Chapter 6

Pre-cooling reduces thermal strain during 1500 m swimming

Submitted as:

Bogerd N, Bogerd CP, Perret C, Rossi RM & Daanen HAM Pre-cooling reduces thermal strain during 1500 m swimming.
Abstract

The purpose of present study was to examine possible beneficial effects of cooling prior to and during warm-up on subsequent 1500 m all-out swimming performance. Eight triathletes were submitted to two experimental trials consisting of i) 10 min warm-up with cycling at 40 % VO$_{2\text{peak}}$ and ii) subsequent all-out swimming in 27.6 ± 0.3 °C water temperature. The first trial served as a control, whereas in the second trial cooling was administered for 45 min prior to the swimming i.e. 35 min during rest and 10 min during warm-up. Cooling decreased body core temperature (0.2 ± 0.2 °C; p<0.05) during rest, and reduced its increase during warm-up. Hence, prior to the swimming the body core temperature was lower (p<0.05) in cooling (37.1 ± 0.4 °C) compared with the control (37.7 ± 0.4 °C). Lower body core temperature in cooling persisted nearly throughout the whole swim but did not significantly improve swimming time. Mean swimming time for the control was 23:04 ± 02:02 min and for the cooling 22:47 ± 02:09 min. Thermal perception was cooler for cooling than for control during warm-up and swimming. In conclusion, pre-cooling reduced body core temperature during warm-up and swimming, but did not significantly improve swimming time.
6.1 Introduction

Cooling prior to exercise (pre-cooling) is shown to counteract increased body core temperature and to improve subsequent exercise performance (Marino, 2002). The limiting effect of increased body core temperature on endurance exercise performance is mainly shown for running and cycling. However, Nadel et al. (1974) showed that increased body core temperature can limit also swimming performance. Specifically, the increase is shown to be related to water temperature and participant’s body fat percentage (Holmer & Bergh, 1974; Nadel et al., 1974; Costill et al., 1967).

Long distance swimming occurs as a separate event and as part of the triathlon. Triathlon deserves special attention since it is shown that an early exit from the water plays an important role in the final success of the triathlete (Peeling & Landers, 2009). Bolster et al. (1999) indicated that decreased body core temperature prior to swimming results in lower body core temperature throughout swimming and partly during subsequent cycling. This study however investigated the thermal state of the participants rather than the competitive swimming time. Thus, possible effects of pre-cooling on all-out swimming time have not been yet reported. The temperature range between 25.5 and 28 °C presumably imposes the lowest thermoregulatory risk for a swimming triathlete (without immersion suit) (Dallam et al., 2005). The highest temperatures in this range, close to 28°C, may lead to heat strain. Therefore, investigating the effect of pre-cooling seems most appropriate for water temperatures around 28°C.

Body core temperature and skin temperatures have been mostly recorded only discontinuously (Peeling & Landers, 2007; Laursen et al., 2006; Kerr et al., 1998). This led to an incomplete picture of thermal strain in 1500 m all-out swimming. Continuous monitoring is necessary to understand the changes taking place in the body during pre-cooling and during the swim.

It is hypothesized that i) an increase in body core temperature is observed during 1500 m all-out swimming in ~ 28 °C water temperature and ii) that the expected increase in body core temperature is counteracted using application of pre-cooling, which will be reflected in improved swimming performance.

6.2 Methods

6.2.1 Participants

Eight (4 females, 4 males) triathletes participated in the study. The anthropometric characteristics of the participants are given in Table 6.1. Per week, the participants exercised an average of 3.1 ± 0.6 h of swimming, 6.1 ± 1.6 h of cycling and 4.3 ± 1.1 h of running. Two females were taking contraceptives and showed a 28-day menstrual cycle.
Experimental trials were performed during non-menstruating days in these participants. The other two female participants showed a 21 and 27 day menstrual cycle, respectively. In these participants the experimental trials were conducted in the luteal phase of the menstrual cycle. The experimental procedures were verbally explained, and written informed consent was obtained from all participants prior to the study. The study was approved by the Cantonal Ethical Committee of St. Gallen, Switzerland and conducted in accordance with ethical standards.

Table 6.1 Anthropometric characteristics of the participants. Values are given as mean ± standard deviation for all 4 female and all 4 male participants. $VO_{2\text{peak}}$ is peak oxygen consumption; $P_{\text{peak}}$ is peak power output for cycling exercise.

<table>
<thead>
<tr>
<th>Anthropometric characteristics</th>
<th>Females</th>
<th>Males</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>25 ± 9</td>
<td>34 ± 2</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>59.9 ± 9.2</td>
<td>78.7 ± 4.5</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>165 ± 8</td>
<td>181 ± 6</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>22.3 ± 4.9</td>
<td>16.0 ± 2.9</td>
</tr>
<tr>
<td>$VO_{2\text{peak}}$ (ml·min$^{-1}$·kg$^{-1}$)</td>
<td>59.0 ± 7.4</td>
<td>61.5 ± 5.8</td>
</tr>
<tr>
<td>$P_{\text{peak}}$ (W)</td>
<td>298 ±15</td>
<td>380 ± 24</td>
</tr>
</tbody>
</table>

6.2.2 Experimental design

Each participant attended one preliminary and two, non-randomized, experimental trials. As shown in Figure 6.1, in the first experimental trial swimming was preceded by 10 min warm-up (CON). In the second experimental trial swimming was preceded by 45 min of pre-cooling (COOL), where 35 min of cooling was administered during rest and 10 min during the warm-up. In both conditions warm-up was performed with cycling at 40% $VO_{2\text{peak}}$, whereas subsequent swimming was performed at competition speed (all-out). Cooling was provided using an ice-vest (Arctic Heat, Burleigh Heads, Australia). The two experimental trials were not randomized since pre-cooling would be trivial when the body core temperature would have shown a decrease during swimming. The experimental trials were conducted on the same time of day, at least one week apart, to avoid influence of circadian rhythm, acclimation and training effect.
6.2.3 Experimental procedure and measurements

In the preliminary trial the participant’s body mass (ID5 Multi range, Mettler Toledo, Greifensee, Switzerland), height (Hoechst Mass, Germany), skin-fold thicknesses (Harpender Skinfold Caliper, British Indicators, UK) and VO$_2$peak were determined.

In the experimental trials a radio pill (CorTemp™, HQ Inc., Palmetto, USA) was used to record body core temperature in the intestines ($T_m$). The pill was ingested 6 h prior to the experimental trials, which allowed the pill to reach the intestines and to avoid temperature fluctuations when passing the stomach. The signal emitted by the pill was recorded (HT150001, CorTemp™, HQ Inc., Palmetto, USA) every 20 s. Thermistors (MSR 145W, Prospective Concepts, Glattbrugg, Switzerland) measuring the skin temperature were embedded in neoprene patches which served as insulation to avoid possible effect of water temperature. These were attached to the left calf ($T_{\text{calf}}$), left thigh ($T_{\text{thigh}}$), left upper arm ($T_{\text{arm}}$), and left chest ($T_{\text{chest}}$). The sensors were connected to a corresponding miniaturized data logger recording the skin temperature every 20 s. A heart rate transmitter and the corresponding heart rate monitor (810i, Polar, Kempele, Finland) were secured to register the heart rate every 5 s. After instrumentation the participants put on triathlon apparel and the ice-vest for COOL trial. Prior to the pre-cooling, warm-up and at the end of the warm-up, participants were asked to rate their thermal perception and comfort according to ISO 10551 (2001). Pre-cooling and warm-up were performed in a room with a temperature of 24.2 ± 1.3 °C and 54 ± 5% relative humidity. After warm-up participants removed the socks and shoes, and the ice-vest if wearing one and put on the swimming cap and goggles. They plunged into the 25 m swimming pool and performed all-out front crawl. When the swimming was terminated, participants rated thermal perception and comfort, and perceived exertion (Borg, 1982). The water temperature was 27.6 ± 0.3 °C and did not differ between the conditions.
6.2.4 Calculations

Skin fold thicknesses were used to calculate participant’s body fat percentage (Durnin and Womersley, 1974). Weighted mean skin temperature \( (\bar{T}_{sk}) \) was calculated according to Ramanathan (1964):

\[
\bar{T}_{sk} \ (°C) = 0.3 \cdot T_{arm} + 0.2 \cdot T_{calf} + 0.3 \cdot T_{chest} + 0.2 \cdot T_{thigh} \quad \text{(Eq. 6.1)}
\]

\( T_{in} \) and \( \bar{T}_{sk} \) were used to calculate the body temperature according to Kenney (1998):

\[
\bar{T}_{b} \ (°C) = 0.67 \cdot T_{in} + 0.33 \cdot \bar{T}_{sk} \quad \text{(Eq. 6.2)}
\]

Body temperature was used to calculate the change in body heat storage for the two time points i) after the warm-up and ii) after swimming. Body heat storage \( (S) \) was calculated according to Burton (1935):

\[
S \ (W \cdot m^{-2}) = \Delta \bar{T}_{b} \cdot m \cdot CE \cdot AD^{-1} \cdot t^{-1} \quad \text{(Eq. 6.3)}
\]

\( \Delta \bar{T}_{b} \ (°C) \): the difference in \( \bar{T}_{b} \) between the start and the end of the warm-up or the swimming

\( m \) (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 warm-up or swimming

6.2.5 Statistics

SPSS 14.0 for Windows was used for the statistical analysis. The statistical significance level was set at \( p<0.05 \). Due to technical problems with measuring \( T_{in} \) during swimming in one female participant this data were excluded from the analysis. A paired t-test was used to compare the differences in \( T_{in} \) prior to and after pre-cooling for COOL, and to compare the rating of perceived exertion and swimming time between CON and COOL at the end of swimming. Two-way ANOVA was employed to analyze the time, intervention and interaction effect of \( T_{in}, \bar{T}_{sk} \), body heat storage, heart rate, thermal perception and thermal comfort during the warm-up and swimming. A Bonferroni corrected t-test was used for post-hoc comparisons. Pearson’s correlation coefficient was used to identify correlation between the \( T_{in} \) change during swimming and the swimming time, and between the \( T_{in} \) change during swimming and the participants’ body fat percentage. All values are reported as mean ± standard deviation.
6.3 Results

During 35 min of rest $T_{in}$ decreased by $0.2 \pm 0.2 \, ^\circ \text{C}$ ($p<0.05$). As shown in Figure 6.2, during the warm-up an increase of $0.2 \pm 0.1 \, ^\circ \text{C}$ ($p<0.01$) was observed in CON, whereas in COOL $T_{in}$ remained unaltered and lower than for CON. Accordingly, the participants started all-out swimming with lower $T_{in}$ in COOL ($37.1 \pm 0.4 \, ^\circ \text{C}$) compared to
CON (37.7 ± 0.4 °C). Lower $T_{in}$ persisted until the 17th min of exercise. During swimming a similar $T_{in}$ increase was observed for CON (0.7 ± 0.4 °C) and COOL (1.0 ± 0.3 °C). The participants completed swimming with $T_{in}$ of 38.4 ± 0.4 °C for CON and 38.1 ± 0.3 °C for COOL (p>0.05). The individual increase in $T_{in}$ during swimming for both conditions is shown in Figure 6.3. As shown in Figure 6.4 we did not observe a correlation between the change in $T_{in}$ during swimming and the swimming time ($r=-0.5$; $p=0.08$). Similarly, no correlation was observed between the change in $T_{in}$ during swimming and participants’ body fat percentage ($r=-0.1$; $p>0.5$).

A decrease of 0.7 ± 0.4 °C (p<0.01) in $T_{sk}$ was observed during 35 min of pre-cooling at rest. Although during the warm-up $T_{sk}$ increased for both conditions participants started swimming in COOL (31.3 ± 0.6 °C) with lower (p<0.01) $T_{sk}$ opposed to CON (33.1 ± 1.0 °C). During the swimming, $T_{sk}$ for CON decreased with 1.9 ± 0.9 °C (p=0.001), whereas for COOL it remained unaltered. Similar $T_{sk}$ was observed for CON (31.2 ± 1.2 °C) and COOL (31.4 ± 0.7 °C) at the end of swimming. During the warm-up body heat storage increased only in CON (p<0.01), whereas no change was observed for COOL (Figure 6.5). During the swimming no change was observed for CON (p=0.52), however an increase was observed for COOL (Figure 6.6).
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**Figure 6.5** Change in body heat storage \( (S) \) during the warm-up in the control (CON) and pre-cooling (COOL) conditions. An asterisk \( (*) \) denotes a significant difference between CON and COOL. The marker \( \# \) denotes a significant increase of \( S \) in CON.

**Figure 6.6** Change in body heat storage \( (S) \) during the swimming in the control (CON) and pre-cooling (COOL) condition. An asterisk \( (*) \) denotes a significant difference between CON and COOL. The marker \( \# \) denotes a significant increase of \( S \) in COOL.

Heart rate increased during warm-up and swimming for both conditions, however no differences were observed between the conditions. Mean swimming time did not change \( (p>0.05) \) with pre-cooling (Table 6.2). Specifically, in 5 out of 8 participants improvement of \( 41 \pm 32 \) s was observed for COOL compared with CON, whereas remaining 3 participants swam \( 23 \pm 8 \) s slower in COOL compared with CON.

**Table 6.2** The swimming time of all participants for the control (CON) and the pre-cooling (COOL) conditions and the difference between the conditions. A ‘m’ designates a male participant and ‘f’ a female participant.

<table>
<thead>
<tr>
<th>Participant</th>
<th>CON (min:ss)</th>
<th>COOL (min:ss)</th>
<th>diff (COOL-CON)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 m</td>
<td>26:24</td>
<td>25:03</td>
<td>-0:21</td>
</tr>
<tr>
<td>2 m</td>
<td>21:15</td>
<td>20:54</td>
<td>-0:01</td>
</tr>
<tr>
<td>3 m</td>
<td>21:21</td>
<td>20:12</td>
<td>-0:09</td>
</tr>
<tr>
<td>4 m</td>
<td>22:14</td>
<td>22:34</td>
<td>+0:20</td>
</tr>
<tr>
<td>5 f</td>
<td>25:49</td>
<td>26:21</td>
<td>+0:22</td>
</tr>
<tr>
<td>6 f</td>
<td>21:53</td>
<td>21:47</td>
<td>-0:06</td>
</tr>
<tr>
<td>7 f</td>
<td>21:52</td>
<td>21:25</td>
<td>-0:27</td>
</tr>
<tr>
<td>8 f</td>
<td>23:42</td>
<td>24:00</td>
<td>+0:18</td>
</tr>
</tbody>
</table>

\( \text{mean} \pm \text{sd} \)

\( 23:04 \pm 02:02 \)

\( 22:47 \pm 02:09 \)

\( -00:17 \pm 00:41 \)
Prior to the swimming, participants rated thermal perception in CON as slightly warm (1 ± 1), while in COOL was perceived as cool (-2 ± 1), which was different between the conditions (p=0.02). Similarly at the end of all-out swimming participants rated thermal perception in CON as hot (3 ± 1), in contrast to warm (2 ± 1) in COOL, which was also different between the conditions (p=0.02). Participants reported to feel less thermally comfortable (p=0.05), due to cold in COOL (1.1 ± 0.6) as opposed to CON (0.6 ± 0.5). However, at the end of the swimming, the participants reported to feel less thermally comfortable due to warmth (p<0.01) in CON (1.0 ± 0.9) as opposed to COOL (1.3 ± 0.7). Rating of perceived exertion did not differ between CON (16 ± 2) and COOL (16 ± 1) at the end of swimming.

6.4 Discussion

The aim of the present study was to investigate i) if body core temperature (\(T_n\)) increases during 1500 m all-out swimming in ~28 °C water temperature and ii) if pre-cooling counteracts the possible \(T_n\) increase and improves all-out swimming time. Our results show that pre-cooling reduces the body core temperature during warm-up and during swimming without significantly improving swimming time.

The observed \(T_n\) increase (0.7 ± 0.4 °C) during swimming in CON was slightly higher than the 0.58 °C reported by Costill et al. (1967) where swimming was performed of a similar duration (20 min) and a similar intensity, but at a lower water temperature (26.8 °C). The increase was also higher than the 0.25 °C reported by Bolster et al. (1999) where 15 min of swimming was performed in water with a similar temperature, though presumably at lower intensity. In both these studies the body fat percentage of the participants was lower (Bolster et al. (1999) 8.3 ± 1.7%; Costill et al. (1967) 7.7 ± 1.8%) than that measured in the present study (22.3 ± 4.9% for females and 16.0 ± 2.9% for males). Thus, the larger increase in \(T_n\) observed in present study might be explained by differences in water temperature, body fat percentage or duration of swimming. Nevertheless, also the method for measuring the body core temperature might explain the difference. We did not observe a significant correlation between \(T_n\) increase and participant’s body fat percentage on an individual level. This result is in line with some (Trappe et al., 1995), but not with all previous studies (Holmer & Bergh, 1974; Nadel et al., 1974). The absence of a correlation may be attributed to the fact that the subjects were swimming in relatively warm water where the thickness of subcutaneous fat may play a less important role opposed to swimming in colder water. Similarly, no correlation was found between the \(T_n\) increase and the duration of swimming (Figure 6.4). However, the p-value of 0.08 suggests that there might be a tendency for this relationship.

Since continuous monitoring of \(T_n\) during swimming has been largely ignored, it is unknown if \(T_n\) is adequately regulated or if uncompensable heat strain occurs under
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conditions of the present study. In the majority of participants a continuous increase is observed (uncompensable heat strain), whereas only in few the initial temperature increase levelled-off (thermal steady-state). Recent evidence indicates that where the attainment of high body core temperature is possible, work rate is reduced in anticipation of high body temperatures (Marino, 2004). Since we did not register lap times it is not possible to conclude if thermal steady-state observed in some participants is consequence of decreased swimming pace or heat loss matching the metabolic heat production. It is thus concluded that in the given conditions $T_{in}$ generally shows a continuous increase suggesting the presence of heat strain.

Pre-cooling decreased body core temperature prior to the warm-up, prevented its increase during the warm-up and nearly throughout the whole swim. This is in agreement with previous reports for cycling and running exercise. Similarly as observed in the present study, Arngrimsson et al. (2004) reported that the pre-cooling effect ceased before the end of 5 km all-out running (~17 min). However, for swimming Bolster et al. (1999) reported decreased body core temperature to persist throughout 15 min swimming and 10 min into the cycling exercise. Prior to swimming Bolster et al. (1999) report a decrease in body core temperature of 0.53 °C, which resembles $T_{in}$ decrease observed in the present study. For swimming in control condition (no pre-cooling) they report an increase of 0.28 °C, which is lower than $0.5 \pm 0.5$ °C observed at 15th min of swimming in present study. This might suggest that higher water temperature and the intensity of swimming in present study caused higher increases in body core temperature through swimming.

Unlike Bolster et al. (1999) who investigated the effect of pre-cooling on thermoregulatory responses, our study investigated the effect of pre-cooling on swimming time. We observed no improvement. Nevertheless, the observed improvements in thermal perception and comfort may reduce the feeling of fatigue. Thus, positive effects of relieved thermal strain during swimming should be further investigated on subsequent cycling performance. It is important to note that CON and COOL were not randomized. Since the trials were spaced for at least seven days, it is unlikely that any order effect has taken place.

Fluctuations of female reproductive hormones affect body core temperature during the course of a normal menstrual cycle. The increased body core temperature observed in the luteal phase has been shown to decrease time to exhaustion when exercising in the heat (Tenaglia, 1999). Thus, the effect of initially increased body core temperature on exercise performance in females opposed to males cannot be excluded. However, since both conditions were conducted under similar hormonal state for the females, differences among the conditions are unlikely.

In conclusion, pre-cooling has been shown to reduce core temperature prior to and during swimming in 28°C water and improve thermal sensation, but did not lead to improved performance during swimming.

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References


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