Chapter 7

General discussion

The work presented in this thesis aimed at answering the questions that the investigation of the interaction among personal cooling-systems, human body and exercise performance has not yet addressed. For this purpose the chapter 2 provided the basis for the understanding of the questions put forward in chapters 3 to 6. In chapters 3 to 6 the following questions were addressed: i) can be thermal effects of personal cooling-systems assessed with thermal manikins translated to the human participants, ii) are there possibilities to improve the cooling efficiency of personal cooling-systems iii) does application of pre-cooling-systems, apart from improving running and cycling performance, enhances also the swimming performance. The final chapter 7 aims at providing a summary of the results obtained through the chapters 3 to 6. The relevance of these results to the existing knowledge on the interaction among personal cooling-systems, human body and exercise performance will be given where possible. Furthermore, where possible, suggestions how the obtained results can be implemented into practice will be provided. The chapter 7 will conclude with recommendations for future research regarding the interaction among personal cooling-system, human body and exercise performance.

In the **chapter 3** we hypothesized that thermal effects of a personal cooling-system assessed using thermal manikin are not transferable to human participants. This is since application of personal cooling-system on human skin will induce vasoconstriction. Therefore, decreased skin blood flow will result in decreased heat transfer between the human body and the cooling-systems (Cheuvront *et al.,* 2003). Indeed, the results indicated that the heat transfer between the cooling-system and the human participants was lower than the one assessed with the thermal manikin. This observation was obtained independently from the intensity of the cooling provided by the cooling-system. Thus, it was suggested that the observed vasoconstriction is the underlying mechanism decreasing the heat transfer between the cooling-systems and the human body. Nevertheless, this limitation was at least partly overcome when the thermal manikin was coupled with the thermophysiological human simulator. Namely, compared with the thermal manikin, the thermophysiological human simulator was able to predict heat transfer between the cooling-system and the manikin, especially for the cooling-system providing mild cooling intensity. Furthermore, the thermophysiological human simulator also successfully predicted the course of body core temperature through cooling. The prediction of mean skin temperature was successful for mild cooling, but not for strong cooling. It is likely that this limitation originates in nonhomogeneity of cooling. Namely, the thermophysiological human simulator uses the average heat flux from the entire manikin as an input values for the physiological model. Thus, in case of strong cooling intensity, the heat extracted from the manikin's torso was relatively high compared to that lost from the whole manikin. This was however, not the case with mild cooling intensity. In summary, the results shows that in humans the ice-vest has more than double cooling power than the cooling-shirt. This also applies to the thermal manikin. However, cooling power determined using thermal manikin was two times higher for the cooling-shirt and 1.5 times higher for the ice-vest compared to the cooling power determined using human participants. This may be attributed to the absence of vasoconstriction in the surface of the manikin. The cooling power calculated using thermophysiological human simulator showed that cooling power of the cooling-shirt was in the same magnitude as measured for the humans. However, this method was insensitive for the stronger cooling supplied by the ice-vest. Thus, the cooling power of the ice-vest was seriously underestimated using the thermophysiological human simulator. In hindsight, the conclusions should be expended with the critical note that the thermophysiological human simulator is insensitive for strong cooling and should be applied with care.

Only few studies investigated the possibilities to improve cooling efficiency of personal cooling-systems (Cheuvront *et al.,* 2003; Shvartz, 1970; Webb, 1970). To our knowledge, however, none investigated the possibilities to improve the cooling efficiency for the cooling-systems used in sports, such as cooling vests. In the **chapter 4** we hypothesized that mild cooling opposed to strong cooling circumvents vasoconstriction and thermogenesis and improves cooling efficiency reflected in improved time to exhaustion. Mild and strong cooling intensity was provided by two cooling vests currently available in the market. The results showed that application of both cooling intensities induce vasoconstriction, whereas none of the cooling intensities cause thermogenesis. In fact, a decrease in body heat storage was two times higher for strong cooling compared to mild cooling. Furthermore, higher decrease in body heat storage for strong cooling was reflected in improved exercise performance. The results suggest that decreasing the intensity of cooling does not avoid vasoconstriction. Other authors (Duffield, 2008; Daanen *et al.,* 2006) suggested that increasing the surface area or the duration of pre-cooling amplifies the beneficial effects of pre-cooling on exercise performance. Our observations, however, suggest that also the intensity of cooling amplify the beneficial effects. Namely, strong cooling opposed to mild cooling improved exercise performance. For field applications, such as for competition, these results would suggest if an athlete can chose among various cooling vests (providing cooling to similar surface area), the athlete should chose the cooling vest providing the highest intensity of cooling. Only then it can be expected that pre-cooling is likely to have beneficial effects on subsequent exercise performance in hot environments.

Furthermore, to increase cooling efficiency another approach presented in **chapter 5** was chosen. Repeated cold exposures have been shown to lead to minor acclimation effects, including hypothermic adaptation. We hypothesized that such adaptation would potentially improve pre-cooling efficiency, reflected in improved subsequent exercise performance. We did not observe any effect of repetitive cooling on skin blood flow or any changes in intestinal or skin temperatures. Consequently, no changes in body heat storage were observed. It is assumed that this was observed due to the low cooling intensity applied. The change in body heat storage is reported to range from 6 to 13 $kJ \cdot kg^{-1}$ for cold air exposure and from 21 to 26 kJ·kg^{-1} for water immersions (Leppaluoto *et al.,* 2001). In the present study, however, the mean change in body heat storage upon cooling was limited to 3.6 ± 1.2 kJ·kg^{-1}. This mild repetitive cooling improves thermal perception and thermal comfort but it does not have any effect on cooling efficiency and exercise performance. These results suggest that no advantageous or disadvantageous effects can be expected if the athlete will use an ice-vest repetitively. However, it may be expected that with such procedure the athlete will feel less cold during pre-cooling.

The limiting effect of increased body core temperature for endurance exercise performance is mainly shown for running and cycling. However, Nadel *et al.,* (1974) showed the increased body core temperature can limit also swimming performance. Thus, in the study presented in **chapter 6** we hypothesise that if all-out 1500 m swimming performance causes increases of body core temperature above 38 °C, it is likely that application of pre-cooling might show beneficial effects on swimming performance. The body core temperatures higher than 38 °C are likely to negatively affect exercise performance (Nybo, 2008). The results obtained showed that 1500 m all-out swimming induces body core temperature to increase to 38.4 ± 0.4 °C. However, although pre-cooling prevented body core temperature to increase during warm-up and partly into the swimming, it did not improve exercise performance. The exercise performance in this study was self-paced. As addressed in sub-section 2.1.2, Tucker *et al.* (2004) suggests that for self-paced exercise afferent sensory input from the thermoreceptors in the skin must form part of integrated response that mediates decreased power output. Thus, not only increases in body core temperature but also increases in skin temperature can play an important role for regulating exercise performance. Since exercise was conducted in water, increases in skin temperature were not observed. In fact, the swimming was completed with mean skin temperatures of about 31.2 ± 1.2 °C. This is much lower than skin temperatures usually observed at the completion of running exercise in hot environments. Thus, the relatively low thermal input from the skin thermoreceptors may have contributed to the finding that the there were no differences in exercise performance although increases in body core temperature were observed. Nevertheless, it is of importance to note that all-out 1500 m swimming constitutes Olympic triathlon distance. Thus, swimming is followed by cycling and running. The reduced thermal strain during swimming may play an important role for subsequent running and cycling exercise. In addition, application of pre-cooling also prevented increases in body core temperature during the warm-up. This might be important aspect for an athlete prior to the competition, as preventing increases in body core and skin temperatures are very likely to improve athlete's thermal comfort in hot environments.

The results presented in this thesis show that cooling power of personal cooling-systems is overestimated when determined with thermal manikin and compared with the cooling power determined on human participants. It was shown that improving the cooling efficiency cannot be achieved using a decreased intensity of cooling. However, increasing the intensity of cooling is shown to improve the exercise performance. Furthermore, the efficiency of cooling is not likely to be improved with repetitive cooling. However, improvements in thermal sensation and thermal comfort are to be expected. And application of pre-cooling is shown to reduce heat strain during the swimming performance, however it does not improves the performance. Nevertheless, the observed decrease in heat strain might play an important role to improve heat strain and/or exercise performance during subsequent cycling and running performance.

7.1 Future work

In **chapter 3** we observed that the thermal manikin coupled with the thermophysiological human simulator provides assessment of thermal affects that can be translatable to human participants. However, this is only true for mild cooling intensities. Thus, for future work it is necessary to improve the model of human thermal physiology for strong intensities of cooling. Since to our knowledge this is the first study attempting to validate the assessment of personal cooling-system's thermal effects with the thermal manikin and the thermal manikin coupled with the model of human thermal physiology, future work needs to focus on the assessment of personal cooling-systems other than the cooling vests, in different environmental conditions and for different activities. Results obtained in the study presented in **chapter 4** showed that cooling efficiency cannot be avoided with decreasing the intensity of cooling. Nevertheless, it was observed that higher cooling intensity increase exercise performance. Thus, further developments of cooling vests should focus on the development of mechanisms to enable to provide high intensities of cooling. While on the other hand, the practical aspect of using such improved personal cooling-systems at field setting should not be disregarded. In addition, it would be worth to implement already known mechanisms enabling the improvements of cooling efficiency such as intermittent cooling and cooling the surface areas with low vasomotor tone. Furthermore, in **chapter 5** it has been shown that repetitive cooling does not improve cooling efficiency. Since, too low cooling intensity might prevented initiation of cold habituation future work should attempt to investigate if repetitive cooling of higher cooling intensities provokes cold adaptation. If this is true, it should be investigated if this results in improved cooling efficiency and exercise performance. Pre-cooling is shown not to enhance swimming performance in **chapter 6**. Nevertheless, it was shown that pre-cooling decreases thermal strain during the warm-up and at least partly into the exercise. All-out 1500 m swimming constitutes Olympic triathlon distance, thus the swimming is followed by cycling in running. Thus, for future research it is of importance to identify if decreased thermal strain during the swimming has an effect on subsequent cycling and running exercise.

References

Cheuvront SN, Kolka MA, Cadarette BS, Montain SJ & Sawka MN (2003) Efficacy of intermittent, regional microclimate cooling. J Appl Physiol 94: 1841-1848

Daanen H, van Es E & de Graaf J (2006) Heat Strain and gross efficiency during endurance exercise after lower, upper or whole body precooling in the heat. Int J Sports Med 26: 1-10

Leppaluoto J, Korhonen I & Hassi J (2001) Habituation of thermal sensations, skin temperatures, and norepinephrine in men exposed to cold air. J Appl Physiol 90: 1211-1218

Nadel ER, Holmer I, Bergh U, Astrand PO & Stolwijk JA (1974) Energy exchanges of swimming man. J Appl Physiol 36: 465-471

Nybo L (2008) Hyperthermia and fatigue. J Appl Physiol 104: 871-878

Shvartz E (1970) Effect of a cooling hood on physiological responses to work in a hot environment. J Appl Physiol 29: 36-39

Tucker R, Rauch L, Harley YX & Noakes TD (2004) Impaired exercise performance in the heat is associated with an anticipatory reduction in skeletal muscle recruitment. Pflugers Arch 448: 422-430

Webb P (1970) Thermoregulation in actively cooled working man In: *Physiological and behavioural temperature regulation* (eds) Hardy J D, Gagge A P & Stolwijk J A. Thomas, Springfield, USA, pp. 757-774