The effects of warm-up and pre-cooling on endurance performance in high ambient temperatures

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ABSTRACT

It is well established that warm conditions have a detrimental effect on endurance performance. If skin temperature is exceeded by the ambient temperature, heat dissipation is impaired and heat storage is likely to occur. A warm-up, which by definition entails increasing body temperature, is generally considered a vital part of the preparation for competition - including endurance performances in hot weather. On this understanding, the question arises if cooling prior to competition (pre-cooling) might be a better alternative. Twenty subjects performed two laboratory endurance tests in conditions of high ambient temperature and relative humidity. One test followed a 20-minute warm-up and the other a 20-minute pre-cooling procedure. The comparison of results shows that pre-cooling significantly extends the time to exhaustion and slows the increase in both body core temperature and heart rate. The authors conclude that pre-cooling, as opposed to a warm-up, optimises thermoregulatory processes before physical effort in warm conditions.

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Introduction

It is well established that high ambient temperatures have a detrimental effect on endurance performance (NADEL 1993). Our studies support findings that endurance performance is reduced with respect to duration as well as physiological and psychological performance parameters. Compared with temperate conditions (20°C), a high ambient temperature of 30°C led to a 2.3% decrease in performance in a 10-minute exercise bout (JOCH, ÜCKERT ET AL 2006, 35). However, the question of which strategies can be applied to compensate for or minimise heat-induced decreases in performance has been left largely unanswered. Sufficient fluid intake is a possible answer (FALK 1996) and cold application provides another (JOCH, ÜCKERT 2003).

If we focus on endurance performance in heat conditions, the question arises whether warming up (including the concomitant increase in core temperature) is sensible considering the additional thermal stress it creates (GONZALES-ALONSO ET AL 1999). It is useful, therefore, to compare the effects of a warm-up and pre-cooling. The practical relevance lies in the fact that:

- Competitions, such as the 2008 Olympic Games in Beijing, will be held in ambient temperatures exceeding 30°C at all times of day.
- There is no coherent (systematically and experimentally tested) position in the literature on the implications of warm-up (or, possibly, alternatives to it) for endurance performance in high ambient temperatures.
- Although pre-cooling has been discussed more widely during the last two decades, it has not yet been compared with an active warm-up.

The following hypotheses can be deduced from the biological fundamentals of thermoregulation and the science-based standards of preparing for competition.

- Due to higher core temperatures, endurance performance is impaired after warm-up. Indicators of this effect are: decreased time to exhaustion, increased heart rate, increased lactate concentration and higher core temperature at exhaustion.
- The decisive performance parameters measured in an exercise protocol are better after pre-cooling than after warm-up: increased time to exhaustion, decreased heart rate, decreased lactate concentration and decreased core temperature.

Methods

Twenty male subjects between 20 to 35 years of age (mean: age 25.4 years; weight 77kg; height 183cm) performed two endurance tests over a period of three weeks. Both tests were performed in the laboratory in an ambient temperature of 30°C and 55% relative humidity. All subjects performed the tests in identical conditions. The tests were performed in randomised order according to the different types of preparation: 20-minute warm-up (WU) and 20-minute pre-cooling (PC). The warm-up was performed at an intensity of 70% of the individual maximum heart rate. For pre-cooling, a cooling vest (Arctic Heat), which had a temperature of 1 to 4° Celsius (in accord with the manufacturer's recommendation), was worn on the skin.

The exercise pattern consisted of an incremental endurance test (ZINTL/EISENHUT 2001) on the treadmill (Kinetic S 3 [Kettler] Ense, Germany). The protocol commenced at a workload of 9 km/h (NEUMANN ET AL. 2005) and this was increased by 1 km/h every 5 minutes until volitional fatigue and break-up of the test.

Volitional fatigue and break-up were determined in accordance with the subjects' personal perception. Heart rate (beats per minute) was continuously measured by a heart rate monitor (S 810 [Polar], Kempele, Finland). Core temperature was measured in the inner auditory canal by an infrared ear-thermometer (ThermoScan 602 [Braun], Königsberg, Germany) after 5, 10, 15, 20, 25, and 30 minutes as well as after volitional break-up. Blood lactate values were measured in a blood sample taken from the finger after 5, 15, and 25 minutes and at the point of volitional break-up.

Results

Break-up time

In the WU tests, subjects had to discontinue the exercise after 26 minutes (average: 26:51) whereas in the PC tests the subjects performed for 32 minutes (average: 32:27) before reaching their point of volitional fatigue and break-up. This is a difference of more than 5 minutes (5:36) or 20% (20.85), respectively. The difference in favour of pre-cooling is significant ($p < 0.001$). No contrary result was found in any of the 20 subjects.

Table 1: Mean core temperature during the endurance step test on the treadmill after preliminary warm-up (WU) and after pre-cooling (PC) respectively; with n = 20 male subjects – regressive number after 25 minutes of testing.

Test pairs / time	Core temperature in degree	Difference (absolut percent)	Number (n)	Significance (p)
5 min	36.96° (PC) - 37.41 (WU)	0.45 / 1.21%	20 (PC/WU)	p≤0.003 (s)
10 min	37.04° (PC) - 37.55 (WU)	0.51 / 1.37%	20 (PC/WU)	p≤0.001 (s)
15 min	37.18° (PC) - 37.67 (WU)	0.49 / 1.31%	20 (PC/WU)	p≤0.003 (s)
20 min	37.34° (PC) - 37.95 (WU)	0.61 / 1.63%	20 (PC/WU)	p≤0.001 (s)
25 min	37.50° (PC) - 38.05 (WU)	0.55 / 1.46%	20 (PC)-16 (WU)	p≤0.004 (s)
30 min	37.86° (PC) - 38.57 (WU)	0.71 / 1.69%	19 (PC)-13 (WU)	p≤0.001 (s)
35 min	38.14° (PC) - 38.84 (WU)	0.70 / 1.83%	12 (PC)-4 (WU)	p≤0.119 (ns)

Core temperature

Core temperature prior to testing was identical in both sets of tests and averaged 36.32°C. However, during the warm-up, core temperature rose to an average of 37.61°C, exceeding the value recorded after pre-cooling (average: 37.06°C) by 0.55°. On the basis of this data, it can be assumed that pre-cooling does not lead to a decrease in core temperature but only to a decrease in skin temperature, which enhances the body's ability to dissipate heat from the core to the environment. During the first 20 minutes of the WU tests, core temperature rose by 0.33° to an average of 37.95°C whereas in the PC tests the increase amounted to only 0.28° (average: 37.34°C). All measured differences in temperature between the two conditions are statistically significant ($p<.05$). The 20-minute point was chosen as the reference time because all subjects (n = 20) were still exercising for the whole of the period. From then on, depending on the individual fitness level, subjects had to break up the test at

Table 2: Mean heart rate during the endurance step test on a treadmill after preliminary warm up (WU) and pre-cooling (PC), respectively; with n = 20 male subjects – regressive number after 25 minutes of testing.

Test pairs / time	Heart rate (in beats per min)	Difference (absolut percent)	Number (n)	Significance (p)
5 min	123.45(PC) - 141.80(WU)	18.35/	20 (PC/WU)	p≤0.001 (s)
10 min	139.40(PC) - 155.75(WU)	15.35/	20 (PC/WU)	p≤0.001 (s)
15 min	151.80(PC) - 166.00(WU)	14.20/	20 (PC/WU)	p≤0.001 (s)
20 min	162.45(PC) - 176.60(WU)	14.15/	20 (PC/WU)	p≤0.001 (s)
25 min	172.41(PC) - 182.41(WU)	10.00/	19 (PC)-17 (WU)	p≤0.001 (s)
30 min	179.15(PC) - 186.00(WU)	6.85/	13 (PC)-13 (WU)	p≤0.004 (s)
35 min	180.33(PC) - 186.67(WU)	6.34/	3 (PC)-3 (WU)	p≤0.5 (ns)

different points. After 30 minutes of exercise (WU tests: n = 13; PC tests: n = 19), the difference between 38.57°C after warm-up and pre-cooling amounted to 0.73° (38.57°C v. 37.84°C). Thus, we can say that core temperature rises progressively in the course of an endurance test; however, this progression is more distinct in WU than in PC conditions.

Heart rate

After 20 minutes of exercise (n = 20 in WU and PC), the subjects' mean heart rate increased to 175.6 bpm in the WU tests and to 162.4 bpm in the PC tests, a difference of 14.4 bpm or more than 10%. In the 30th minute, the difference between the PC tests (186 bpm; n = 16) and the PC tests (179.2 bpm; n = 16) in an average of 6.8 bpm or 3.8%. The relatively small difference at this point is, presumably, be explained by the drop out of four less fit subjects. It is noticeable that the highest heart rate differences occur at the beginning of the tests (see Table 1). Over the course of testing, the differences taper off successively. This implies that, particularly in the beginning of an endurance test, pre-cooling prevails over warm-up. All differences in heart rate in the 20th and the 30th minute are significant according to the paired t-test ($p < .05$).

Lactate

The blood lactate values presented and interpreted here are only those up to the 25th minute because by the 35th minute only 2 (WU) and 8 (PC) subjects respectively were still exercising. After 25 minutes, 17 (WU) and 20 (PC) subjects respectively were still exercising. Among these, a mean blood lactate value of 4.55 mmol/l was measured in the WU tests compared with 5.15 mmol/l in the PC tests. This difference is not statistically significant.

Discussion

The results of the study show quite conclusively that in high ambient temperatures warming up in preparation for an endurance performance is performance reducing rather than performance enhancing compared with a pre-cooling procedure. The performance duration is distinctly lower – after a 20-minute warm-up procedure at 70% of maximum heart rate, subjects had to break up the endurance step test earlier, indicating a lower performance maximum. Heart rate and core temperature, both factors limiting endurance performance, are also distinctly higher at pre-set points of the test (20th and 30th minute) if the subjects warmed up prior to testing instead of completing a pre-cooling procedure. Only in regard to the blood lactate values, is this correlation less distinct, although, in the beginning of the endurance test, after 5 and 15 minutes, lactate values are still slightly lower after pre-cooling than after a warm-up. Therefore, considering the lactate values, pre-cooling seems to affect performance particularly in the beginning of endurance loading - temporally close to the pre-cooling procedure.

Pre-cooling, as practiced here - this is the overall result of this study – is to be preferred over warm-up as a means of preparing for an endurance performance in conditions of high ambient temperatures. The positive physiological effects of pre-cooling compared to a warm-up are more discernable in the beginning of loading (temporally close to the cooling procedure) than later on. This holds true for the heart rate as well as the lactate values. The improved endurance performance becomes particularly visible in the distinctly longer period of exercising until reaching the point of volitional fatigue and break-up. Against the background of these results, the following explanatory conclusions can be drawn:

Pre-warming, in the sense of a “classic” warm-up, necessitates a higher thermoregulatory effort. This result can be deduced from, among others, higher heart rate values measured at the same load. Particularly in the beginning of the test this greater effort becomes visible. In the course of progressive body warming, induced by the working muscles – and without additional cooling (!) – the difference in effort is reduced.

Only a minor part of the whole amount of energy available to the body, about 25%, is used for muscular locomotion; the remainder is required for thermoregulation. This is associated with the fact that human core temperature is kept constantly at 37°C (with only a small range of variation) in order to ensure optimal functioning of the inner organs such as the liver, the kidneys and the brain. To guarantee a constant status of 37°C in the core, permanent thermoregulation - between core and periphery as well as between the heat producing working muscles and the heat dissipating skin – is necessary. If this self-regulating system is destabilised by high ambient temperatures, the increased heat production of the working muscles and, additionally, a warm-up procedure, a heat surplus becomes inevitable. This necessitates a greater cooling effort by the thermoregulatory system otherwise the total system would collapse (hyperthermia). Therefore, if more than 75% and in some cases even up to 90% is necessary for body cooling, less energy is available for muscular locomotion. The result is an immoderately high expenditure of energy and, thus, a reduction in physical performance (locomotion). The impairments for physical performance after a warm-up are the clearest at the beginning of testing, which is proof of the fact that the external cooling is the proximate cause of the better performance in the pre-cooling tests.

Pre-cooling, as opposed to a warm-up, optimises thermoregulatory processes. Normally in extreme heat conditions, the human thermoregulatory system cannot do without external cooling. Such conditions are predominantly found in sports, particularly, if a lot of heat is produced in the working muscles and, due to high ambient temperatures, this heat surplus can not be dissipated to the environment by conventional thermoregulatory mechanisms (convection, conduction, radiation, and sweating). In this context, convection (dissipation of heat via the blood stream) is of extraordinary importance. However, if the ambient temperature and, thus, the skin temperature are elevated, this mechanism is impaired. Therefore, skin cooling is particularly important because heat can only be transported from locations of higher temperatures to those of lower temperatures. This cooling can be achieved either by evaporation of sweat on the skin or by wearing a cooling vest beforehand.

For this reason, pre-cooling (via a cooling vest) aims primarily at cooling the skin and not at a reduction of core temperature. The increase of core temperature during the pre-cooling procedure from 36.52° to 37.06°C (Table 1) shows that core temperature is higher than before, although not as high as after a warm-up (37.61°C). Therefore, it can be stated that the body core and its temperature are largely unaffected by a cooling procedure using a cooling vest. External body cooling, as a prophylactic procedure, supports the human thermoregulatory system insofar as it compensates for the fact that the evaporation of sweat alone does not suffice in reducing skin temperature, which is necessary for convective heat dissipation. Significantly lower heart rate values, particularly in the beginning of loading (thus immediately after cooling), are proof of thermoregulatory optimisation.

Ideal ambient temperatures for endurance performances

The accurate determination of an ideal ambient temperature depends on the duration of loading: the longer the duration and, therefore, the period of muscular work, the higher is the rate of the body's heat production and the lower the ambient temperature should be in order to prevent a blatant and performance reducing heat surplus. In a marathon for example, it is a range of 10 to 12° C. This is not only a theoretical optimum but also a value frequently backed up by sports practice: the current world best marks in marathon running in the men's event (Tergat (KEN) 2:04:55, Berlin, 28 September 2003) as well as in the women's event (Radcliffe (GBR) 2:15:25, London, 13 April 2003) were run in this temperature range. For shorter endurance performances the ambient temperatures can be slightly higher, say 18 to 20°C. The shorter the duration of performance, the higher is the ideal performance enhancing ambient temperature – for 400m and 800m races even up to 28°C.

Consequences for sports practice

In the context of preparation for endurance performances, the current results have three main implications:

1. Preparatory procedures that affect core temperature, like the "classic" warm-up, should be avoided or, at least, reduced in terms of duration and intensity.
2. However, preparatory procedures can be employed to improve muscular coordination and flexibility. In this case, these measures do not affect the body's heat balance and, thus, can no longer be called "warm-up".
3. In order to optimise this type of preparation, particularly in high ambient temperatures, the preparatory run should be done using a cooling vest, which is close-fitting and worn directly on the skin. The vest should be lightweight and cooled down to a range of 1 to 5°C. An application of 20 to 30 minutes is regarded as sufficient.

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