), and strong cooling (SC) during the pre-cooling session. A cross (†) denotes a decrease in $T_{sk}$ between the beginning and the end of the MC and SC. An asterisk (*) denotes a difference in $T_{sk}$ between the MC and SC ($p<0.05$).

Figure 4.3 Rectal temperature ($T_{re}$) for no cooling (CON), mild cooling (MC), and strong cooling (SC) during the pre-cooling session. A cross (†) denotes a decrease in $T_{re}$ between the beginning and the end of the CON ($p<0.05$).
Body heat storage decreased by 7.7 ± 5.7 W·m⁻² in control, 21.2 ± 5.1 W·m⁻² in mild cooling and 39.5 ± 8.4 W·m⁻² in strong cooling. The decrease differed among the conditions. No differences were observed between the heart rates during the pre-cooling session in any conditions investigated. Thermal perception did not differ among the conditions prior to the pre-cooling session. At the end of pre-cooling session the subjects felt colder (p=0.03) only in strong cooling when compared to control. Table 4.1 shows absolute values of the investigated thermophysiological parameters obtained for each condition prior to and at the end of the pre-cooling session.

Table 4.2 shows the values for $\dot{V}O_2$, $\dot{V}CO_2$ and metabolic heat production obtained for each condition prior to and at the end of the pre-cooling session. No differences were observed in $\dot{V}CO_2$ among the conditions prior to pre-cooling. At the end of pre-cooling lower $\dot{V}CO_2$ was observed for control, compared with mild cooling (p=0.01) and strong cooling (p=0.03). $\dot{V}O_2$, respiratory exchange ratio and metabolic heat production were not different among the conditions at any time point investigated. Differences were observed between the respiratory values measured prior to and at the end of the control condition. A small but significant decrease of 22 ± 23 ml·min⁻¹ (p=0.04) in $\dot{V}O_2$ and of 27 ± 23 ml·min⁻¹ (p=0.02) in $\dot{V}CO_2$ was observed. A decrease in metabolic heat production amounted to 4.3 ± 4.1 W·m⁻² (p=0.03).

4.3.2 Exercise session

The mean transfer time between the pre-cooling session and the exercise session was 13:01 ± 2:32 min and did not differ among the conditions. During this time $T_{sk}$ increased in all conditions, however at the start of the exercise $T_{sk}$ was still the lowest for strong cooling. During the exercise $T_{sk}$ increased by 3.1 ± 0.5 °C, 3.9 ± 0.8 °C and 4.1 ± 0.9 °C in control, mild and strong cooling, respectively. At the end of the exercise there were no differences in $T_{sk}$ for mild and strong cooling compared with control. However, $T_{sk}$ was lower in strong cooling compared with mild cooling (p=0.03). Increase in $T_{sk}$ for the first 30 min of exercise (where all the participants were still exercising) is shown in Figure 4.4. Opposed to $T_{sk}$, an additional decrease in $T_{re}$ was observed for all the conditions during the transfer time. Although this decrease was larger for mild and strong cooling than for control, participants started the exercise session with similar $T_{re}$. During exercise session $T_{re}$ increased by 2.1 ± 0.6 °C in control, by 2.1 ± 0.6 °C in mild cooling and by 2.3 ± 0.7 °C in strong cooling. $T_{re}$ at the end of exercise did not differ among the conditions. Similarly, no differences in the slope of $T_{re}$ were observed among the conditions. Increase in $T_{re}$ for the first 30 min of exercise is shown in Figure 4.5.
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<th>Precooling intensity</th>
<th>Cooling efficiency</th>
<th>Exercise performance</th>
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Note: The table above shows the results of different precooling intensities and their effects on cooling efficiency and exercise performance. The data is based on a study conducted in a controlled environment with varying precooling intensities. Further research is needed to confirm these findings.
The body heat storage increased during the exercise by 116.1 ± 16.4 W·m² in control, by 116.2 ± 13.3 W·m² in mild cooling and by 118.8 ± 15.4 W·m² in strong cooling, where this increase did not differ among the conditions. There were no differences in the heart rates observed among the conditions at the end of the exercise session.

The sweat rate did not differ among the conditions. The participants lost 10.4 ± 2.5 g·min⁻¹·m⁻², 10.2 ± 2.8 g·min⁻¹·m⁻² and 9.4 ± 2.4 g·min⁻¹·m⁻² in control, mild cooling and strong cooling, respectively. The amount of the water ingested during the exercise session was 507 ± 307 ml for control, 599 ± 393 ml for mild cooling and 723 ± 436 ml for strong cooling and did not differ among the conditions (p>0.05).

At the 5th min of the exercise session the participants rated thermal perception as warm in control (2 ± 1) and in mild cooling (2 ± 1), whereas as slightly warm in strong cooling (1 ± 1). By 15th min of the exercise, thermal perception in control (3 ± 1) and mild cooling (3 ± 0) corresponded to hot. At the same time thermal perception in strong cooling corresponded to warm (2 ± 0). Thermal perception did not differ among the condition at any other time point (Table 4.1). Rating of perceived exertion was not significantly different among the conditions at any time point investigated (Table 4.1).

Two participants managed to perform 60 min cycling in all conditions. Two other participants managed to complete the full 60 min exercise in strong cooling, but not in control and mild cooling. With the two latter conditions, their mean exercise time was 46:46 ± 05:12 min and 53:10 ± 02:28 min, respectively. The remaining four participants cycled for 36:44 ± 09:20 min, 41:16 ± 06:02 min and 41:46 ± 07:02 min in control, mild cooling and strong cooling, respectively. Thus, compared with control mean time to exhaustion was 05:09 ± 04:55 min (p=0.05) longer in mild cooling and 07:46 ± 05:45 min (p=0.03) longer in strong cooling.
Figure 4.4 Mean skin temperature during the initial 30 min of the exercise session. CON represents no cooling, MC mild cooling and SC strong cooling.

Figure 4.5 Rectal temperature during the initial 30 min of the exercise session. CON represents no cooling, MC mild cooling and SC strong cooling.
4.4 Discussion

The aim of the present study was to investigate the vasoconstrictive and thermogenic effects of mild and strong pre-cooling. In addition, the effect of mild and strong intensity of cooling on exercise performance (time to exhaustion) in the heat was investigated. The cooling power of an evaporative cooling-shirt providing mild cooling and of ice-vest providing strong cooling had been assessed as described previously (Kocjan & Rossi, 2008). Comparing the cooling power with the observed change in body heat storage during pre-cooling session provides information on improved efficiency of the heat extraction from the participant’s body by the cooling garment. The cooling efficiency (heat extracted from the body divided by the total cooling power of the cooling garment) corresponded to 78 ± 17% in mild cooling and 80 ± 20% in strong cooling, and was not significantly different between the two methods of pre-cooling. Therefore, it can be concluded that mild cooling did not promote the cooling efficiency.

An explanation of the underlying mechanisms for this observation may be derived from skin blood flow data. With the exception of the shoulder, skin blood decreased to a similar extent in mild cooling and strong cooling. Thus, the vasoconstriction response to the application of mild intensity cooling was essentially similar to that observed with strong intensity cooling. The presence of vasoconstriction during mild or strong cooling was furthermore reflected in unaltered rectal temperature during pre-cooling session. Conversely, in control a small, but significant, decrease in rectal temperature was observed. These results suggest that the absence of vasoconstriction in control enabled the heat exchange between the core of the body and the ambient (sport shirt), resulting in decreased rectal temperature. On the contrary, initiation of vasoconstriction in mild and strong cooling prevented the heat exchange between the core of the body and the cooling garment. However, it enabled the exchange of heat between the cooling garment and the skin. These observations are in agreement with other studies (Kurz et al., 1995; Belani et al., 1993) reporting decreased efficiency of active cooling due to thermoregulatory vasoconstriction. For instance, Kurz et al. (1995) showed that anesthetized patients in which vasoconstriction occurred throughout surgery required nearly one hour more to reach targeted body core temperature of 32 °C, compared to patients in which vasodilatation was maintained. Specifically, active cooling was facilitated by a full-body convective cover filled with a cold air (14 -15 °C). It can thus be concluded that the method and the intensity of mild cooling used in the current study does not promote the cooling efficiency due to initiation of vasoconstriction.

Both cooling methods did not show an effect on oxygen consumption and thus we can conclude that thermogenesis due to cooling did not occur (Table 4.2). This is in contrast with previous observations in cold air. For instance, van Ooijen et al. (2004) exposed participants to mild cooling (lying 3 hours at an air temperature of 15 °C) and
observed an increase of metabolic heat production of 7.0% to 11.5%. In our study, the cooling intensity and surface area were probably insufficient to trigger thermogenesis. However, lower carbon dioxide production for control compared with mild and strong cooling, and decreased oxygen consumption and carbon dioxide production for control was observed at the end of the pre-cooling session when compared to values prior to the pre-cooling session. These differences, though significant, were only minor (Table 4.2) and thus their physiological effect is likely negligible. Also, the respiratory exchange ratio was unaffected by cooling (Table 4.2). Excessive cooling has been shown to lead to shivering and depletion of glycogen stores (Jacobs et al., 1994). Since no substantial change in respiratory exchange ratio and thereby substrate use was observed during the pre-cooling, we do not expect a decrement in the subsequent exercise performance. Therefore, any change in performance can be attributed to thermal changes.

Observed improvements in time to exhaustion and thereby exercise performance support previous findings (Gonzalez-Alonso et al., 1999; Lee & Haymes, 1995; Olschewski & Bruck, 1988). Improved exercise performance was in some (Gonzalez-Alonso et al., 1999; Lee & Haymes, 1995) but not in all pre-cooling studies (Kay et al., 1999) ascribed to lower body core temperature observed prior to the exercise. In present study differences among the conditions prior to exercise were observed for $T_{sk}$ (only lower for SC) but not for $T_{re}$. It seems that the heat, which was extracted mainly from peripheral areas, created a heat sink. The heat sink is likely to have persisted partly into the exercise and enabled increased exercise performance. Kay et al. (1999) suggested that reduced skin temperature increases thermal gradient between the core and “shell” thereby attenuating the rise in body core temperature during the exercise. The absence of attenuated rise in body core temperature in present study is likely to be ascribed to lower cooling intensity and thus lower heat sink opposed to that provided by Kay et al. (1999). It is therefore concluded that in present study strong cooling, opposed to control and mild cooling, created a heat sink that alleviated thermal strain during the exercise and enabled improved exercise performance.

Surface area and duration of pre-cooling were constant in the present study, whereas the intensity of cooling was manipulated. Increasing the surface area or the duration of cooling is suggested to amplify beneficial effects of pre-cooling (Duffield, 2008). For instance, when whole-body cooling is compared with partial-body cooling (legs or torso) a lower body core temperature during the subsequent exercise is observed with whole-body cooling (Daanen et al., 2006). Increasing the duration of pre-cooling will amplify beneficial effects when a smaller surface area of cooling, such as with an ice-vest, is provided (Arngrimsson et al., 2004; Marsh & Sleivert, 1999). As evident in present study also the intensity of pre-cooling (surface area and duration constant) warrants amplification of beneficial effects. A positive effect of higher intensity of pre-cooling was previously indicated for cooling during exercise (Bennett et al., 1995). Bennett et al. (1995) showed
that application of a six-pack cooling vest opposed to a four-pack vest results in smallest rise in body core and skin temperatures during the exercise. It is thus concluded that beneficial effects of pre-cooling can be amplified not only with increasing the surface area and the duration, but also with increasing the intensity of pre-cooling.

In conclusion, the results of the present study suggest that decreasing the intensity of pre-cooling does not prevent vasoconstriction. Indeed, mild cooling causes similar vasoconstriction to that observed with strong cooling. No thermogenesis was observed during pre-cooling. Strong cooling created the largest heat sink which coincided with the greatest improvement in time to exhaustion. Thus, it is concluded that, although the application of an ice-vest initiates vasoconstriction, it should be considered as a beneficial method for pre-cooling individuals performing endurance exercise in heat.

References


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