

R. J. Maughan

TEMPERATURE REGULATION DURING MARATHON COMPETITION

R. J. MAUGHAN, PhD

*Institute of Environmental and Offshore Medicine, Ashgrove Road West,
ABERDEEN AB9 2ZD*

In resting man, deep body temperature is maintained at about 37-38°C. The existence of such a steady temperature indicates that the rates of metabolic heat production is balanced by the rate of heat loss to the environment. At rest the main challenge to the regulation of body temperature comes from changes in environmental conditions. At low ambient temperatures, especially if this is coupled with a high rate of air movement across the body surface, the rate of heat loss will exceed the rate of heat production and body temperature will fall. At high ambient temperatures, heat will be gained from the environment and body temperature will rise unless protective measures are initiated. During hard physical exercise, metabolic rate may rise 10 or 15-fold, and this rate of heat production may be sustained for several hours. For the exercising individual, therefore, cold exposure does not normally represent a serious challenge to the body's homeostatic mechanisms, but the problems of heat loss when exercising at a high ambient temperature may be acute.

Heat balance at rest

When body temperature is constant, heat loss is equal to heat gain according to the equation:

$$M \pm R \pm C \pm K - E = 0$$

where M = metabolic heat production, R = radiant heat exchange, C = convective heat exchange, K = conductive heat exchange and E = evaporative heat loss. It should be noted that M is always positive and E is always negative; R, C and K may be positive or negative depending on the relative temperatures of the skin and the environment.

It is also important to remember that, although it is the body core temperature which is regulated, it is the temperature of the skin relative to that of the environment which determines whether heat is gained or lost. At low ambient temperatures, skin temperature is decreased by diversion of blood away from the skin; this decreases heat lost to the environment by radiation,

convection and conduction. When skin temperature is low, sweat secretion is inhibited, and evaporative heat loss is minimal unless externally applied fluid is present. With a reduced blood flow, the insulative power of the skin and subcutaneous layer is increased, and a large temperature gradient from the core to the periphery can be tolerated. In this situation, heat loss by radiation is small, and loss by conduction is negligible, unless the body is immersed in water; loss by convection depends largely on the movement of air across the body. In still, cold air, heat loss by convection is small, but movement of air across the body resulting from wind or from movement of the body through the air, will result in a high rate of heat loss. In a hot environment, heat will be gained by solar radiation and by radiation from objects in the environment; heat gain from these sources may be 2-3 times as great as the resting metabolic heat production. Heat will also be gained by convection if the air temperature is greater than that of the skin. Heat transfer by conductance is again unlikely to be significant unless there is a large area of contact between the body surface and hot objects in the environment, but prolonged contact between the feet and hot road surfaces, for example, may result in local overheating. In view of the heat gains from these sources and the continued metabolic heat production, it is apparent that body temperature can only be maintained if the rate of evaporative heat loss is increased. This is achieved by active secretion of sweat on to the body surface; the high latent heat of vaporisation of water makes this process particularly effective in promoting heat loss, evaporation of 1 litre of sweat from the skin requiring about 580 kcal.

Heat balance during exercise

During exercise, the steady state situation described above does not normally exist. The increased energy expenditure associated with muscular work is accompanied by an increased rate of heat production. Either this is balanced by an increased rate of heat loss, or body

temperature rises, the body tissues acting as a heat store. In practice, both effects normally occur, their relative magnitude depending on the circumstances. The rate of heat production during exercise is proportional to running speed, and is also affected by factors such as body weight and mechanical efficiency. Running at a speed of 16 km.hr⁻¹, equivalent to completing the marathon distance in approximately 2 h 37 min, requires an oxygen consumption of approximately 3.7 l.min⁻¹ for a 70 kg athlete (Maughan and Leiper, 1983). This compares with a resting oxygen consumption for the same individual of about 0.25 l.min⁻¹. Heat production for the runner amounts to about 1100 kcal.hr⁻¹. If all this heat was stored, body temperature would rise at a rate of 0.33°C per minute. This situation would lead to collapse and death within a short space of time; during the 2½ hours of marathon running, body temperature probably rises by no more than 2-3°C, so clearly the heat loss mechanisms are extremely effective. Even for the slower runners, the rate of heat production is high; for the 5¼ hour marathon runner, who averages 8 km.hr⁻¹, oxygen uptake is about 2.1 l.min⁻¹ (and will be higher in heavier runners). This corresponds to a rate of heat production of about 630 kcal.hr⁻¹. Although considerably less than that of the faster runner, this still represents a high value, and an additional problem is incurred in that the duration of the event is twice as great, which brings problems of its own.

The greatly increased rate of heat loss which must accompany hard exercise if body temperature is to be maintained, is achieved largely by an increased evaporative heat loss; although the increased skin temperature which normally occurs will also permit an increased loss by radiation and convection, this effect is of minimal importance (Nielsen, 1938).

Temperature regulation during marathon running

In spite of the high efficiency of the sweating mechanism in promoting heat loss, the ability to maintain body temperature within tolerable limits may still be a critical factor in determining performance in marathon running. Even in races of shorter duration, extreme rises in body temperature may occur, particularly when the ambient temperature is high. Hughson et al (1980) reported 26 cases of heat injury which required hospitalisation among 2,900 participants in two Canadian 10 km races; ambient temperature at the two races was 24.3°C and 31.8°C. Similar problems may occur, however, at relatively low ambient temperatures. Sutton et al (1972) observed a number of cases of hyperthermia among competitors in the 14 km Sydney 'City-to-Surf' race in spite of an air temperature of only 15.6°C. Three collapsed competitors in this race were found to have a rectal temperature of 41.5°C or higher. In longer races such as the marathon, problems may be even more severe. Pugh et al (1967) found that several runners had a rectal temperature in excess of 40°C at the

end of a marathon race held at an ambient temperature of 23°C. Costill (1972) recorded a rectal temperature of 41.3°C in a competitor who failed to complete a marathon race where the ambient temperature was 31.1°C.

Clearly in these competitors the rate of heat production has exceeded the capacity of the heat loss mechanisms. Acute elevation of body temperature in this way is a potentially life-threatening situation; the first signs of hyperthermia are normally a deterioration of mental function, often followed by disorientation and collapse. This area has recently been the subject of a comprehensive review (American College of Sports Medicine, 1984).

In runners exercising at high work rates for prolonged periods, it is perhaps not surprising that cases of hyperthermia and heat illness occur. In several instances, however, rather low post-race rectal temperatures have been recorded among marathon runners. Pugh et al (1967) found a mean post-race rectal temperature of 39.0°C among 47 runners taking part in a race held at an air temperature of 23°C; the lowest individual temperature among these runners was 36.7°C, although one runner in the same race had a temperature of 41.1°C. In a more recent study, the mean rectal temperature recorded on 59 runners immediately after a marathon race, was 38.3°C; air temperature was 10-12°C (Maughan, 1985). The lowest individual temperature was 35.6°C, and four runners recorded rectal temperatures of less than 37.0°C. In this study, there was not a statistically significant relationship between the post-race rectal temperature and the time taken to complete the race (Fig. 1), but there was a significant correlation ($p < 0.01$) between the post-race temperature and running speed over the second half of the race (Fig. 2). It seems that some of these runners set off at a speed which they cannot sustain; body temperature is elevated and sweating is initiated to promote heat loss; at some point during the race, the runner is forced by fatigue to decrease his speed; this results in a decreased rate of heat production, but heat loss continues at a high rate; in this situation, body temperature will fall. The rate of fall of temperature may be rapid in lightly clad runners reduced to walking speed or forced to stop completely, especially if the weather conditions are unfavourable. In one competitor who collapsed on the finishing line of a marathon race, rectal temperature was subsequently found to be 34.3°C (Ledingham et al, 1982).

The situation can thus arise where, in the same race, one individual may collapse from hyperthermia whereas another runner in a similar state of collapse may be suffering from hypothermia. In view of the similarity of some of the symptoms of these two extreme conditions, the importance of measuring rectal temperature before instituting treatment is obvious. Oral temperature is not

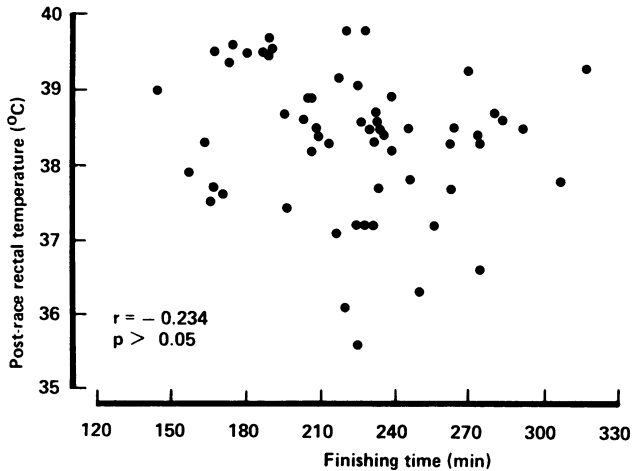


Fig. 1: In a group of 59 marathon runners, rectal temperature was measured immediately after completion of the race. No statistically significant relationship was found to exist between rectal temperature and the time taken to complete the race (Reproduced from: Maughan (1985) *Int.J.Sports Med.* 6, *In Press*).

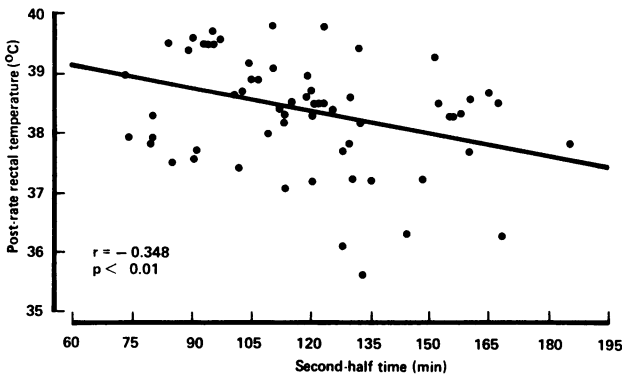


Fig. 2: In the same runners, post-race rectal temperature was correlated with the time taken to cover the second half of the race; the lowest values for rectal temperature were found among those who ran most slowly over the latter part of the race (Reproduced from: Maughan (1985) *Int.J.Sports Med.* 6, *In Press*).

a reliable measure of deep body temperature in this situation (Rozycki, 1984).

Fluid balance

Although active secretion of sweat is effective in preventing excessive rises in body temperature, the loss of large amounts of body water may itself cause serious problems. Sweating rate is approximately proportional to running speed, but total sweat loss is not related to

the time taken to complete a marathon race (Maughan, 1985). The variation in sweat rate between individuals working at the same relative work load can be extremely high, however, and marathon runners competing under the same conditions and with the same fluid intake may lose between 1% and 6% of body weight. Costill (1972) has reported body weight losses of more than 8% in runners competing at high ambient temperatures. These large fluid losses result in reductions in plasma volume as well as loss of interstitial and intracellular water. The reduction in plasma volume will have a detrimental effect on performance; there is a requirement for a high blood flow to the skin to promote heat loss, but blood flow to the working muscles must be maintained to provide oxygen and substrates. Losses of fluid corresponding to as little as 2% of body weight will reduce physical working capacity (Saltin, 1964). The sensation of fatigue commonly experienced in the latter stages of a marathon race may thus result as much from the effects of dehydration as from substrate depletion or hyperthermia.

Precautions

Part of the challenge of marathon competition lies in pushing the body to its limits, and it is not uncommon to see participants finishing in a state of distress. Some of these instances could have been avoided if proper precautions had been observed. Proper clothing should be worn depending on the environmental conditions. In warm conditions, clothing should obviously be designed to promote heat loss and should, therefore, be light and loose fitting. In extreme heat, some form of headgear to protect against solar radiation may be useful. In cool weather, clothing should be adequate to minimise the risk of hypothermia, especially for slow runners and those likely to walk for prolonged parts of the race. A hat and gloves are particularly effective in reducing heat loss, as large amounts of heat are normally lost from the head and hands. It is important to remember also, that the event lasts up to 6 hours and in some cases even longer. Major changes in weather conditions can occur during this time, and some flexibility in the amount of clothing worn may be necessary.

An adequate fluid intake will help to guard against hyperthermia and dehydration. It is the responsibility of the race organiser to provide frequent drinks stations and of the competitors to make use of these. Runners should be fully hydrated before the start of the race and should drink at all feeding stations where possible. The sensation of thirst is not a reliable guide to the need for fluid, and it is particularly important to drink at the early drinks points to allow time for the water to be absorbed from the stomach. The composition of the drink taken is not critical, but plain water or dilute glucose/electrolyte solutions are best. Alcohol should be avoided on the night prior to the event as it may lead to dehydration and disturbances of temperature regulation.

Viral infections may adversely affect the ability of an individual to regulate his body temperature as well as having potentially dangerous effects on the myocardium. For these reasons, it is most unwise for any individual to take part in a marathon race, or other hard physical activity, while suffering from, or recovering from, such an illness.

These precautions will not guarantee immunity from heat-related problems, nor will they compensate for lack of adequate training in the pre-competition period, but they may help to reduce the number of casualties on race day.

ACKNOWLEDGEMENTS

R. J. Maughan is supported by a grant from Shell (UK) Exploration and Production Limited.

References

- American College of Sports Medicine, 1984 "Position statement; Prevention of illness during distance running". *The Physician and Sports Medicine* 12: 43-51.
- Costill, D. L., 1972 "Physiology of marathon running" *JAMA* 221: 1024-1029.
- Hughson, R. L., Green, H. J., Houston, M. E., Thomson, J. A., MacLean, D. R. and Sutton, J. R., 1980 "Heat injuries in Canadian mass participation runs". *Canad.Med.Ass.J.* 122: 1141-1144.
- Ledingham, I. McA., MacVicar, S., Watt, I. and Weston, G. A., 1982 "Early resuscitation after marathon collapse". *Lancet* 2 (8207): 1096-1097.
- Maughan, R. J., 1985 "Thermoregulation in marathon competition at low ambient temperature". *Int.J.Sports Med.* 6. In Press.
- Maughan, R. J. and Leiper, J. B., 1983 "Aerobic capacity and fractional utilisation of aerobic capacity in elite and non-elite male and female marathon runners". *Eur.J.Appl. Physiol.* 52: 80-87.
- Nielsen, M., 1938 "Die Regulation der Körpertemperatur bei Muskelarbeit". *Skand.Arch.Physiol.* 79: 193-230.
- Pugh, L. G. C. E., Corbett, J. L. and Johnson, R. H., 1967 "Rectal temperature, weight losses and sweat rates in marathon running". *J.Appl.Physiol.* 23: 347-352.
- Rozycki, T. J., 1984 "Oral and rectal temperatures in runners". *The Physician and Sportsmedicine* 12: 105-110.
- Saltin, B., 1964 "Circulatory response to submaximal and maximal exercise after thermal dehydration". *J.Appl.Physiol.* 19: 1125-1132.
- Sutton, J. R., Coleman, M. J., Millar, A. P., Lazarus, L. and Russo, P., 1972 "The medical problems of mass participation in athletic competition". *Med.J.Aust.* 2: 127-133.

BOOK REVIEW

Title: EXERCISE AND AGEING: AN UNPROVEN RELATIONSHIP
Author: E. W. Thornton
Publisher: Liverpool University Press
 Price: £2.50 Soft cover

This "slim volume" — 31 pages including 4 pages of bibliography reviews the published literature on exercise and ageing in an admirably concise way.

Most of the studies relate to the effects of exercise in improving cardiovascular efficiency, reducing CHD, and thus influencing longevity.

Such other factors as muscular strength, flexibility, and physiological benefits, which affect quality rather than quantity of life seem to have been less extensively investigated.

Surprisingly too, women seem to have been largely ignored in the publications.

The author discusses the physiology of ageing, and emphasises the difficulties in designing valid experiments with suitable control and quantitative data. He makes the point (perhaps the nub of the whole problem) that "people select for themselves occupations and activities which involve different amounts of physical activity and exercise. It may be that people with a predisposition to CHD find physical exertion unpleasant and even sickening because of the associated diminished cardiac output."

Perhaps this explains the high drop-out rate in most exercise programmes, and the apparent discrepancies between the human studies and the more stringently controlled animal experiments (also described in this book) where there are no volunteers and no drop-outs to invalidate the results.

This booklet was produced for the Institute of Human Ageing and is obviously just one small part of a much larger study of the problems of ageing.

With a rapidly increasing elderly population this is a subject that should be "exercising the minds" of all groups involved in promoting positive health.

H. Selcon