THE EFFECT OF A HOT CLIMATE AND EXTERNAL COOLING ON GRADED CYCLING PERFORMANCE

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Introduction

If heat production exceeds heat loss, heat storage will occur which eventually will lead to an increased core temperature – or hyperthermia. Hyperthermia is recognized as a major factor limiting endurance performance[4]. Arngrímsson et al.[2] for example investigated the effect of different climates (e.g. 18 vs 26°C WBGT) on graded exercise test (GXT) performance of runners. They found a reduced maximum oxygen uptake ($\dot{V}O_{2\,\max}$) due to a hot climate.

Applying external cooling to an endurance athlete during exercise is known to reduce heat strain[5] and to improve subjective perception[3]. However, applying external cooling on the skin might also have a detrimental effect on the thermoregulatory response of the body. It is sometimes found to reduce sweat production[6] and to increase vasoconstriction of blood vessels in the skin[1].

The goal of this study is to quantify the deterioration of endurance performance, expressed in time to exhaustion and maximum oxygen uptake, due to a hot climate. If so, to test whether the performance deterioration can (partly) be counterbalanced by application of external cooling on the skin.

Figure 1. A subject on the cycle ergometer wearing the cooling garments.
Photo: TNO Defence, Security and Safety.

Methods

Eight male cyclists voluntarily participated in one standard GXT (sGXT) and three individualized GXTs (iGXT), which were separated by at least 5 days. From the sGXT maximum external power (P_{max}) was obtained. The following protocol was used for the iGXT; 10 min warming up period at 30% P_{max} outside the climatic chamber, which was followed by body weight determination after which the subjects entered the climatic chamber. In the climatic chamber the individualized GXT was conducted on a cycle ergometer, starting at 30% P_{max} and increased every minute with 3.5% P_{max} until exhaustion. The following trials were randomly assigned:

- 9.3 °C WBGT (T_a=10°C and 85% RH) cold no cooling (CN);
- 23.8°C WBGT (T_a=35°C and 19% RH) hot no cooling (HN);
- 23.8°C WBGT (T_a=35°C and 19% RH) Hot with cooling (HC).

The absolute water vapor pressure was almost consistent throughout all trials (1.04kPa vs. 1.10kPa). Therefore sweat could evaporate at the same rate at equal skin temperatures. To ensure equal circumstances, a water perfused cooling suit (long sleeved shirts and trousers, Delta Temax, Med-Eng Systems, Canada, size M and L, figure 1), was worn in all conditions. Only in condition C the shirt and trousers were connected to separate cooling circuits consisting of insulated tubes and a thermostat bath with an integrated pump (Tamson TLC 3, Tamson, The Netherlands).

During the trials exercise time, oxygen consumption, skin temperature at four sites ($\bar{T}_s$), rectal temperature (T_{re}), heart rate (HR) and weight change were recorded, along with temperature and velocity of in and out flowing cooling water in both circuits and 4 subjective scales were scored (rating of perceived exertion, perceived comfort, perceived temperature and perceived wetness). Average body temperature ($\bar{T}_b$), heat storage (S), wet heat loss (E) and cooling power of the garment (P_c) were calculated.

An ANOVA repeated measures was used to test the overall results and the average values from t=0; 4; 8; 12; 16 and end min. Significance was reached if $p<0.05$. The study was approved by a medical ethical committee.

Results

A malfunction of the humidity regulator of the climatic chamber occurred, causing a large variation in RH of the cold trials (table 1).

Table 1. Average climate characteristics.

Trial	Subgroup	WBGT (°C)	T_a (°C)	RH (%)
CN	Overall	9.5	12.5 (±1.6)	56.1 (±24)
	Low RH	11.6	13.1 (±2.3)	78.1 (±5)
	High RH	7.4	11.9 (±0.4)	34.1 (±10)
HN		22.3	35.1 (±0.5)	12.7 (±4)
HC		21.8	34.7 (±0.8)	11.3 (±2)

Overall effect

Time to exhaustion was similar for all conditions, CN (21:17 ±1:04), HN (20:23 ±0:50) and HC (20:38 ±1:13). Moreover, no difference was found in time to exhaustion nor in $\dot{V}O_{2\max}$.

Rectal temperatures reached maximum values of 38.1 (±0.3), 38.4 (±0.2) and 38.1 (± 0.2)°C respectively. Observed differences between CN, HN en HC are shown in Table 2.

Table 2. Observed differences between conditions

		Trial		
		CN	**HN**	**HC**
Variable	**Unit**	**Mean (sd)**	**Mean (sd)**	**Mean (sd)**
$\Delta\overline{T}_s$	°C	1.09 (±1.09)	3.76 (±0.63)	2.74 (±1.49)
Effect		HN↑ HC↑	CN↓	CN↓
$\Delta\overline{T}_b$	°C	0.67 (±0.34)	1.32 (±0.27)	1.03 (±0.34)
Effect		HN↑ HC↑	CN↓ HC↓	CN↓ HN↑
Heat storage	$W*m^{-2}$	74 (±38)	145 (±28)	113 (±35)
Effect		HN↑ HC↑	CN↓ HC↓	CN↓ HN↑
Evaporation	$W*m^{-2}$	240 (±43)	332 (±42)	288 (±47)
Effect		HN↑	CN↓ HC ↓	HN↑
Perceived temperature		2.6 (±1.3)	3.8 (±0.5)	2.9 (±0.9)
Effect		HN↑	CN↓ HC ↓	HN↑

Time effect

The average development of $\overline{T}_s$ is shown in figure 2. $\overline{T}_s$, $\overline{T}_b$ and S showed a significant different development in the first 8 min after onset of the iGXT, whereby HN increased more rapidly than HC which, at its turn, increased more rapidly than CN.

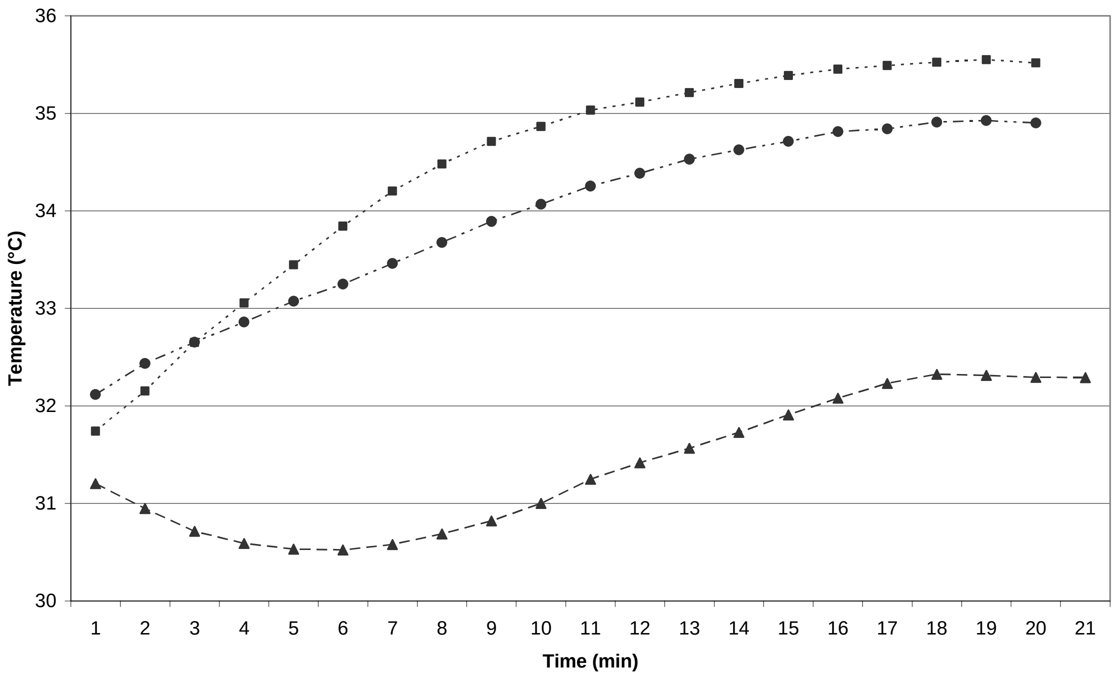

Figure 2. The average skin temperature (n=8) in all three conditions CN (▲), HN (■) and HC (●).

Cooling system

Based on the temperature difference between suit inlet and outlet temperature and rate of flow it was calculated that the heat gain of the water in the cooling suit was 319 (±24) W. The cooling power of the suit was consistent throughout the iGXT. This resulted in a significant lower heat storage in the body of 30 $W*m^{-2}$, compared to condition HN. Therefore the cooling efficiency was 19%.

Discussion

Although significant influences of climate and cooling on thermal parameters were shown, no influence of a hot climate or application of external cooling was found on graded cycling performance. An explanation is that the climate and exercise protocol did not result in high core temperatures. The core temperature is generally recognized as the cause of performance deterioration in a hot climate[4].

However, the heat storage was reduced due to the application of external cooling. Therefore it increases the heat buffer of the body and might, under more severe or longer lasting conditions, result in a reduced core temperature increase. External cooling also resulted in a favorable perceived temperature. A negative effect of the external cooling was observed in a reduced wet heat loss, which is consistent with other research[6].

Partly due to the reduced wet heat loss a cooling efficiency of only 19% was observed. Thus it will be hard to substantially improve endurance performance in a hot climate with functional sports clothing based on external cooling. However, in elite sports performance marginal advantages can result in the gold medal or no medal at all.

From the time analysis it became clear that cooling was most effective in the first 8 min of exercise, while metabolic heat production was low. Therefore it remains unclear if applied cooling would benefit elite endurance performance while these athletes have a consistent high heat production.

It is recommended that more research is conducted on the effect of external cooling on endurance performance during a simulated race in controlled conditions. The cooling efficiency is another point of interest for future research since this could be the key in development effective and functional performance enhancing sportswear. Moreover, it has to be taken into account that active cooling is currently hard to realize in sport events, but innovative designs may lower the threshold for use.

Conclusions

The external cooling applied in this study resulted in reduced heat storage in the body and a favorable temperature sensation. Therefore it holds the potential of enhancing endurance performance in a hot climate. Unfortunately, a cooling efficiency of only 19% was observed. More research is necessary, particularly to gain more insight in how to optimize cooling efficiency.

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