# THE INFLUENCE OF WATER RESTRICTION ON THE PERFORMANCE OF MEN DURING A PROLONGED MARCH

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When planning outdoor gatherings, youth camps or military exercises, the provision of adequate water supplies always creates logistic problems. Restrictions on water or fluid intake have sometimes been advocated to solve this problem. However, such restriction is false economy and may be fraught with danger. Evidence gained through experience and scientific studies indicates that man cannot operate efficiently nor effectively, when he is deprived of water for prolonged periods. He develops a water deficit and becomes morose and difficult to handle. When the deficit exceeds certain proportions, collapse and death can be expected.

Unfortunately the consequences of water restriction are not always appreciated. Most results and examples are based on small numbers of subjects or on insufficiently documented incidences. It was deemed necessary, therefore, to do an extensive and controlled experiment on this subject.

The purpose of this study was to assess the influence of a limited water supply on the performance of men doing an endurance route-march in summer conditions on the South African highveld, and to determine the amount of water necessary to keep men in complete water balance during such operations.

## METHODS

Observations were made on 60 trained, healthy, young White males before, during and after completion of an endurance route-march. They were divided into 2 equal groups with respect to height and weight; group I received drinking water *ad libitum* and group II received one bottle containing approximately 1 litre of water. The physical characteristics of all the subjects who successfully completed the march and their respective pack weights are given in Table I.

TABLE I. PHYSICAL CHARACTERISTICS

| *Group* | *No.* | *Av. age (yrs.)* | *Av. ht. (cm.)* | *Range* | *Av. wt. (kg.)* | *Range* | *Pack wt. (kg.)* |
|---|---|---|---|---|---|---|---|
| I | 22 | 19·0 | 176·9 | 159·8–188·0 | 67·5 | 56·8–80·0 | 23·7 |
| II | 18 | 19·3 | 177·0 | 162·0–185·4 | 70·8 | 53·2–86·8 | 24·1 |

After the initial preparations and the necessary resting observations were completed, the subjects commenced to walk in orderly rank under the supervision of an instructor. They marched at an average speed of 6·6 km./hour (4·1 m.p.h.) for 50 minutes of each hour and then rested for 10 minutes, during which period observations on oral and rectal temperatures were made. The marching usually started at about 08·30 hrs. and terminated at approximately 15·00 hrs. The distance covered was 29 km. (18 miles).

The men walked for the most part on a gravel road and the terrain covered consisted of flat, slightly uphill, declining and undulating stretches. They wore regulation army dress consisting of khaki overalls, helmets, socks, anklets and boots. They carried full packs on their backs plus a rifle, and the additional weights of pack, rifle and clothing averaged 24 kg. (53 lb.) Included in the packs of group II were their water rations carried in bottles attached to their belts. Both groups drank whenever they pleased, except that group II was restricted to 1 bottle of water. Group I drank accurately-measured volumes taken from canvas containers and no food was consumed during the march.

Heart rates were measured electronically during exercise. The information was transmitted to, and recorded on, a portable electrocardiograph. Cup electrodes, filled with foam rubber impregnated with electrode paste, were fastened in a row on the sternum by means of 'suitable adhesives'. Only in a few instances, mostly due to loose leads, was the interference so great that stethoscopes and stopwatches had to be used for counting heart rates.

Rectal and oral temperatures were measured with clinical thermometers. Only a limited number of oral temperatures were taken for comparative purposes and these were recorded simultaneously with the rectal temperatures. In all temperature recordings the thermometers were left *in situ* for at least 3 minutes while the subjects remained in the erect position.

The subjects were weighed in the nude before the march, and again immediately after completing the march or after collapse. All water intakes and urine outputs during the march were measured in calibrated flasks. Sweat rates were calculated from the arithmetic sum of weight loss, fluid intake and urine output.

The ambient temperatures were measured at hourly intervals. An Assman psychrometer to record wet- and dry-bulb temperatures and a Globe thermometer arrangement for the recording of the combined influences of radiation, air temperature and wind velocity were used. Only the initial, third hour and last hour results are given in Table II.

Oxygen intakes were determined during various stages of the march using an Edwards face mask, a Max Planck respirometer and a butyl rubber bag for the collection of the samples. These samples were analysed for $O_2$, $N_2$ and $CO_2$ content by means of a Beckman oxygen analyser. Observations were made on only 3 men, in order not to interfere too much with the

subjects during the march. Samples were taken on these men while they were walking on level ground, as well as uphill or downhill.

TABLE II. ENVIRONMENTAL TEMPERATURES

| Date | Dry-bulb temp. °C | | | Wet bulb temp. °C | | | Globe temp. °C | | |
|---|---|---|---|---|---|---|---|---|---|
| | Init. | 3 hr. | 5 hr. | Init. | 3 hr. | 5 hr. | Init. | 3 hr. | 5 hr. |
| 20/2/64 .. | 21·7 | 25·0 | 27·0 | 16·0 | 17·8 | 17·5 | 29·0 | 37·5 | 44·5 |
| 25/2/64 .. | 27·0 | 30·9 | 31·0 | 19·0 | 19·0 | 19·2 | 40·0 | 45·5 | 49·5 |
| 27/2/64 .. | 24·3 | 30·0 | 30·6 | 17·8 | 18·5 | 18·0 | 35·0 | 50·0 | 46·7 |
| 5/3/64 .. | 22·5 | 28·0 | 31·1 | 17·0 | 19·2 | 19·2 | 32·4 | 43·0 | 41·6 |
| 6/3/64 .. | 26·5 | 28·0 | 32·0 | 19·0 | 19·8 | 19·2 | 31·1 | 41·7 | 41·7 |

## RESULTS

Only 18 men out of 30 from the water-restricted group were able to complete the route-march; 7 fell out or collapsed because of exhaustion and 5 developed boot-rub. Eight from the *ad lib* group were unable to complete the task, 7 having developed foot blisters or cramps and only 1 collapsed. The average distance covered by the 12 unsuccessful water-restricted men was 20·06 km. (12·9 miles) and that by the 8 from the *ad lib* group 18·9 km. (11·8 miles). The average third hour rectal temperatures of the 2 unsuccessful groups differed by 0·3°C (0·5°F), being 38·1°C (100·6°F) for the *ad lib* group and higher for the others. This difference was also reflected in the state of water balance; the *ad lib* group was dehydrated to 3·9% of their body-weights and the restricted group to 4·8% of theirs.

For statistical reasons the results obtained from the unsuccessful subjects were excluded from the comparisons

TABLE III. AVERAGE SCORES FOR SUCCESSFUL SUBJECTS

| Group | % Wt. loss | Water intake (l.) | Urine output (ml.) | Sweat loss (l.) | Rectal temp. | | | Heart rate | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Init. | 3 hr. | 5 hr. | Init. | 3 hr. | 5 hr. |
| I | 2·9 | 2·709 | 134 | 4·508 | 37·3 | 38·2 | 38·3 | 89 | 143 | 151 |
| II | 4·8 | 1·175 | — | 4·525 | 37·5 | 38·4 | 38·8 | 85 | 142 | 152 |

made between the 2 groups tested. Table III contains the average scores of the successful marchers. The individual scores of groups I and II are given in Tables IV and V and that of the unsuccessful marchers in Table VI.

The average weight loss of group I subjects was 2·2 kg. in comparison with that of 3·7 kg. for group II. This gives water deficits of 1·4 - 4·2% (average 2·9%) and 3·4 - 7·2% (average 4·8%) of body-weights respectively for the 2 groups. This extent of dehydration occurred in spite of water intakes of 2,709 ml. for group I and 1,175 ml. for group II. Sweat rates indicated no difference between the two groups—both losing on the average about 4·5 l. during the march.

The effect of the differences in dehydration on temperature regulation is clearly shown. Group I had a final rectal temperature of 38·3°C (101·0°F), while that of group II was 38·8°C (101·8°F). The comparative results for the oral and rectal temperatures taken simultaneously on 3 different days are given in Fig. 1. Oral temperatures actually decreased during the march, while rectal temperatures showed a constant rise.

During the only warm day (25 February 1964) large weight losses were recorded for group II, the average loss being 4·5 kg. The range was from 3·1 to 6·0 kg. (Fig. 2). The average weight loss of group I on this day was 2·4 kg. with very little scatter about this mean. These losses repre-

TABLE IV. INDIVIDUAL SCORES FOR GROUP I

| Subj. | Age (yrs.) | Ht. (cm.) | Wt.1 (lb./oz.) | Load (lb.) | Wt.2 (lb./oz.) | % Loss | Total urine (ml.) | Total water (ml.) | Total sweat (ml.) | Heart rate | | | | | Rectal temp. | | | Oral temp. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | 1 hr. | 2 hr. | 3 hr. | 4 hr. | 5 hr. | Init. | 3 hr. | 5 hr. | Init. | 3 hr. | 5 hr. |
| 1 | 19 | 183 | 167/5 | 64 | 160/11 | 4·0 | 440 | 2,375 | 4,950 | 122 | 136 | 124 | 140 | 146 | | 101·7 | 102·2 | 97·8 | 97·0 | |
| 2 | 19 | 188 | 173/4 | 48 | 169/6 | 2·2 | | 2,775 | 4,533 | 118 | 128 | 124 | 136 | 130 | | 99·7 | 100·4 | 99·0 | 97·0 | |
| 3 | 18 | 170 | 151/5 | 57 | 147/1 | 3·5 | 235 | 3,275 | 5,421 | 124 | 124 | — | 152 | 150 | | 99·8 | 101·7 | 98·6 | 96·8 | |
| 4 | 19 | 185 | 158/12 | 41 | 155/4 | 2·2 | 300 | 2,450 | 3,738 | 116 | 122 | 124 | 146 | 136 | | 100·4 | 100·6 | 99·0 | 96·6 | |
| 5 | 19 | 178 | 142/0 | 48 | 138/12 | 2·3 | | 2,300 | 3,774 | — | 136 | 124 | — | 140 | | 100·2 | 101·0 | 98·6 | 96·8 | |
| 6 | 20 | 171 | 125/4 | 44 | 121/10 | 2·9 | 270 | 1,950 | 3,324 | 136 | 140 | 136 | 128 | 144 | 98·2 | 99·0 | 99·4 | | | |
| 7 | 18 | 181 | 147/8 | 50 | 143/8 | 2·7 | 280 | 2,430 | 3,964 | 148 | 156 | 156 | 168 | 152 | 98·2 | 100·8 | 100·8 | | | |
| 8 | 19 | 180 | 153/4 | 47 | 151/1 | 1·4 | | 2,475 | 3,467 | 128 | 146 | 152 | 122 | 146 | 98·8 | 100·8 | 101·3 | | | |
| 9 | 18 | 170 | 139/10 | 52 | 136/14 | 2·0 | 100 | 2,205 | 3,352 | 164 | 182 | 168 | 144 | 154 | 98·8 | 100·7 | 100·2 | | | |
| 10 | 18 | 172 | 142/2 | 64 | 139/8 | 1·9 | | 2,925 | 4,116 | 138 | 166 | 162 | 160 | 152 | 98·8 | 102·3 | 101·5 | | | |
| 11 | 20 | 178 | 164/2 | 51 | 159/0 | 3·1 | 265 | 3,730 | 5,780 | 136 | 176 | 160 | 138 | 148 | 99·5 | 101·3 | 100·8 | | | |
| 12 | 18 | 184 | 158/9 | 54 | 153/1 | 3·5 | | 3,100 | 5,595 | 140 | 156 | 140 | 144 | 144 | 99·0 | 101·8 | 100·8 | | | |
| 13 | 21 | 173 | 132/3 | 52 | 126/14 | 4·0 | | 3,500 | 5,910 | 144 | 164 | 136 | 130 | 146 | 99·0 | 100·8 | 100·8 | | | |
| 14 | 20 | 172 | 145/9 | 42 | 140/14 | 3·7 | 240 | 1,900 | 4,070 | 144 | 172 | 144 | 148 | 158 | 99·5 | 101·0 | 101·4 | | | |
| 15 | 20 | 174 | 132/2 | 59 | 126/11 | 4·1 | 425 | 2,950 | 4,991 | 132 | 130 | 126 | 156 | 152 | 99·0 | 100·6 | 101·0 | | | |
| 16 | 21 | 181 | 150/4 | 61 | 144/10 | 3·8 | | 3,325 | 5,877 | 128 | 132 | 136 | 148 | 148 | 99·8 | 100·8 | 101·0 | | | |
| 17 | 21 | 174 | 134/5 | 48 | 130/15 | 2·5 | 185 | 2,775 | 4,121 | 128 | 130 | 122 | 126 | 126 | 99·2 | 100·0 | 101·0 | | | |
| 18 | 20 | 180 | 149/2 | 58 | 146/2 | 2·0 | 215 | 3,325 | 4,471 | 144 | 164 | 164 | 178 | 180 | 99·7 | 101·0 | 101·3 | | | |
| 19 | 18 | 160 | 148/10 | 52 | 143/0 | 3·8 | | 2,235 | 4,787 | 160 | 160 | 150 | 192 | 180 | 99·4 | 100·7 | 102·0 | 98·6 | 98·2 | 100·0 |
| 20 | 20 | 180 | 146/14 | 58 | 140/12 | 4·2 | | 1,800 | 4,589 | 152 | 158 | 162 | 176 | 168 | 100·0 | 100·7 | 102·4 | 98·6 | 98·4 | 98·4 |
| 21 | 18 | 174 | 132/10 | 44 | 129/15 | 2·0 | | 3,050 | 4,269 | 136 | 136 | 138 | 126 | 136 | 100·0 | 100·3 | 99·4 | 98·2 | 97·3 | 95·2 |
| 22 | 18 | 184 | 162/15 | 48 | 160/0 | 1·8 | | 2,750 | 4,082 | 140 | 140 | 152 | 152 | 176 | 99·2 | 100·6 | 100·4 | 97·5 | 97·8 | 97·3 |
| Means | 19·0 | 176·9 | 148/1 | 52 | 143/14 | 2·9 | 134 | 2,709 | 4,508 | 137 | 148 | 143 | 148 | 151 | 99·2 | 100·7 | 101·0 | 98·4 | 97·3 | 97·7 |

TABLE V. INDIVIDUAL SCORES FOR GROUP II

| Subject | Age (yrs.) | Ht. (cm.) | Wt.1 (lb./oz.) | Load (lb.) | Wt.2 (lb./oz.) | % Loss | Total urine (ml.) | Total sweat (ml.) | Heart rate | | | | | Rectal temp. | | | Oral temp. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 1 hr. | 2 hr. | 3 hr. | 4 hr. | 5 hr. | Init. | 3 hr. | 5 hr. | Init. | 3 hr. | 5 hr. |
| a .. .. | 19 | 185 | 191/5 | 53 | 183/12 | 4·0 | — | 5,616 | 120 | 132 | 118 | 128 | 142 | — | 100·6 | 101·7 | 98·8 | 98·4 | — |
| b .. .. | 19 | 178 | 152/2 | 48 | 146/15 | 3·4 | — | 3,528 | 126 | 128 | 126 | 156 | 168 | — | 101·0 | 102·3 | 98·8 | 98·4 | — |
| c .. .. | 19 | 173 | 146/10 | 54 | 140/0 | 4·5 | — | 4,191 | 126 | 132 | 128 | 138 | 124 | — | 101·0 | 102·4 | 98·8 | 98·8 | — |
| d .. .. | 19 | 176 | 148/12 | 57 | 140/11 | 5·4 | — | 4,843 | 156 | 160 | 146 | 148 | 156 | 99·2 | 101·4 | 101·3 | — | — | — |
| e .. .. | 20 | 173 | 136/10 | 56 | 130/4 | 4·7 | 240 | 3,837 | 136 | 140 | 132 | 132 | 144 | 98·4 | 101·5 | 102·1 | — | — | — |
| f .. .. | 19 | 162 | 146/14 | 55 | 140/8 | 4·3 | — | 3,497 | 148 | 140 | 128 | 128 | 146 | 98·8 | 100·5 | 100·6 | — | — | — |
| g .. .. | 20 | 177 | 160/14 | 44 | 155/1 | 3·6 | — | 3,587 | 140 | 168 | 156 | 140 | 160 | 99·2 | 103·3 | 103·3 | — | — | — |
| h .. .. | 19 | 175 | 146/2 | 61 | 140/8 | 3·9 | — | 3,477 | 152 | 162 | 152 | 148 | 156 | 99·7 | 101·0 | 101·0 | — | — | — |
| i .. .. | 20 | 178 | 182/0 | 59 | 168/14 | 7·2 | — | 7,149 | 120 | 146 | 144 | 140 | 148 | 99·6 | 100·9 | 102·0 | — | — | — |
| j .. .. | 21 | 176 | 150/4 | 50 | 140/11 | 6·4 | — | 5,523 | 148 | 156 | 148 | 150 | 152 | 100·1 | 100·3 | 102·5 | — | — | — |
| k .. .. | 18 | 176 | 127/10 | 46 | 120/14 | 5·3 | — | 4,247 | 164 | 174 | 168 | 156 | 168 | 99·8 | 101·7 | 102·2 | — | — | — |
| l .. .. | 19 | 176 | 148/14 | 59 | 138/6 | 7·1 | — | 5,948 | 156 | 164 | 170 | 164 | 166 | 99·2 | 101·4 | 102·0 | — | — | — |
| m .. .. | 20 | 185 | 174/8 | 50 | 166/6 | 4·7 | — | 4,871 | 140 | 150 | 150 | 166 | 152 | 100·1 | 100·7 | 101·0 | 99·4 | 97·7 | 98·1 |
| n .. .. | 19 | 174 | 151/1 | 55 | 146/3 | 3·2 | — | 3,386 | 138 | 140 | 136 | 140 | 144 | 100·0 | 100·3 | 101·9 | 98·7 | 97·9 | 98·4 |
| o .. .. | 19 | 179 | 167/12 | 54 | 160/14 | 4·1 | — | 4,304 | 148 | 124 | 112 | 148 | 140 | 99·7 | 100·4 | 102·0 | 99·3 | 96·7 | 98·2 |
| p .. .. | 21 | 183 | 173/0 | 55 | 165/8 | 4·3 | — | 4,587 | 134 | 144 | 144 | 160 | 156 | 100·1 | 101·1 | 102·1 | 99·0 | 97·0 | 98·4 |
| q .. .. | 18 | 184 | 161/1 | 55 | 152/5 | 5·4 | — | 4,809 | 112 | 140 | 140 | 140 | 144 | 99·4 | 101·4 | 102·2 | 98·1 | 97·6 | 97·6 |
| r .. .. | 19 | 174 | 139/10 | 48 | 133/5 | 4·5 | — | 4,049 | 140 | 148 | 152 | 156 | 168 | 98·8 | 100·6 | 100·4 | 96·0 | 96·8 | 96·4 |
| Means .. .. | 19·3 | 177 | 155/13 | 53 | 148/6 | 4·8 | — | 4,525 | 139 | 147 | 142 | 147 | 152 | 99·5 | 101·1 | 101·8 | 98·5 | 97·7 | 97·9 |

TABLE VI. INDIVIDUAL SCORES FOR UNSUCCESSFUL SUBJECTS

| Group | Subj. | Age (yrs.) | Ht. (cm.) | Wt.1 (lb./oz.) | Load (lb.) | Wt.2 (lb./oz.) | % Loss | Total urine (ml.) | Total water (ml.) | Total sweat (ml.) | Heart rate | | | | | Rectal temp. | | | Oral temp. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | 1 hr. | 2 hr. | 3 hr. | 4 hr. | 5 hr. | Init. | 3 hr. | 5 hr. | Init. | 3 hr. | 5 hr. |
| Water | S | 18 | 167 | 141/8 | 54 | 132/14 | 6·1 | 165 | 2,600 | 6,358 | 144 | 174 | 156 | 150 | — | 99·4 | 99·7 | — | — | — | — |
| *ad lib.* | R | 20 | 173 | 141/8 | 49 | 132/3 | 6·6 | 220 | 1,980 | 5,994 | 156 | 158 | 144 | 154 | — | 99·4 | 100·6 | — | — | — | — |
| I | S | 20 | 180 | 176/6 | 57 | 174/2 | 1·3 | — | 1,400 | 2,421 | 160 | 180 | 156 | — | — | 99·5 | 100·3 | — | 98·7 | 98·0 | — |
| | R | 19 | 176 | 159/7 | 52 | — | — | — | 1,500 | — | 144 | 148 | 144 | — | — | 100·4 | 102·0 | — | 99·2 | 98·5 | — |
| | P | 19 | 167 | 128/1 | 57 | — | — | — | 520 | — | 134 | 130 | 130 | — | — | 99·8 | 99·9 | — | 98·6 | 99·0 | — |
| | K | 19 | 169 | 141/8 | 47 | 137/14 | 2·6 | — | 1,200 | 2,844 | 186 | 174 | 182 | — | — | 99·9 | 101·3 | — | 98·4 | 98·6 | — |
| | McE | 19 | 181 | 146/6 | 47 | 142/1 | 2·8 | 345 | 1,300 | 2,798 | 138 | 136 | 142 | — | — | 98·4 | 100·1 | — | 97·8 | 97·0 | — |
| | S | 20 | 173 | 154/15 | 51 | 148/13 | 4·0 | 225 | 1,200 | 3,764 | 156 | 148 | 150 | — | — | 100·3 | 100·5 | — | 97·8 | 96·6 | — |
| | Means | 19 | 173 | 148/11 | 52 | 144/11 | 3·9 | 239 | 1,460 | 4,030 | 152 | 156 | 151 | — | — | 99·6 | 100·6 | — | 98·4 | 98·0 | — |
| Water | S | 19 | 173 | 135/5 | 54 | 130/9 | 3·5 | | | 3,329 | 120 | 120 | 124 | 144 | | 99·8 | 100·3 | — | 98·0 | 96·0 | — |
| re- | W | 19 | 173 | 138/12 | 49 | 134/13 | 2·8 | | | 2,961 | 124 | 128 | 120 | — | | — | — | 101·1 | 99·2 | — | — |
| stricted | F | 18 | 177 | 161/0 | 57 | 151/13 | 5·7 | | | 5,352 | 148 | 162 | 172 | 166 | | 100·0 | 102·6 | 103·1 | — | — | — |
| II | P | 19 | 172 | 165/11 | 61 | 156/12 | 5·4 | | | 5,239 | 154 | 160 | 160 | 140 | | 99·3 | 100·8 | — | — | — | — |
| | B | 19 | 168 | 116/11 | 50 | 111/7 | 4·6 | | | 3,585 | 152 | 158 | 154 | 146 | | 99·6 | 100·6 | — | — | — | — |
| | G | 19 | 177 | 141/2 | 55 | 132/6 | 6·2 | | | 4,974 | 124 | 128 | 124 | 144 | | 99·6 | — | — | — | — | — |
| | N | 18 | 175 | 145/12 | 55 | 140/4 | 3·8 | | | 3,670 | 120 | 136 | 124 | — | | 100·2 | 100·8 | — | — | — | — |
| | B | 18 | 166 | 134/0 | 53 | 127/6 | 5·0 | | | 3,896 | 128 | 152 | 124 | 132 | | 99·1 | 100·7 | — | — | — | — |
| | S | 18 | 173 | 128/9 | 52 | — | — | | | — | 168 | — | — | — | | 100·0 | 100·6 | — | 98·8 | 98·6 | — |
| | E | 19 | 184 | 151/7 | 61 | 140/15 | 6·9 | | | 5,798 | 144 | 152 | 156 | — | | 99·5 | 102·7 | 102·7 | 98·2 | 99·6 | 99·1 |
| | S | 19 | 182 | 156/14 | 40 | 150/15 | 3·8 | | | 3,868 | 136 | 144 | — | — | | 99·4 | 101·0 | 101·0 | 98·2 | 97·8 | 98·2 |
| | v.D | 19 | 184 | 158/7 | 55 | 149/13 | 5·5 | | | 5,098 | 144 | 152 | 164 | — | | 100·0 | 100·5 | 100·8 | 98·2 | 98·2 | 97·5 |
| | Means | 19 | 175 | 144/8 | 54 | 138/13 | 4·8 | | | 4,343 | 139 | 145 | 142 | 145 | | 99·7 | 101·1 | 101·7 | 98·4 | 98·0 | 98·3 |

sent dehydration from 5·3 to 7·2% for group II and only 3·6% for group I. On 25 February group I had an average rectal temperature of 38·2°C (100·8°F) and group II 39·0°C (102·2°F).

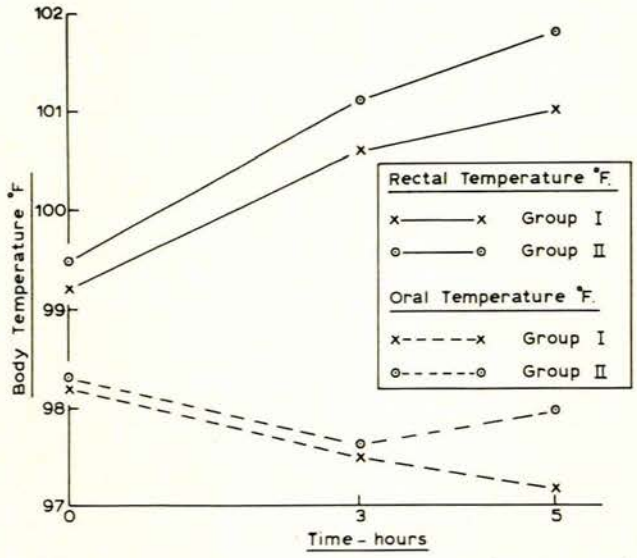


*Fig. 1.* Average group body temperatures during the march.

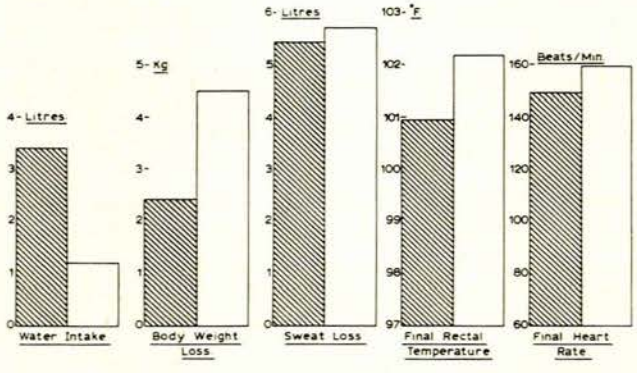


*Fig. 2.* Average scores for route-march on 25 February 1964—the hottest day. [▨] = water *ad lib.* (group I). [□] = one water bottle (group II). 3rd hour wet bulb Globe thermometer 78·06°F: WB = 66·2°F, DB = 87·2°F, GB = 114·8°F.

Using the results of both groups, the extent of dehydration was plotted against last-hour rectal temperatures in Fig. 3. There is an obvious rectilinear relationship between these 2 variables, the greater the dehydration the higher the rectal temperature.

There was no marked difference in the pulse rate responses of the 2 groups. Pulse rates increased to between 130 - 140 beats/min. during the first hour, rose to over 148 beats/min. during the second and then levelled off. In general, the pulse rates varied with the terrain covered, being higher after an uphill stretch and lower after a downhill one.

The temperature of the water in the canvas containers, carried on the observation truck, was kept low by evaporation and remained at about 21·5°C (70·5°F). The temperature of the water in the bottles carried on the belts of group II subjects steadily rose from an initial temperature of 24°C to 28°C (75° - 83°F) at the end of the third hour, and 31·5°C (89°F) towards the end of the march. The men were reluctant to drink this tepid water. Most of the men in group II finished their drinking water supply by the end of the third hour.

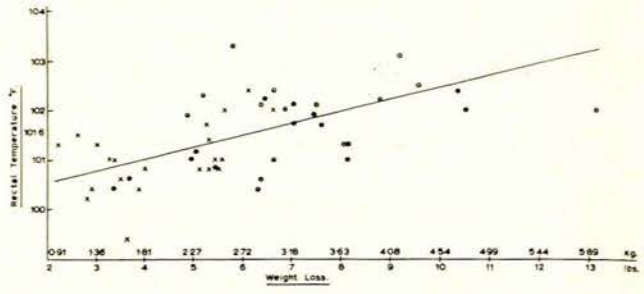


*Fig. 3.* Rectal temperatures vs. weight loss. • = pooled averages of 6 groups. × = group I (water *ad lib.*) individual results. ⊙ = group II (water bottles only) individual results.

The results obtained from the $O_2$-intake measurements are contained in Table VII. The average $O_2$ requirement for the

TABLE VII. OXYGEN INTAKE DURING THE MARCH

| *Subject* | *Age (yrs.)* | *Ht. (cm.)* | *Wt. (kg.)* | *Pack wt. (kg.)* | *Uphill (l./min.)* | *Level (l./min.)* | *Downhill (l/min.)* |
|---|---|---|---|---|---|---|---|
| i | 20 | 178 | 82·3 | 26·8 | 2·169 | 1·702 | 1·698 |
| j | 21 | 176 | 68·2 | 22·7 | 1·926 | 1·463 | 1·435 |
| k | 18 | 173 | 58·2 | 20·9 | 1·954 | 2·036 | 1·553 |
| Average | 20 | 176 | 69·6 | 23·5 | 2·017 | 1·734 | 1·562 |

different phases of the march was found to be 1·8 l./min. This represents an energy requirement of 540 k.cal./hr. or about 2,300 k.cal. for the 29 km. march, the total marching time being 225 minutes.

At the start, and even up to about the third hour of marching, there was little to distinguish between the 2 groups with respect to general appearance and behaviour. Thereafter a distinct difference in reaction and appearance occurred. Whereas the morale of the *ad lib* group remained high throughout, that of the restricted group was markedly poor; they became morose, aggressive and disobedient towards their superiors and showed obvious signs of fatigue. A subject from group II defied all orders and attempted to snatch water from a subject in the other group. One of the unsuccessful subjects complained bitterly to the officer-in-charge when refused additional water and then summarily refused to walk further. He was given extra water, allowed to ride on the truck and then became most apologetic about his behaviour.

The response to discipline among the groups decreased markedly towards the latter part of the march. The members of group II were mainly responsible for this decline. On being reprimanded for not keeping up the pace, they talked back and were difficult to control. To some extent this behaviour also influenced the men in group I, but in general, these men were still easy to handle and kept their positions in order of marching until the end.

## DISCUSSION

The environmental conditions prevailing during these route-marches were certainly not extreme. Rain fell on most mornings, making the air probably a little more humid than usual, but on no occasion did the dry-bulb temperature exceed 32·2°C (90°F). Under these conditions the body temperature response of fully hydrated subjects would depend mainly on the severity of the exercise.[10,15] However, the 2 groups were not in water balance and this had a marked influence on their physiological responses.

Although group I had available to them large quantities of cool, clear water, they still went into a state of water deficit, i.e. 'voluntary dehydration'. Some members of this group had to be encouraged to drink and it almost seemed as if they personally rejected the idea of taking adequate amounts of water. Instead of taking small quantities of water frequently, as recommended by experts,[7] they delayed drinking and then took volumes of over 1 litre at a time. In some cases a typical diuretic response was noted; whereas only 1 man in group II micturated, 50% of those in group I passed urine. The highest percentage of voluntary dehydration observed among the subjects of group I was 4·2% of body-weight and this subject also developed the highest body temperature in the group, viz. 39·1°C (102·4°F).

Voluntary dehydration serves no useful purpose and should be avoided at all costs. The only member of the original *ad lib* group who collapsed, did so because he voluntarily dehydrated himself to the extent of 6·6% of his body-weight. This is about the highest value for voluntary dehydration observed during this study but cannot be regarded as an exception, as another member of the same group also exceeded 6% of body-weight loss when he fell out because of blisters on his foot. This points to a serious lack in the appreciation or training of adult men with respect to proper drinking regimes. Special efforts should be made to eliminate this shortcoming and to stress the dangers of fluid loss. Such voluntary dehydration also shows up the inadequacy of the thirst mechanism to induce men to drink water according to the amount of fluid lost through sweat.

The average percentage of dehydration in group II, 4·8% of their body-weight, is very near to the dangerous level of water debt with respect to performance. According to Ladell[9] and Adolph *et al.*[1] 5 - 6% dehydration results in high pulse rates, high rectal temperatures and 'dehydration exhaustion'. Five of the 6 men from group II who exceeded dehydration values of 5% had rectal temperatures of 38·9°C (102°F) and above; the fact that they completed the march pays tribute to their willpower and drive.

Support for Adolph's concept of 'dehydration exhaustion' is further found in the fact that no less than 8 men of the unsuccessful group exceeded 5% of dehydration. One of these subjects developed a rectal temperature in excess of 39·4°C (103°F). All of them were obviously under stress. Small wonder then that there was a lack of cooperation and drive to continue with the march.

Grande *et al.*[5] pointed out the direct relationship between extent of dehydration and rectal temperature. Several other workers have provided evidence that even in cool environments dehydration results in an abnormal increase in body temperature when doing physical work.[2,3] In Figs. 2 and 3 these results are again substantiated; the greater the extent of dehydration, the higher the rectal temperature. The fact that there is but little difference in the rectal temperature responses of the 2 groups at the end of the third hour of marching must be attributed to their being in about the same state of water imbalance. Group I drank only an average total amount of 1,480 ml. up to this hour and the men of group II, with 1,175 ml. available, had in general emptied their bottles during the first 3 hours although requested to space their drinking over 5 hours. Group II also made better use of what little water they had, drinking smaller quantities more frequently and thereby avoiding any diuretic response; only 1 subject from this group passed urine, compared with an average urine output of 100 ml. for the first 3 hours in group I.

The average rectal temperature difference between the groups at the end of the march was 0·45°C (0·8°F) in favour of group I, showing the advantage of being less dehydrated than the others. The results obtained on 25 February 1964 (Fig. 2) provided an even better indication of what could happen when water is limited to 1 bottle only. The *ad lib* group, again, did not drink enough to replace sweat loss, but their rectal temperatures were on the average 0·8°C (1·5°F) lower than those of the restricted group who developed body temperatures averaging 39·0°C (102·2°F) at the end of the march. According to all the available literature the difference between a fully hydrated group and group II would have been much greater.[1,6,11]

The lack of difference between the 2 groups with respect to heart rate must be attributed to the fact that (*a*) up to the third hour the 2 groups were in equal water balance and (*b*) during the final part of the march group II subjects tended to fall back whereas group I always kept strictly to the set pace and marching order.

There was no significant difference in the total amount of sweat produced by the 2 groups. This could be due to the fact that sweat rate is decreased with increased dehydration.[4,8] Opposing this effect, however, is the increased body temperature which tends to increase the sweat rate.[3] The high body temperature and the large body water deficit in group II are thus opposing factors, the one tending to cancel the effect of the other. The final sweat rates would thus not be different from those obtained in group I. In general, then, the following vicious circle is set up:

Physical activity → increase in body temperature → increase in sweat rate → dehydration → reduction of sweat → increase in body temperature → increase in sweat rate → etc.

According to Ladell[9] sweat secretion during acute exposures is not affected until there is a considerable water debt, i.e. about 5 - 6% loss in weight due to water depletion. Grande *et al.*[5] have shown the deleterious effects when dehydration is maintained over prolonged periods. Sweat production decreased in subjects dehydrated to only 1·5% of their body-weights.

Working on the basis of the above results and assuming that an 18-mile march under similar environmental conditions would be part of a day's activity, then the following

calculations can be made for a man weighing about 70 kg. (154 lb.):

| | | |
|---|---|---|
| (*a*) Basal water requirements—sleeping for 8 hours | = | 500 ml. |
| (*b*) Water requirements in semi-active state (2 × basal) 8 hours | = | 1,000 ml. |
| (*c*) Water requirements during route-march 5 hours | = | 4,600 ml. |
| (*d*) Water requirements during preparations ($\frac{1}{3}$ × *c*) 3 hours | = | 900 ml. |
| Total requirements | = | 7,000 ml. |

Thus 7 litres of water (12 pints) would be required per man per day if equilibrium between fluid intake and loss is to be maintained. About 1·0 litres of this is normally supplied by the food taken in and in its oxidation. Approximately 6 litres of fluid should therefore be supplied daily in the form of water or beverages. This is in agreement with the recommendations of Welch *et al.*[14] As there are great differences between individuals this amount may not be sufficient for some men. Changes in environmental conditions and/or the severity of tasks would also alter the water requirements. In planning the drinking-water requirements of men it is essential to provide at least one additional litre of water for each 5·5°C (10°F) increase in dry-bulb temperature, with 6 litres being the minimum for 32·2°C (90°F) conditions (dry). Should they be required to march or work in direct sunlight then this amount would be inadequate, and the same is true when activities are executed in hot humid areas. On the only warm sunny day during the present study (Fig. 2) the average total sweat loss was 1 litre higher than that used in the above calculation.

The comparative values of oral and rectal temperatures shown in Fig. 1 again emphasize the unreliability of oral temperatures, and lend support to our previous findings.[12] Even with all the necessary precautions with respect to correct positioning and keeping the thermometers under the tongue for at least 3 minutes, the oral temperatures recorded during the march were, on an average, about 0·55°C (1·0°F) below those temperatures recorded immediately before marching. The average difference between the oral and rectal values at the end of the march was almost 2·2°C (4°F).

It should be stressed that the exercise employed for this study must be classified as bordering on the severe. The men walked at the brisk pace of 6·6 km./hr. (4 m.p.h.) and carried packs weighing as much as one-third of their own body-weights. The average $O_2$ requirement for the task was 1·8 l. $O_2$/min., i.e. about 60% of the average maximum oxygen intake capacity for young South African males aged 19. This rate of exercise, although easily tolerated by physically fit, young men for long periods of time,[16] would result in the accumulation of metabolites in the unfit and those with less-than-average work capacity.


## SUMMARY

Two groups of 30 men each were made to carry out a route-march of 18 miles in full army kit. The members of one group were supplied with water *ad libitum* and those of the other group were rationed to 1 litre of water during the march. Temperature conditions during the study were mild. Dry-bulb temperatures did not exceed 31·1°C (88°F): the wet-bulb temperature was about 19°C (66°F) and Globe temperature readings varied from 37·8° to 49°C (100° - 120°F) depending upon the degree of cloud cover.

Twelve of the 30 men given only 1 litre of water and 8 of the 30 men given water *ad lib* failed to complete the march. Of those who fell out, 7 of the men on 1 litre of water collapsed while only 1 of the men given water *ad lib* collapsed. Boot-rub accounted for 16% of the total casualties in both groups. The final average rectal temperature of the water-restricted group was 38·8°C (101·8°F), compared with 38·3°C (101°F) for the *ad lib*-water group. Oral temperatures proved to be quite useless as a means of detecting rise in body temperatures: oral temperatures fell and rectal temperatures rose as the march progressed, and at the end of the march there was an average difference of 2·2°C (4°F) between oral and rectal temperatures. The average water losses in sweat were 4·5 litres in both groups of men. Taking into account water requirements for body function for the rest of the 24 hours, an amount of at least 7 litres (12 pints) per man per day is required for men engaged in similar activities in the summer of temperate regions. The group of men provided with only 1 litre of water exhibited dehydration to an extent of 5%, at which level they showed low morale and lack of motivation, became quarrelsome and difficult to control and refused to continue the route-march.


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