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Effects of pre-cooling on thermoregulation and endurance exercise

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ABSTRACT

Warm and humid climatic conditions have a negative effect on endurance performance. The classic strategy to tackle the problem from a performance perspective is twofold: compensation of the organism's negative water balance and optimisiation of the adaptation mechanisms to high ambient temperatures. However, because these strategies have only limited effects and because they do not decisively affect the heat-induced decrease in performance, further means have been discussed and, to a certain extent, put into practice. A number of researchers, coaches and athletes have explored the possibility of cooling the body prior to exercise, through the use of cooling jackets and other items worn by the athlete and through the use of cooling chambers, as a means to improve endurance performance. This article discusses the fundamentals of pre-cooling and summarises key studies on the techniques conducted to date. The authors conclude that external cooling is a sensible and necessary means to avoid or attenuate the performance-reducing effects of heat in endurance sports.

AUTHORS

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Introduction

Warm and humid climatic conditions have a negative effect on endurance performance and research confirms that increased body heat is a limiting factor during exercise (MARINO, 2002). This, of course, affects sports events. At the Olympic Games in Atlanta (1996) and Athens (2004), for example, athletes faced above-average ambient temperatures and these had a negative effect on performances, particularly in the endurance sports. Very probably, cometitors will face a similar situation at the coming Games in Beijing (2008).

The classic strategy to tackle the problem from a performance perspective is twofold: compensation of the organism's negative water balance and optimisiation of the adaptation mechanisms to high ambient temperatures. However, because these strategies have only limited effects and because they do not decisively affect the heat-induced decrease in performance, further means have been discussed and, to a certain extent, put into practice in an effort to improve the heat tolerance of top-level athletes.

A number of researchers, coaches and athletes have explored the possibility of cooling the body prior to exercise, through the use of cooling jackets and other items worn by the athlete and through the use of cooling chambers, as a means to improve endurance performance. The findings point to significant potential in this area and at the Olympic Games in Athens athletes from some German teams made use of this possibility.

This article discusses the fundamentals of pre-cooling and summarises key studies on the techniques that have been conducted to date.

Fundamentals of thermoregulation

The work of the muscles during endurance exercise causes the body's core temperature to increase. In the musculature the temperature can rise from circa 34°C under resting conditions to over 40°C during long and intensive exercise. The blood flow carries the heat out of the muscles to the rest of the body and, although delayed, this leads to an increase of the body's core temperature. This endogenic heat production. for example marathon runners – but above all in endurance sports with an interval character (DRUST et al, 2000) – leads to body core temperatures which can increase to up to 42°C in extreme cases (MARON et al, 1977). Even in cross-country skiers competing under ambient temperatures below 0°C, body core temperatures of more than 40°C have been measured. In isolated cases and following extreme heat development, rectal temperatures of 43°C (without harm to the subject) have been recorded (KHOGALI and HALES, 1983).

These high body core temperatures far exceed the so-called "optimum temperature" for physical performance of 38.5-39°C and invite performance-reducing effects. There are several physiological processes responsible for the attenuation of the endurance performance under heat conditions:

- There is, in the main, an increase of energy consumption – to allow the body to maintain its thermoregulatory functions - which amounts to c. 75%. This means that only the remaining part of the energy can be used for muscular locomotion. BADKE (1995) uses the term: "utility effect of muscle activity", which amounts, at best, to 30% in humans. At least, 70% of the transformed energy is converted into heat.
- Following an expansion of the skin's vascular capacity (vasodilation), blood is transferred from the body's core to the peripheral areas - to facilitate heat loss to the atmosphere. This transfer results in a reduction of blood volume in central parts of the circulatory system, which, in turn, leads to an increase in heart rate and a concomitant reduction in stroke volume.
- Sweat production sets in at a skin temperature of more than 35°C. Energy is needed for this: one litre of evaporated sweat extracts c. 580 kcal from the organism.
- Due to the limited blood supply, and earlier than under normal ambient temperature conditions, the muscle is forced to partially draw the energy necessary for producing muscle work via anaerobic processes.
- With extended work duration under heat conditions, the maximum oxygen uptake is reduced by 25%.

Moreover, under conditions of high ambient temperatures and concurrent physical work, the risk to the athlete's health increases as the endogenous cooling processes are less and less able to compensate for the twofold performance-reducing heating effect on the organism. The thermal stress can lead to heat exhaustion or heat stroke (BOLSTER et al, 1999).

For endurance exercises on the time scale and intensity of a marathon, 10 to 12°C is seen as the optimum temperature range. Indeed, the world record in the marathon (2:04:55 by Paul Tergat of Kenya) was run at an outdoor temperature of 10°C on 28 September 2003 in Berlin. The women's world record (2:15:25 by Paula Radcliffe of Great Britain) was accomplished at an outdoor temperature of 12°C on 13 April 2003 in London. Under the demands of endurance performance the so-called comfort temperatures (c. 20-23°C), which are valid under resting conditions, result in considerable heat stress.

The relevance of thermoregulation for physical performance, meaning the interplay of heat and cold in the context of physical performance, has been predominantly presented, hitherto, one-sidedly in favour of the heat. However, according to BRÜCK (1987), such a "heat-fixation" 'is not compatible with the physiological facts' because if the body is cooled in advance of physical strain (the cause of heat production) there is an enhancement of the oxygen pulse with the effect of an increase in stroke volume and an improved exploitation of the blood's oxygen content. Both effects lead to a temperature induced economising of circulatory functions and thus to improved endurance performance.

In an effort to take advantage of this phenomenon and prevent the negative effects of heat on performance, two methods of external cooling have been tried – whole body pre-cooling (wbPC) and partial pre-cooling (pPC).

Effects of Pre-cooling

In the context of pre-cooling, and irrespective of the traditional cold water or ice applications, we have to differentiate between, on the one hand, partial body cold applications, of which the one using a cooling jacket is the most widely discussed method (see also DICKHUT et al, 2004), and a whole body cold application in a cold chamber at -110°C, on the other hand.

Partial Pre-cooling

In the following, we are referring to two internationally published studies on endurance sports under heat conditions using cooling jackets, that come to claerly positive results.

Study 1: Pre-cooling via cooling jackets resulted in an increase of performance of 16 to 17.5% in a 35 minute endurance exercise protocol (COTTER et al., 2001).

Performance was increased after pre-cooling to 2.95 + 0.24 W kg $^{-1}$ without additional leg cooling (LW) and to 2.91 + 0.25 W kg $^{-1}$ with additional leg cooling (LC). In control, performance only amounted to 2.52 + 0.28 W kg $^{-1}$ (p = 0.00).

In addition, pre-cooling led to a drop in body core temperature of 1.9°C in the LW group and of 2.8°C in the LC group, respectively. At the same time, pre-cooling caused a decrease in heart rate in both groups: under norm conditions the test was performed at 96.1 + 1.8 % of the maximum heart rate but it was performed at 95.3 + 1.8 % after pre-cooling in the LW group and at 95.8 + 1.5% in the LC group. The additional use of cooling cuffs did not show any extra effects.

Conclusion

The study proves the positive effects of pre-cooling via cooling jackets ("...effectively reduced physiological and psychophysical strain such that endurance performance was significantly improved in moderately-humid heat"; COTTER et al., 2001, p. 677).

Study 2: Pre-cooling-induced increase in endurance performance in triathletes during cycling (SMITH et al., 1997)

This study also proves a pre-cooling-induced increase in endurance performance. The cooling jacket was worn during the warm up period – or rather the preparation period (at the outset: 75 Watt/min then in stages of 25 Watt/min up to 200 Watts/min). At the end of the warm up (at 200 Watt) exercising was continued to the individual's point of exhaustion without the cooling jacket. Pre-cooling increased the break up time significantly ($p < .05$) to 34.8 + 6.8 min (vs. 33.7 + 6.7 min without pre-cooling). The maximum performance after pre-cooling amounted to 341 + 56.7 Watt vs. 332 + 56.0 Watt ($p < .05$). The higher exercise time after pre-cooling led, analogously, to a higher lactate break up value: 11.0 + 3.7 mmol/l vs. 10.0 + 3.2 mmol/l.

Conclusion

The study ascertains positive effects of pre-cooling ("use of the cooling vest delayed the onset of fatigue in the heat"; SMITH et al., 1997, p. 263).

Whole Body Pre-cooling

The following refers to the most important results found in our research projects (JOCH, ÜCKERT and FRICKE, 2004; JOCH and ÜCKERT, 2003):

- Using a sub-maximum interval exercise protocol (heart rate between 162 and 178 bpm) in an ergometer test with different exercise intensities (between 150 and 250 Watts) over a duration of 26 minutes, highly significantly ($p < .001$) lower heart rate values were ascertained, on average, after whole body pre-cooling than under the same conditions without cold application in advance (n = 17 male subjects). The absolute heart rate values were 6 to 12 bpm lower – an average of 7%.
- Lactate measurement was carried out in the same test at the 8th, 16th and 24th minutes always at the end of the 250 watt level. The results show that at all points of measurement the lactate values were lower after pre-cooling (PC) than in the control without pre-cooling (C):
  - *at minute 8 the difference amounted to 0.9 mmol/l: 5.7 (C) and 4.8 mmol/l (PC)*
  - *at minute 16 the difference amounted to 0.8 mmol/l: 7.1 (C) and 6.3 mmol/l (PC)*
  - *at minute 24 the difference amounted to 0.4 mmol/l: 6.5 (C) and 6.1 mmol/l (PC).*

These findings do not corroborate the results of LEE and HAYMES (1995) who found that pre-cooling had no effect on lactate production. On the other hand, they do corroborate the finding by the same authors that the effects seem to diminish in the course of exercise duration.

- Under the exercise conditions mentioned above, energy-consumption was recorded at the 8th, 16th and 24th minute. It was found here that calorie consumption

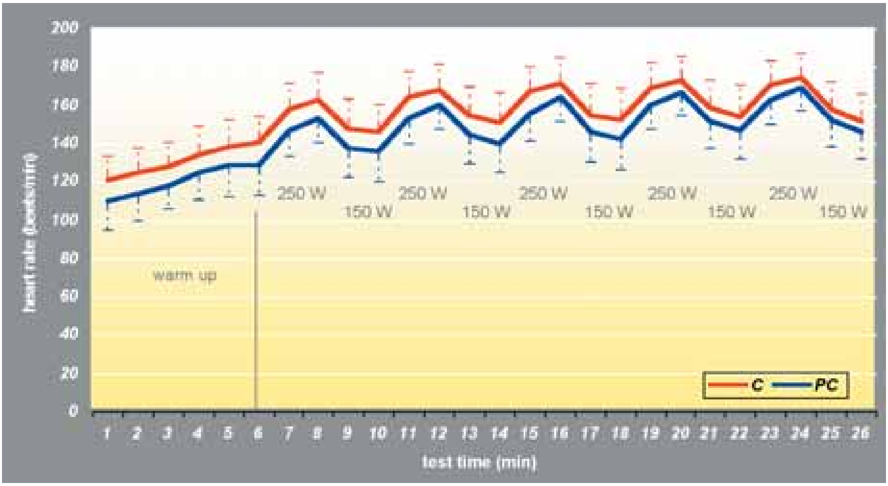

Figure 1: Heart rate values in a sub-maximum interval ergometer test, with different exercise levels between 150 and 250 Watts (C = control; PC = pre-cooling)

under precooling conditions was always lower than without whole body pre-cooling. The decrease under pre-cooling conditions amounted to 12 % (8th minute), 15% (16th minute) and 32% (24th min).

Conclusion

External cooling is a sensible and necessary means to avoid or attenuate the performance-reducing effects of heat – normally boosted by high ambient temperatures – in endurance sports. Such cooling (beyond traditional cold water or ice application) can be applied in different ways:

- As pre-cooling, i.e. as a means of preparation for training and competition;
- During training and competition if the cooling jackets weight does not lead to a reduction in performance;
- After training and competition: especially as a regeneration-enhancer (ÜCKERT and JOCH, 2003);
- At competition breaks, e.g. in games but also in throwing and jumping disciplines in track and field.

With respect to the effects, cold chambers provide favourable and scientifically well-documented conditions but, however, due to the stationary nature of such chambers, their use is limited to training and they are only employable locally.

Cooling jackets, whose weight under operation conditions differ - depending on the manufacturer - between 800g and 3kg, provide good conditions for training and competition in most endurance sports. They can be used systematically in competition practice and in a wide field of applications.

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REFERENCES

BADTKE, G. (Hrsg.): Lehrbuch der Sportmedizin. Johann Amborius Barth Verlag. Heidelberg/ Leipzig, 3. Auflage.1995

BOLSTER, D.R.; TRAPPE, S.W.; SHORT, K.R.; SCHEFFIELD-MOORE, M.; PARCELL, A.C.; SCHULZE, K.M.; COSTILL, D.L.: Effects of pre-cooling on thermoregulation during subsequent exercise. Medicine and Science in Sports and Exercise 31, 2 (1999) 251-257.

COTTER, J.D. et al.: Effect of pre-cooling, with and without high cooling, on strain and endurance exercise performance in the heat. Comparative Biochemisty and Physiology Part A 123, 667-677. 2001

DICKHUT, H.H. et al: Sport unter besonderen klimatischen Bedingungen – am Beispiel der Olympischen Spiele ... 2004 in Athen, hrsg. vom Bundesinstitut für Sportwissenschaft. Bonn, 2004

JOCH, W.; ÜCKERT, S.: Ausdauerleistung nach Kälteapplikation. Leistungssport 33, 6 (2003) 17 - 22

JOCH, W.; ÜCKERT, S.; FRICKE, R.: Die Bedeutung kurzfristig und hoch dosierter Kälteapplikation für die Realisierung sportlicher Leistungen. BISp-Jahrbuch 2003, Bonn, 245-252

KHOGALI, M.; HALES, J.R.S.: Heat Stroke and Temperature Regulation. Sidney-New York-London: Akademic Press, 1983

LEE, D.T.; HAYMES, E.M.: Exercise duration and thermoregulatory responses after whole body precooling. In: J. Appl. Physiol. 79 (1995) 1971-1979

MARINO, F.E.: Methods, advantages, and limitations of body cooling for exercise performance. Br. J. Sports Med. 36 (2002) 89-94

MARON, M.B. et al.: Thermoregulatory responses during competitive marathon running. J. Appl. Physiol. 42 (1977) 909.

SMITH et al.: Pre-cooling improves cycling performance in hot/humid conditions. Medicine and Science in Sports and Exercise 29, 5 (1997), Supplement, 263

TENFORDE, A.: The effects of cooling core body temperature on overall strength gains and post-exrercise recovery. Spring (2003) 57-61

ÜCKERT, S.; JOCH, W.: Der Einfluss von Kälte auf die Herzfrequenzvariabilität. Österr. J. Sportmedizin 33, 2, (2003) 14-20