Chapter 1

General introduction

Endurance exercise performance is reduced in hot environments (Maughan & Shirreffs, 2004). The decrease in exercise performance is related to high ambient temperature, relative humidity, radiation and low wind speed. In addition, exercise performance is decreased by high metabolic heat production. For instance, competitive marathon runners who will typically maintain a pace corresponding to 70–90% maximal aerobic capacity for more than two hours show a considerable decrease in exercise performance when the wet bulb globe temperature is higher than 5 °C (Ely *et al.,* 2007; Davies & Thompson, 1979).

In general, i) a high body core temperature prior to exercise, ii) a rapid increase in core temperature during exercise, and iii) an end core temperature contribute to the decreased performance in the heat (McLellan & Daanen, *submitted*). While the tolerance of high end body core temperature is related to training (Cheung & McLellan, 1998), the body heat storage either prior to or during the exercise may be manipulated by technical means. To decrease the body heat storage prior to the exercise, cooling (Marino, 2002), acclimation (Taylor, 2000) and hydration (Sawka *et al*., 2001) can be applied. In addition to these methods, clothing (Armstrong, 2000) and adjusting the pacing strategy (Tucker *et al.,* 2004) can reduce the increase in body heat storage during the exercise.

The work described in this thesis focuses on cooling, with particular interest in cooling prior to the exercise, i.e. pre-cooling. Pre-cooling has been shown to decrease initial body heat storage, reflected in reduced skin temperature and in some instances also body core temperatures (e.g. Gonzalez-Alonso *et al.,* 1999). This results in relieved heat strain during the exercise and in increased exercise performance (e.g. Arngrimsson *et al.,* 2004). Increased exercise performance is reflected in increased time to exhaustion, in total maximum work performed in a fixed time, or in a self-paced distance run or cycled in a fixed time (Marino, 2002). In laboratory settings, pre-cooling has been mainly provided using cold air exposure (Hessemer *et al.,* 1984; Schmidt & Bruck, 1981), water immersion (Bolster *et al.,* 1999; Booth *et al.,* 1997) and water perfused garments (Daanen *et al.,* 2006). In field settings, pre-cooling has been mainly provided with cooling vests (Hunter *et al.,* 2006). The functioning of cooling vests is based on ice-packs or frozen gels embedded in different garments. The intensity of cooling (cooling power) provided by a cooling vest has only been rarely addressed. Thus, the cooling power of such systems and the influence of its particular cooling power on the human body remain essentially unknown. Furthermore, only rarely have attempts been made to investigate ways to improve the cooling efficiency of such systems. As suggested by some authors (Cheuvront *et al.,* 2003; Young *et al.,* 1987; Shvartz, 1970), cooling efficiency might be improved by avoiding a vasoconstrictor response. Another limitation in the pre-cooling literature is that the effects of pre-cooling with a cooling vest have been investigated almost exclusively for running and cycling. For instance, Nadel *et al.* (1974) showed that increased body core temperature can also limit swimming performance. Thus, swimming may be another potential sport for the application of pre-cooling. To answer the mentioned unknowns and to fill the gaps in the existing knowledge on the interaction between personal cooling-systems, humans and the endurance exercise performance, the work presented in this thesis is reported and discussed as follows:

Chapter 2: This chapter provides a general overview on heat strain and cooling. A detailed overview of the effect of pre-cooling on exercise performance is given. **Chapter 3:** The thermal effects of personal cooling-systems are nowadays increasingly assessed with the use of thermal manikins. However, it is unknown if the results obtained with the thermal manikin are transferable to humans. This is of concern, since thermal manikins do not possess thermophysiological responses, such as skin vasoconstriction. This mechanism can, however, be simulated when the thermal manikin is coupled with the thermophysiological human simulator. In this chapter, we investigated the cooling power of two cooling-systems on humans, thermal manikin and a thermophysiological human simulator. Furthermore, thermophysiological responses, such as body core and skin temperature measured in humans, were compared with those predicted with a thermophysiological human simulator. **Chapter 4**: Although pre-cooling is known to enhance endurance exercise performance, the optimal cooling intensity is essentially unknown. The initiation of skin vasoconstriction is shown to decrease the heat transfer between the skin surface and the inner layer of the cooling-system. In the study presented, it was hypothesized that mild cooling, as opposed to strong cooling, will circumvent skin vasoconstriction and thermogenesis, and thus improve cooling efficiency reflected in improved time to exhaustion. **Chapter 5**: In an effort to improve the efficiency of pre-cooling, a different approach than the one described in Chapter 4 was chosen. Repeated cold exposures have been shown to lead to minor acclimation effects, including hypothermic adaptation. Specifically, repeated cold exposures were shown to reduce the vasoconstrictor response and to decrease body core temperature. Thus, it was hypothesized that repetitive cold exposure would potentially improve pre-cooling efficiency, reflected in improved time to exhaustion. **Chapter 6**: The limiting effect of increased body core temperature on endurance exercise performance is mainly shown for running and cycling. However, increased body core temperature can also limit swimming performance. The study described aimed at continuously measuring the body core temperature during all-out 1500 m swimming. Since an increase in body core temperature to the levels potentially causing heat strain was observed, it was hypothesized that pre-cooling might improve thermoregulatory state and exercise performance during swimming. Finally in **Chapter 7**, the main findings of the studies described are summarized and discussed. In addition, practical applications of the work presented in this thesis are given.

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