THE DANGER OF AN INADEQUATE WATER INTAKE DURING MARATHON RUNNING*

C. H. WYNDHAM AND N. B. STRYDOM, *Human Sciences Laboratory, Chamber of Mines of South Africa, Johannesburg*

In an article on 'Athletics' Sir Adolphe Abrahams,[1] the then Honorary Medical Officer to the British Olympic athletic team, stated in the *British Encyclopaedia of Medical Practice*: 'I am of the opinion that in the healthy subject the only potential risk to life is heat stroke . . . a danger well exhibited by examples I have seen of alarming collapse and, on one occasion, death . . . The correct precaution would be to prohibit the race in circumstances in which such an occurrence might be expected—a moisture laden atmosphere, a following wind and a day with shade temperature of 85°F or higher.' It is clear from this statement that it is criminal folly to run a marathon in the temperature conditions which, for example, prevailed in Greece a few years ago when Johannes Metsing undoubtedly developed a mild attack of heat stroke. The dry-bulb temperature in some of the valleys on the marathon route in Greece was said to be as high as 115°F, and the humidity was high.

While there is some awareness now of the danger of heat stroke in running the longer distances, such as a marathon, on a hot day, especially if the relative humidity is high, there does not seem to be any realization by medical officers associated with athletics, by sports administrators, or by the athletes themselves that a large water deficit can put a man in danger of heat stroke on even a mildly hot day. A study by Strydom *et al.* from this laboratory[2] on men walking at about 4 m.p.h. for 18 miles over a period of 5 - 6 hours on an ordinary highveld summer's day, brought out the fact that they lost on an average 4,500 ml. (7½ pints) of fluid in sweat. One group of men who drank no water had higher rectal temperatures than men who drank water *ad libitum*. One man in the water-restricted group developed a rectal temperature of 103·3°F. Marathon running is a much more strenuous form of exercise and accordingly the rate of sweat loss would be expected to be much higher. The danger of developing a marked water deficit even in a 2 - 3-hour run is relatively great even in ordinary summer weather. It is not known what effect this would have on the body temperatures of normal, healthy athletes, nor what the risks of developing heat stroke would be.

Marathon runners appear to be unaware of these dangers and most of them refrain from drinking any but small amounts of water during the run. Because we know of at least two deaths from heat stroke in South Africa in circumstances where men were forced to exert themselves actively on hot days without water, and because we are cognizant of the ignorance of sports administrators, sports medical officers and athletes of these dangers, the opportunity was taken during the running of the recent 'Sugar Marathons' to study the extent of water deficits on two groups of 20 runners on cool days and the effects of these water deficits upon their body temperatures.

METHODS AND PROCEDURES

The studies were made on volunteer subjects who were participants in the first 'Sugar Marathons' which were run from the Germiston Callies club-house out along the Main Reef road. The first was on Sunday morning 17 March and the second on Sunday morning 21 April 1968. The distances run were 20 miles.

The weather was cloudy, overcast and cool on the day of the first marathon, and clear but cool on the day of the second marathon. The weather data from the Jan Smuts weather station are given in Table I.

The races were run between 8 a.m. and 12 noon. On the day of each marathon, 20 volunteers were recruited, and the object of the study and also the procedures were explained to them. They were then weighed nude on a beam balance which is sensitive to changes of half an ounce (or 10 G), and rectal temperatures were recorded. They were asked to record the volume of every drink

*Date received: 11 October 1968

TABLE I. WEATHER DATA

Time		Dry-bulb temperature °C	Dry-bulb temperature °F	Relative humidity %
17/3/68	8 a.m.	14·8	58·5	96
	9 a.m.	14·9	58·7	91
	10 a.m.	15·6	60·0	91
	11 a.m.	16·4	61·5	82
	12 noon	17·0	62·6	81
21/4/68	8 a.m.	9·1	48·3	82
	9 a.m.	11·2	52·0	66
	10 a.m.	13·8	57·0	49
	11 a.m.	15·7	60·2	35
	12 noon	16·9	62·5	29

they had; in effect this was carried out by the runner's helper. To aid in this, the helpers were each given 1-litre plastic bottles and were asked to let the runner empty it before refilling and/or to bring back the bottle with the remainder of the water so that the volume could be measured and recorded. The helper was asked to keep an accurate account of the number of bottles emptied. However, some runners preferred to drink cold drinks, and here again the helper was asked to keep an accurate count of the number of bottles.

The aim was to weigh each of the 20 volunteers and to measure their rectal temperatures immediately after they had finished the marathon; but, in effect, in the general mêlée which appears to characterize the end of marathons, some runners did not report until about ½-hour had elapsed. As they had undoubtedly cooled a great deal in that time in the prevailing cool weather, their data were not included in the results. Also, some did not complete the run. Full data were obtained on 31 runners.

Rectal temperatures were recorded with calibrated clinical thermometers inserted into the rectum to a depth of 3 in. The readings were double-checked. The mean weight of the men was 64·2 kg. (141·2 lb.), which is considerably lighter than the average weights of young South Africans of the same age. The latter average 69·7 kg. (153·3 lb.) in the below-20 age-group and 72·5 kg. (155·5 lb.) in the 20 - 29-years age-group.[3]

RESULTS

Sweat Losses

The volumes of sweat lost during the marathons varied between 1,550 and 4,200 ml. (approximately 2¾ - 7 pints of fluid).

The sweat losses were closely correlated with the men's body-weights, the correlation coefficient being 0·90, which is significant at the 1% level. Fig. 1 gives the regression of sweat loss on body-weight and the regression line for sweat loss on weight. The regression equation is:

$y = -2{\cdot}71 + 0{\cdot}086x$

where y is the sweat loss in litres and x is the weight in kilograms. Fig. 1 shows that the light men, i.e. below 55 kg. (110 lb.), lost between 1,500 and 2,000 ml. (approximately 2½ - 3½ pints), whereas those weighing 70 kg. and more (154 lb.) lost between 3,100 and 4,200 ml. (6 - 7 pints) of fluid in sweat. Where the man came in the race did not appear to affect the relationship between body-weight and sweat rate. One of the 70-kg. (154-lb.) men came first and secreted 3·4 litres, and the other came last in the group of 20 volunteers and he secreted 3·2 litres.

The sweat losses for the first marathon on 17 March 1968 were not different from those for the second marathon on 21 April, but, of course, there was little difference between the two days in the air temperatures, although the humidity was higher on the first day. Both days were cool.

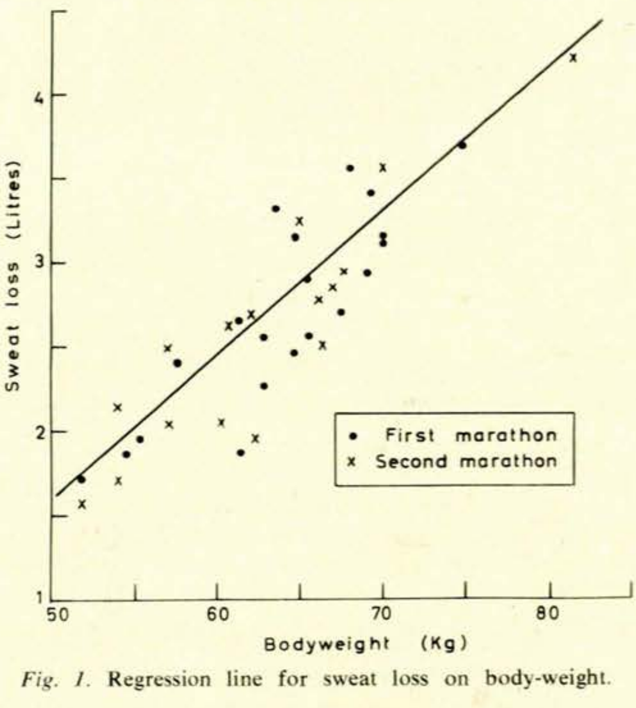

Fig. 1. Regression line for sweat loss on body-weight.

Water Intakes

The runners varied greatly in the amounts of water they drank. Thirteen of the 31 either did not drink at all or drank less than 300 ml. (½ pint), and seven drank between 900 and 2,400 ml. (1½ - 4 pints).

Only one man drank as much as he sweated, i.e. he developed *no* water deficit. All the others drank less than they sweated and the water deficits varied between 1,150 and 4,100 ml. (approximately 1½ - 7 pints).

Effect of Water Deficit on Body Temperature

It was shown above that the amount of fluid lost in sweat is closely correlated with body-weight. It is therefore more meaningful to examine the effect of water deficits upon body temperatures as a percentage deficit from the initial body-weight rather than in absolute volumes of water deficit.

In Fig. 2 are plotted the rectal temperatures of the men, recorded immediately after they finished the marathon, against the percentage water deficits they had developed as a result of the race. The graph shows clearly that up to a water deficit of about 3%, body temperature varied between about 101 and 102°F, but with an increase in the water deficit above 3%, rectal temperature increased in proportion to the extent of the water deficit, resulting in all runners with water deficits of more than 4% having had rectal temperatures above 103°F. One man with a water deficit of 4·8% had a rectal temperature of 105·6°F.

For the men with water deficits of 3% and more, the correlation between rectal temperature and water deficit is 0·67, which is significant at the 5% level. The regression equation for rectal temperature on water deficit, for deficits of more than 3%, is:

$y = 98{\cdot}73 + 1{\cdot}142x$

where y is rectal temperature in °F and x is water deficit as a percentage of body-weight.

Relationship between Rectal Temperature and Body-weight

Nielsen[4] and Wyndham *et al.*[5] have shown that the level a man's body temperature reaches during muscular exercise is directly dependent upon the metabolic rate; the higher the rate of heat production, the higher is the level of rectal temperature. Studies at this laboratory have also shown that when men walk or climb at the same rate, the metabolic rate is directly related to the gross body-weight of the men, the heaviest man having a higher metabolic rate than the lighter man.[6] It would be expected, therefore, that in marathon running the heavier men would have higher rectal temperatures than lighter men when running at roughly the same pace. However, the extent of water deficit also affects the body temperature, as shown above, so that in marathon running any association between rectal temperature and gross body-weight would be affected by the rate of sweating and the amount of fluid drunk.

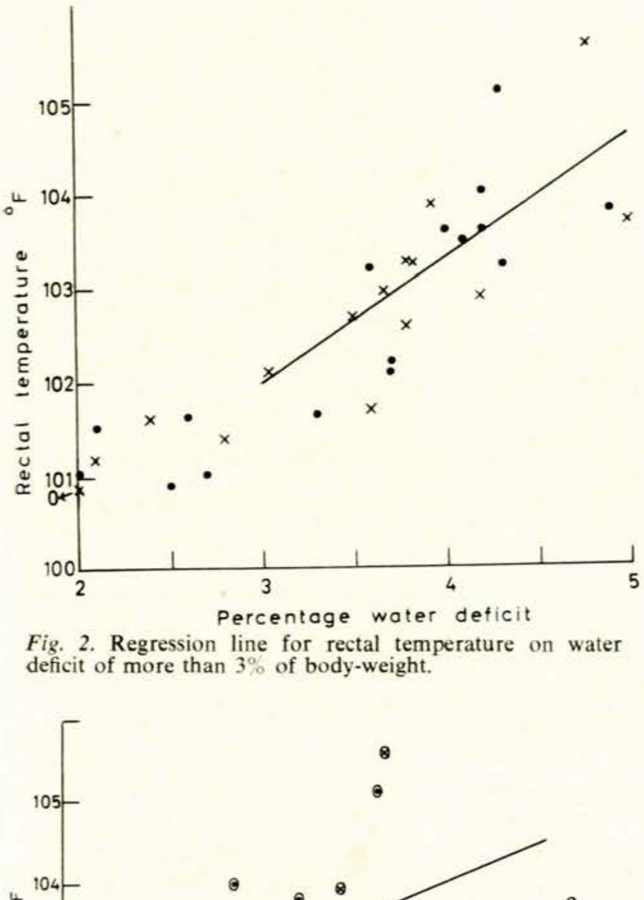

Fig. 2. Regression line for rectal temperature on water deficit of more than 3% of body-weight.

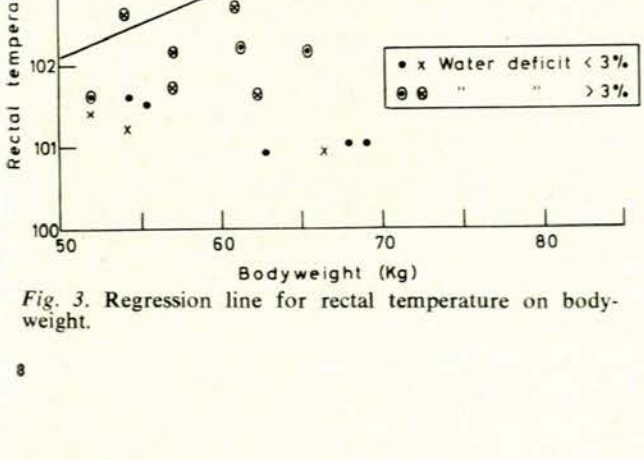

Fig. 3. Regression line for rectal temperature on body-weight.

In Fig. 3 we have attempted to sort out these effects by plotting rectal temperature against body-weight and distinguishing between the runners with more than 3% water deficits and those with less than 3% water deficits. The regression of rectal temperature on body-weight for the men with more than 3% water deficit is:

$y = 98{\cdot}16 + 0{\cdot}079x$

where y is rectal temperature and x is body-weight in kilograms.

This regression indicates that in the men with a water deficit of more than 3%, rectal temperature increased with body-weight. The correlation coefficient is 0·58, which is significant at the 5% level of confidence. However, the men with water deficits of less than 3% showed no rise in rectal temperatures with increase in body-weight.

Results on the Winner of the Marathon

The man who came first ran the 20 miles in just under 2 hours. He weighed 70 kg. (154 lb.) and sweated 3·40 litres in the first and 3·55 litres in the second marathon. His water deficits were 4·3% in the first and 4·8% in the second marathon, and his rectal temperatures were 105·1°F and 105·6°F in the two marathons respectively.

DISCUSSION

The results of these studies give strong support to Sir Adolphe Abrahams's contention that body temperature can rise to heat-stroke levels during muscular exercise. They carry the issue further by showing that one of the most important factors influencing the level to which the rectal temperature rises during marathon running is the extent of water deficit which the runner allows to develop. It is clear that if the water deficit exceeds 3% of the man's body-weight, then, even in cool conditions, rectal temperature rises. If the deficit exceeds 4% it may rise to excessive levels, especially if the man is heavy. On a warm or hot day the rates of sweating would greatly exceed those shown in this study, and the extent of the water deficits would be great in men who refused to drink more than 300 ml. (½ pint). In such circumstances they would be in grave danger of the rectal temperature rising to heat-stroke levels.

The obvious lesson from this study is that coaches, medical officers associated with athletics, and runners themselves should realize the importance of drinking adequate amounts of water during marathon running. The results have shown that if the men, in cool and comfortable weather, can be encouraged to drink more than 1,200 ml. (2 pints), then the risk of rectal temperature rising to dangerous levels is small. However, it should be borne in mind that the rate of sweating is closely related to gross body-weight, so that heavy men should be encouraged to drink at a greater rate than the man of average weight. Air temperature markedly affects the rate of sweating. What the water requirements would be on a warm or hot day cannot be inferred from this study, but the sweat rates could easily be double the present rates. The water requirements of a man of average weight should, in these circumstances, be about 2,400 ml. (4 pints) in order to keep the water deficit below 3% of body-weight.

Marathon runners have apparently developed the erroneous idea that drinking even modest volumes of 1,200 ml. (2 pints) during the course of a 20-mile race is either harmful or likely to affect their performances adversely. It is most important that they come to realize that exactly the reverse is the case. The danger to health, and even of death, of not drinking adequate amounts of water has been emphasized. Heat exhaustion due to water deficit is well recognized by climatic physiologists in men working in hot atmospheres, and the main symptom is that the man becomes very fatigued and cannot continue to work at the required rate. Studies by Strydom *et al.*[7] from this laboratory have shown the marked deterioration in the performance of soldiers after a march in which water was restricted. It is possible, judged by the fact that some men in the present experiments had water deficits of more than 4%, that the fatigue and loss of drive to win which some marathon runners experience in the last 5 miles of a race are due to the water deficits they develop.

The ability to drink sufficient water during marathon running to prevent a large water deficit must be acquired by training. That it is possible to do so is shown by the one runner, who in both marathons drank 2,400 ml. (4 pints) The ideal regimen of water drinking is to take about 300 ml. (half a pint or a large cup) every 20 minutes or so. This should start right from the beginning of the race. There is apparently an international ruling which prohibits marathon runners from drinking any fluid for the first 10 miles of a race. It is an extremely stupid ruling, especially when men have to run marathons in warm and hot conditions, and the sooner it is expunged from the rules the better.

An additional practical point is that in marathon running heavy men are at a disadvantage compared with light men from the temperature regulation and water balance point of view. Heavy men sweat at a much higher rate than light men and also produce heat at a higher rate. In consequence, they have higher rectal temperatures. If the heavy men follow the usual practice of drinking only small quantities of fluid (300 ml. or ½ pint and less), then they are liable to incur very marked water deficits. This action, plus the effect of body-weight on rectal temperature, is calculated to raise their body temperatures to excessive levels, as was demonstrated by one of the 70-kg. (154-lb.) men in this study. These dangers to the heavy men would be greatly accentuated in hot weather. In general, heavy men should either be trained to take adequate amounts of fluid or be discouraged from entering marathon events because of these water balance and temperature regulatory problems.

Pugh *et al.*[8] recently published similar results on men running a standard Olympic-distance marathon in an air temperature of 23°C and relative humidity of 58% in England. They reported high rectal temperatures, high sweat rates and large fluid losses, similar to those reported in this paper. The winner of the marathon developed a water deficit of 5·1 litres (6·7% of body-weight) and a rectal temperature of 106°F (41·1°C). However, Pugh *et al.* do not appear to have noticed the close correlation between sweat rate and gross body-weight or between rectal temperatures and percentage water deficit to which we have drawn attention; nor did they notice the antipyretic effect of an adequate drinking regimen and of the need for marathon runners to be trained to drink greater quantities of fluid than they do at present.

SUMMARY

Sweat losses and rectal temperatures were measured on 31 marathon runners during two 20-mile marathon competitions in relatively cool weather, i.e. air temperature not exceeding 60°F. The results showed that the men lost between 1·5 and 4·2 litres of sweat (2½ - 7 pints) and that there was a close correlation between body-weight and sweat loss. Light men of 55 kg. (115 lb.) lost 1·5 - 2·0 litres (2½ - 3½ pints), whereas heavy men of 70 kg. (154 lb.) lost 3·1 - 4·2 litres (6 - 7 pints). Most runners drank only 300 ml. (½ pint) during the race and developed water deficits of between 1·15 and 4·1 litres (1½ - 7 pints). Plots of body temperature against water deficit (at a percentage of body-weight) showed that in men with water deficits of more than 3%, there was a significant correlation between percentage water deficit and rectal temperature. At 5% water deficit, body temperatures of 104 - 105·6°F were found.

It is concluded that the present practice of marathon runners drinking only small quantities of water is dangerous and that the international ruling which forbids the drinking of water for the first 10 miles is criminal folly in warm weather. Coaches, and others associated with marathon runners, should be made aware of these dangers and should train their runners to drink small amounts of water frequently so that they do not develop water deficits of 3% of body-weight. They should also be made aware of the greater problems which heavy men have in maintaining water balance and of regulating their body temperature.

We wish to thank Prof. J. V. O. Reid, Physiology Department, University of Natal, for arranging for us to make these observations; the S.A. Sugar Association for defraying certain expenses; and the Chamber of Mines of South Africa for permission to publish this paper. We should also like to thank Messrs C. H. van Graan, A. van Rensburg, J. Viljoen, P. Baskind and J. S. Greyson for making these observations, and Mr A. J. A. Heyns, of the Mining Research Laboratory of the Chamber of Mines of South Africa, for the statistical work.

REFERENCES

1. Abrahams, Sir A. *in* Rolleston, H., ed. (1950): *Encyclopaedia of Medical Practice*, vol. 2, pp. 302 - 309. London: Butterworth.
2. Strydom, N. B., Wyndham, C. H., Van Graan, C. H., Holdsworth, L. D. and Morrison, J. F. (1966): S. Afr. Med. J., **40**, 539.
3. Wyndham, C. H. and Sluis-Cremer, G. K. (1968): *Ibid.*, **42**, 280.
4. Nielsen, M. (1938): Skand. Arch. Physiol., **79**, 196.
5. Wyndham, C. H., Bouwer, W.v.d.M., Devine, M. G. and Pattersen, H. F. (1952): J. Appl. Physiol., **5**, 290.
6. Wyndham, C. H., Strydom, N. B., Morrison, J. F., Williams, C. G., Bredell, G. A. G., Peter, J., Cooke, H. M. and Joffe, A. (1963): Ergonomics, **6**, 275.
7. Strydom, N. B., Van Graan, C. H., Viljoen, J. H. and Benade, A. J. S. (1968): S. Afr. Med. J., **42**, 92.
8. Pugh, L. G. C., Corbett, J. L. and Johnson, R. H. (1967): J. Appl. Physiol., **23**, 347.