ORIGINAL ARTICLE

Effects of warm-up and precooling on endurance performance in the heat

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Objective: To examine the effects of different thermoregulatory preparation procedures (warm-up (WU), precooling (PC), control (C)) on endurance performance in the heat.

Methods: 20 male subjects completed three treadmill runs to exhaustion (5 days apart). In each session, all subjects performed an incremental running test after WU (20 min at 70% maximum heart rate (HR)), after PC (wearing a cooling vest (0°C–5°C) for 20 min at rest) or without particular preparation (C). After a 5-min break, the exercise protocol commenced at a workload of 9 km/h and was increased by 1 km/h every 5 min until the point of volitional fatigue. Running performance, HR, blood lactate concentration, tympanic temperature and skin temperature were measured in each trial.

Results: In the PC condition, the running performance (32.5 (5.1) min; mean (SD)) was significantly ($p < 0.05$) higher than in WU (26.9 (4.6) min) and in C conditions (30.3 (4.3) min). During the first 30 min of testing, HR, tympanic temperature and skin temperature were significantly ($p < 0.05$) lower after PC than after WU. There were no significant differences in lactate concentration; however, there was a trend to lower values after WU.

Conclusions: The use of an ice-cooling vest for 20 min before exercising improved running performance, whereas the 20 min WU procedure had a distinctly detrimental effect. Cooling procedures including additional parts of the body such as the head and the neck might further enhance the effectiveness of PC measures.

It is well established that high ambient temperatures have a detrimental effect on endurance performance.^{1,2} Compared with temperate conditions (20°C), an ambient temperature of 30°C brought about a decrease of 2.3% in the performance of a 10 min exercise bout.² The question, however, as to what strategies could be applied to compensate for this heat-induced decrease in performance has been left largely unanswered. Sufficient fluid intake is a possible answer, and application of cold provides another one.^{3,4} In the context of endurance in heat a further question arises—namely, whether warm-up (WU), including the concomitant increase in core temperature (CT) is a sensible measure, taking into consideration the additional thermal stress.⁵

For this reason, it is useful to compare the effects of WU and precooling (PC) to optimise endurance performance. The practical relevance of the objective lies in the fact that competitions—for example, the Olympic Games 2008 in Beijing—will be held in high ambient temperatures, exceeding 30°C at all times of day, and there is no coherent (systematically and experimentally tested) position in the literature on the implications of WU^{6,7} for endurance performance in such temperatures. Although PC has been discussed more widely during the last two decades,^{8–10} it has not yet been studied in comparison with active WU.

METHODS AND PROCEDURES

Sample

Twenty male subjects were tested in this study. They were physical education students at the University of Muenster, Muenster, Germany, and regularly practised types of sport with high endurance and strength components at a high level (soccer, athletics). All gave their informed consent to participate in this study after the University of Muenster Human Ethics Committee had approved of the procedures used. Mean

(SD) values for age, height and weight were 25.6 (3.5) years, 183.4 (7.6) cm and 77.9 (9.5) kg.

Procedure

Research design

After attending a familiarisation session, subjects performed three testing sessions, five days apart. In every session, subjects performed the same test, after WU, after PC (with a cooling vest) or without any thermoregulatory preparation (TPP; control (C)). The tests were set in randomised order to avoid any order effects.

In each test, subjects performed an incremental running test on a treadmill until exhaustion. They wore running shoes, sports socks, shorts and a T-shirt. Subjects were required to refrain from vigorous exercise for 48 h before testing and to avoid any food, drink, cigarettes or caffeinated products for 3 h before the start of a testing session.

Exercise protocol

The effect of the different TPP procedures was tested using an incremental step test on a treadmill. Testing commenced at a pace of 9 km/h, which was increased by 1 km/h every 5 min. Subjects performed up to the point of volitional fatigue (break-off or inability to sustain the pace).

Experimental procedures

Before the familiarisation session and all three tests, the body height and weight of the subjects were measured. Before each testing session, to analyse the heart rate (HR), the HR transmitter and receiver were adjusted and started in the same temperate conditions. Subjects then entered the heated

Abbreviations: BL, blood lactate; bpm, beats per minute; C, control; CT, core temperature; HR, heart rate; PC, precooling; ST, skin temperature; TPP, thermoregulatory preparation; Tt, tympanic temperature; WU, warm-up

Figure 1 Heart rate (beats per min) during warm-up (WU) and precooling (PC).

laboratory (30°C–32°C, 50% relative humidity). These ambient conditions were chosen to represent typical outdoor environmental conditions at the height of summer.

Before exercising, in an initial 5 min resting period (sitting), CT, skin temperature (ST) and HR were measured.

In the C test, subjects commenced exercising immediately after the 5 min resting period, at a pace of 9 km/h on the treadmill.

In the WU test, subjects performed the following WU procedure on the treadmill: a 5 min run at a self-adjusted pace, followed by 15 min at 70% of the individual maximum HR (HR_{max} had been ascertained in a step test outside this study). During WU, the HR was measured continuously and the CT was ascertained every 5 min. The blood lactate (BL) concentration was measured at the end of the WU. Between WU and the start of the step test, there was a 5 min resting period (sitting).

In the PC test, after the initial resting period, the subjects remained seated and wore a cooling vest (0–5°C) against the skin. The PC procedure lasted for 20 min (identical with the WU period). HR, CT and ST were measured at the start of testing and then every 5 min. Before testing, the cooling vests had been submerged (for 10 min) dried and then cooled down at 5°C in a freezer.

Immediately after the 20 min PC procedure, subjects took off the vests and commenced the step test.

During the running step test, the HR was recorded at 5 s intervals. CT was measured every 2 min and BL was ascertained after 5 min of exercise and then every 10 min, each time at the end of a pace step (after 15, 25, 35, and if applicable 45 min). Subjects ran until exhaustion. Testing could be stopped either by the subjects themselves via the stop button of the treadmill or by the supervisor.

Figure 2 Core temperature during warm-up (WU) and precooling (PC).

Following the step test, there was a 5 min resting period (sitting) in the heated laboratory while HR and CT were observed. Subsequently, there was a further 10-min resting period in temperate conditions (20–22°C) without measuring.

Measurements and apparatus

Cooling was achieved using an ice-cold cooling vest (Arctic Heat, Burleigh Heads, Australia) with four integrated cooling panels (filled with a cooling gel consisting of crystals absorbing external and internal heat) on the front and three on the back to avoid cooling the kidney area. To optimise cooling of the torso, the vest was worn directly on the naked skin. The Arctic Heat vest weighs only about 1000 g (activated).

Subjects performed on the Kettler Kinetic S3 (Kettler, Ense-Parsit, Germany) treadmill at the Institute of Sports Science in Muenster, Germany. The Kinetic S3 uses a non-weight-related speed-control system driving the belt via a 2.2 kW motor. To make exercising more convenient, the Kinetic S3 has a suspension system that automatically adapts to the pace and weight of the runner. To mimic aerodynamic drag, the treadmill was adjusted at a gradient angle of 1°.

The difference in HR between PC and WU increased progressively during the TPP (generally $p \leq 0.05$).

HR was measured using the Polar Heart Rate Monitor S810i (Polar, Kempele, Finland) during the whole testing period. The electrosensitive chest belt, which was affixed to the subject's chest just above the manubrium sterni, transmitted the data to the watch at the wrist. After testing, the recorded data were transmitted to a computer and analysed via the Polar Precision Performance Software (V.4.01.029).

BL concentration was measured using the Roche Accutrend Lactate system (Roche Diagnostics, Mannheim, Germany) in combination with BM Lactate Test Stripes and with Softclix lancets (Roche Diagnostics,).

Tympanic temperature (Tt) was measured by the Braun Pro 3000 ThermoScan thermometer, Type 6014 (Braun, Kronberg, Germany). The thermometer measured the infrared radiation generated by the eardrum and the surrounding tissue. To enhance accuracy, each scan consisted of eight measurements per second, of which the highest temperature was displayed. The technical error of measurements amounted to 0.2° for temperatures in the range 35.5–42.0°C, and 0.3°C outside this range.

ST was measured using the Ebro TFN 1093 digital thermometer (Ebro, Ingolstadt, Germany), which has a resolution of 0.1°C (measuring range –50°C to +500°C). The precision of measurement in the temperature range of our tests was 0.004°C (manufacturer's information). The thermometer was equipped with the Ebro EB 14-N surface probe (measuring range –50 to +500), which has an NiCr-Ni measuring tip 15 mm in diameter. During the measurements, the probe was pressed onto the skin of the upper third of the subject's left scapula.

Statistical analysis

Statistical analyses were carried out with SPSS V.12.01 for Windows. Analysis of the means of the data for running performance, Tt, ST, HR and BL during the tests were conducted using a one-way analysis of variance with repeated measurements for thermoregulation preparation (WU, PC, C). Post hoc comparisons were used, where appropriate. Significance was set at $p < 0.05$.

RESULTS

Thermoregulatory preparation

Heart rate

The cooling vest reduced cardiovascular and thermal strain during the TPP (figs 1–3). During active WU (20 min), the HR

Figure 3 Skin temperature during warm-up (WU) and precooling (PC).

increased by 61 beats per minute ($p < 0.001$), whereas during PC, it decreased by 8.9 bpm ($p \leq 0.01$; fig 1).

Tympanic temperature

Tt rose during WU and during PC. However, the increase during WU (1°C ; $p < 0.001$) was clearly higher than during PC. During WU, Tt rose from 36.6°C (0.5°C) to 37.6°C (0.5°C), whereas during PC, it increased by 0.54°C ($p < 0.001$), from 36.6°C (0.6°C) to 37.1°C (0.4°C). Thus, the difference between the Tts in WU and PC was increased during the 20 min of TPP (fig 2).

Skin temperature

During WU, ST rose from 34.2°C (0.9°C) to 34.7°C (0.8°C), which is an increase of 0.42°C ($p < 0.01$). By contrast, during PC, a significant decrease (by 0.69°C ; $p < 0.001$) from 33.6°C (0.9°C) to 32.9°C (0.7°C) was observed. Already at the beginning of the 20 min TPP (WU or PC), a significant difference in ST temperature (0.56°C (1.08°C); $p \leq 0.05$) was observed. At the end of the preparation period, the difference amounted to 1.67°C (0.89°C); $p < 0.001$). Thus, the different TPPs (WU, PC, C) caused an inverse behaviour of the ST curves (fig 3), similar to that of the HR curves.

Lactate concentration

After the 20 min WU, subjects reached a BL concentration of 2.68 (0.71) mmol/l. Therefore, subjects exercised below the anaerobic lactate threshold, which indicates that an adequate WU workload was chosen. Fatigue-related metabolic influences can be regarded as having been eliminated.

Exercise performance

After PC, the running performance was better (by 2.2 (1.94) min) compared with the C test (32.5 (5.1) vs 30.3 (4.3) min; $p < 0.001$; fig 4). Of all 20 subjects, 16 ran more after PC, 2 ran less (1 min each) and 2 had identical results.

After PC, generally subjects ran longer (32.5 (5.1) min) than after WU (26.9 (4.6) min). The additional running time after PC test amounted to 5.6 (2.5) more minutes ($p < 0.001$).

After WU, all subjects ran less compared with the C test. After WU, the break-off time was 26.9 (4.6) min, whereas in C, subjects performed for 30.3 (4.6) min. The difference of 3.4 (2.2) min is significant ($p < 0.001$).

Comparing C, PC and WU, the maximum running time was found after PC, with 2.2 min more than after C and 5.6 min more than after WU. Thus, the best running performance was achieved after 20 min of PC.

Figure 4 Running performance (bars) and heart rate (squares) in the control test and after precooling or warm-up. bpm, beats per minute. *** $p < 0.001$ (heart rate difference).

Heart rate

At the beginning of the step test, the HR was significantly lower ($p \leq 0.05$) after PC (80.7 (10.9) bpm) than in C (87.9 (13.7) bpm) or WU (116.2 (10.4) bpm) conditions.

The HR_{max} was higher after PC (192.1 (8.7) bpm) than in C (189.8 (7.7) bpm), although the difference was not significant ($p > 0.05$; fig 4). This difference in HR was caused by the prolonged running times after PC.

Up to the 30th minute of testing, the HR was significantly lower after PC than after WU ($p < 0.01$). After 35 min of testing, the difference in HR was no longer significant ($p > 0.05$). The same applies to the individual HR_{max} at the point of volitional fatigue, with a difference of 0.8 bpm (192.1 (8.6) bpm after PC and 191.3 (6.5) bpm after WU; $p > 0.05$).

After WU, during the first 25 min of testing, the HR was significantly ($p < 0.001$) higher than in C. After 30 and 35 min, the differences were not significant ($p > 0.05$). The differences in the individual HR_{max} were also not significant: after WU, the individual HR_{max} amounted to 191.3 (6.5) bpm compared with 189.8 (7.7) bpm in C, although, in C conditions, subjects ran for a longer time.

During the step test, the lowest HR values were found after PC and the highest after WU (fig 5).

During the step test in PC conditions, the HR up to minute 35 was generally lower than in C ($p > 0.05$). Only one subject was able to run for >40 min in the C test; all the others had to break off earlier. After PC, three subjects reached the 40 min barrier. The subject's HR in C conditions was 176 bpm and the mean HR of the three subjects in PC conditions amounted to 192 (12.12) bpm.

Figure 5 Heart rate during the step test in the control (C) conditions and after precooling (PC) or warm-up (WU). bpm, beats per minute.

Figure 6 Blood lactate concentration (mmol/l) during the step test in the control (C) test and after precooling (PC) or warm-up (WU).

Lactate concentration

There were no significant differences in lactate concentration between the different testing conditions (fig 6). However, there was a trend to lower lactate concentrations after WU compared with PC and C. Significant differences were observed only in the beginning. After 5 min, lactate concentrations in the C test differed significantly from those in PC and WU.

In minute 5, significant ($p < 0.01$) differences were found between PC (2.79 (0.6) mmol/l) and C (3.56 (1.0) mmol/l). Between WU (2.82 (1.1) mmol/l) and C (3.56 (1.0) mmol/l), the differences reached a significance level of $p < 0.5$.

There was a general trend to lower lactate concentrations after WU compared with C, and there was no significant difference in lactate concentrations during the step test in WU and PC conditions.

The individual maximum lactate concentration in the step test was lowest after WU (5.20 (1.33) mmol/l) (fig 6). This was even lower than the C value of 6.91 (2.2) mmol/l. The high maximum value at the point of exhaustion after PC (7.70 (2.06) mmol/l) can be explained by the longer running performance.

Tympanic temperature

During the step test, Tts were significantly higher after WU, than after PC and in C. At the start of the test, core (tympanic) temperature (CT) after WU was 0.93°C (0.72) higher than CT after C ($p < 0.001$); after 5 min, the difference amounted to 0.66°C (0.73°C; $p < 0.001$), after 10 min to 0.59°C (0.66°C; $p < 0.001$), after 15 min to 0.49°C (0.73°C; $p < 0.01$), after 20 min to 0.58°C (0.82°C; $p < 0.01$), after 25 min to 0.47°C (0.75°C; $p < 0.01$), after 30 min to 0.59°C (0.74°C; $p \leq 0.05$) and after 35 min to 0.59°C (1.1°C; $p > 0.05$) (fig 7).

Tts were also generally higher after WU than after PC: 0.56°C (0.67°C; $p < 0.001$) at the start, 0.45°C (0.60°C; $p \leq 0.001$) after 5 min, 0.51°C (0.58°C; $p < 0.001$) after 10 min, 0.49°C (0.63°C; $p < 0.01$) after 15 min, 0.61°C (0.68; $p < 0.001$) after 20 min, 0.56°C (0.66; $p < 0.01$) after 25 min, 0.71°C (0.49°C; $p < 0.001$) after 30 min and 0.71°C (0.65°C; $p > 0.05$) after 35 min.

Significant differences in Tt between PC and C were found at the beginning of the step test: 0.38°C (0.43°C; $p < 0.001$) at the start and 0.20°C (0.43°C; $p \leq 0.05$) after 5 min. Over the course of exercise, CT values were almost identical in the two conditions. However, towards the end of the test (after 30 min), there was a trend to lower CT values after PC compared with C, although $p > 0.05$.

Figure 7 Core temperature (°C) during the step test in the control (C) conditions and after precooling (PC) or warm-up (WU).

Skin temperature

A significant ($p < 0.01$) increase in ST was found in all three testing conditions (fig 8). ST rose in C by 1.92°C (1.11°C), during WU by 1.06°C (0.82°C) and during PC by 2.21°C (1.12°C).

Comparing all three testing conditions (C, WU, PC), even at the beginning, significant differences in ST were found as a consequence of the different preparation procedures. After PC, ST (32.95°C (0.75°C)) was 0.8°C (1.1°C) lower than in C (33.73°C (0.89°C); $p < 0.01$) and 1.67°C (0.88°C) lower than after WU (34.67°C (0.83°C); $p < 0.01$).

Thus, in each condition, the highest ST values were measured after WU, whereas the lowest were found after PC.

At the end of the step test, the differences in ST between the three testing conditions were not generally significant. ST after C (35.56°C (0.95°C)) and after WU (35.73°C (0.53°C)) did not differ significantly. However, a significant difference in ST was found between PC and WU conditions. The ST rose to 35.1°C (0.88°C) after PC and to 35.73°C (0.53°C) after WU, which is a difference of 1.67°C (0.88°C; $p < 0.001$). Although ST after PC was also lower than after C (35.65°C (0.95°C)), the difference of 0.41°C (0.97°C) was not significant ($p > 0.05$).

Thus, the lowest ST (at the end of testing) was found after PC, although only the differences between PC and WU were significant. At the point of volitional fatigue, after WU, ST did not significantly differ from C.

Figure 8 Skin temperature (°C) at the beginning and end of the step test in the control test (C) and after precooling (PC) or warm-up (WU).

What is already known on this topic

- In addition to the lack of warm-up and precooling studies utilising performance-based test protocols, little was previously known about on the effect of different thermoregulatory preparation procedures on endurance performance in the heat.

What this study adds

- This study has shown that precooling (the use of an ice-cooling vest for 20 min before exercising) improved running performance in the heat, whereas the 20-min warm-up procedure had a detrimental effect.

DISCUSSION

The aim of this study was to investigate whether classic WU (active) or PC (passive) was able to enhance endurance performance in the heat.

The effects of WU and PC procedures before an endurance performance had not yet been compared directly. The results indicate that there are significant differences between the PC and WU conditions in measures of running performance, HR, CT and ST. There were no significant differences in BL concentration.

The reduction of CT was regarded as the basis of performance enhancement by Duffield *et al.*¹¹ However, it could be shown in this study that there are performance enhancements with no reduction in CT: after PC with the cooling vest, running performance was significantly higher than after WU or C, although the difference in performance between the WU and the PC condition was, distinctly, the highest.

In addition to CT, ST is the decisive factor in PC: at significantly lower ST, higher running performances are found.

Unlike what was seen in the previous studies,^{12,13} the CT did not decrease immediately after the PC procedure, and even increased by 0.5°C ($p < 0.01$). This can be regarded as a compensatory thermoregulatory reaction of the human body. However, a delayed decrease in CT was found to occur with the onset of exercising. This phenomenon is known as the after-drop effect, which can be explained by the reperfusion of cooled peripheral tissue.¹⁴ During endurance performance, a distinct reduction in the rise in CT was measured, supporting the findings of Duffield *et al.*¹¹

Therefore, reducing CT during the PC procedure is not a prerequisite for achieving a performance-enhancing effect in subsequent running exercises.

In conclusion, the use of a cooling vest for 20 min improved running performance compared with that after WU and in C conditions. WU has a negative effect on endurance performance in heat. During the first 30 min of testing, the values for HR, CT and ST were significantly lower ($p \leq 0.05$) after PC than after WU.

Further studies with intensified PC should be conducted. It would be of particular interest to investigate the effects of additional cooling of further body parts.

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