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

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Summary

Endurance exercise performance is reduced in hot environments. This can be counteracted with the application of cooling prior to exercise, i.e. pre-cooling. In field settings, pre-cooling is generally provided by a personal cooling-system. At present, the following are essentially unknown: i) how the cooling power of a system is to be determined, ii) how much and how often cooling should be applied to increase endurance performance, and iii) whether the application of personal cooling-systems can improve exercise performance in sports other than cycling or running. The aim of the work presented in this thesis was to answer these questions.

To investigate thermal effects, such as cooling power and thermophysiological responses initiated with the application of a personal cooling-system, i) humans, ii) a thermal manikin and iii) a thermophysiological human simulator were used. The personal cooling-systems used were: i) a cooling-shirt providing mild cooling, and ii) an ice-vest providing strong cooling. The measurements were first conducted on humans and on a thermal manikin. Subsequently, the thermophysiological human simulator was used to provide data on thermophysiological responses, such as skin and rectal temperatures. The cooling power determined on the thermal manikin was 2 times higher for the cooling-shirt and 1.5 times higher for the ice-vest compared to the cooling power determined in human participants. For the thermophysiological human simulator, the cooling power of the cooling-shirt was similar to that obtained with human participants. However, the cooling power was 2 times lower for the ice-vest when using the thermophysiological human simulator. We have concluded that the thermophysiological human simulator is a useful tool for predicting thermophysiological responses, especially with application of mild cooling intensity. However, the thermophysiological human simulator needs to be further improved for strong cooling intensities in heterogeneous conditions.

To investigate the possibility of increasing the cooling efficiency of personal cooling-systems, two approaches were chosen: i) modifying the cooling intensity and ii) applying intermittent cooling. With the first approach, we hypothesized that mild cooling, as opposed to strong cooling, circumvents skin vasoconstriction and thermogenesis, and thus improves cooling efficiency reflected in improved time to exhaustion. To investigate this, eight males undertook three randomized trials in which different intensities of cooling were applied. Each trial consisted 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 45 min of either i) mild cooling using a cooling-shirt, ii) strong cooling using an ice-vest, or ii) a no-cooling condition that was added as a control. Subsequently, cycling was performed at 65% $\dot{V}O_{2peak}$ in a climatic chamber of 29.3 ± 0.2 °C and 80 ± 3% relative humidity. During the pre-cooling session, mild and strong cooling decreased the skin blood flow in comparison with the control condition. However, no differences were observed between mild and strong cooling. Thermogenesis was not observed in mild and strong cooling. The reduction in body heat storage after pre-cooling was two times larger for strong cooling (39.5 ± 8.4 $W \cdot m^{-2}$), as opposed to mild cooling (21.2 ± 5.1 $W \cdot m^{-2}$). This resulted in the greatest improvement in time to exhaustion for strong cooling. We have concluded 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. Furthermore, in the second study, we hypothesised that repeated exposure to cold will lead to minor acclimation effects. This effect may potentially improve pre-cooling efficiency, reflected in subsequent improved exercise performance. To investigate this, eight healthy males were exposed to cooling with an 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 1^{st}, 5^{th} and 10^{th} days, 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 differences in body heat storage were observed. Nevertheless, on the 10^{th} day, the participants felt less cold and thus less thermally uncomfortable ($p < 0.05$) compared to the first day. For the graded exercise, the time to exhaustion was similar for the 1^{st} (14:51 ± 05:25 min), 5^{th} (15:32 ± 05:27 min) and 10^{th} days (15:29 ± 05:21 min). It was concluded that although repeated cooling improves thermal sensation and thermal comfort, it does not have any effect on cooling efficiency and exercise performance. Thus, it is suggested that repeated use of an ice-vest is likely to have neither advantageous nor disadvantageous effects on exercise performance in the heat.

To investigate whether pre-cooling can improve exercise performance in activities other than cycling and running, eight triathletes were submitted to two experimental trials, in which each trial consisted of i) 10 min warm-up with cycling at 40 % $\dot{V}O_{2peak}$ and ii) subsequent 1500 m all-out swimming in water of 27.6 ± 0.3 °C. 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 the 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). The lower body core temperature in cooling persisted nearly throughout the entire swim but did not significantly improve swimming time. The 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. We have concluded that pre-cooling relieves thermal strain during warm-up and swimming, but does not significantly improve swimming time.

From the summarized results, we have concluded that the thermophysiological human simulator is a useful tool for predicting thermophysiological responses, especially with the application of mild cooling. Furthermore, the efficiency of personal cooling-systems is not likely to be increased by decreasing the intensity of cooling or repeating the cooling. However, we have shown that pre-cooling increases cycling performance in the heat when high intensity of pre-cooling is provided. Finally, we conclude that pre-cooling relieves thermal strain during the swimming exercise as reflected in decreased body core temperature and improved thermal perception while swimming.