WATER REQUIREMENTS IN HOT COUNTRIES*


Army Personnel Research Establishment, Farnborough.

The quantity of water required for drinking by soldiers in hot countries has long been the subject of dispute and controversy. Despite a great mass of evidence to the contrary the conviction still exists that men can be habituated to work efficiently on reduced intakes. To resolve the problem a project was set up in 1964 to study the intakes and outputs of groups of soldiers under realistic operational conditions in a series of overseas stations. The aim of the project was the production of a guide to normal drinking-water requirements under all probable circumstances of heat stress and military activity. In this context “normal” was interpreted advisedly as the minimum compatible with health and efficiency. By calculating the state of the water balance at twelve-hourly intervals it was planned to use the measured water loss figures as the criterion of replacement requirement and at the same time to investigate any disparity between input and output. Intake of readily available water (and other liquids, but no alcohol) was to be measured, but to be under no influence other than thirst, which was to be taken as the sole arbiter of individual requirement.

This paper is concerned with two important aspects of the larger study, first, with the criteria of sufficiency outlined above, and second, with the extent and importance of voluntary dehydration—the debt incurred when the drinking of freely available water has not kept pace with output.

Experimental method

Four experiments were undertaken, each with a different group of 35-39 acclimatized soldiers. Each experiment followed an identical eleven-day plan, with five days of strenuous activity separating two three-day rest periods. The four countries selected to provide a cross section of typical hot climates were Tripolitania (June, 1964), Swaziland (March, 1965), Bahrain (June, 1965), and Malaya (November, 1965).

In Bahrain, strenuous activity had to be limited to four days. In view of this, findings and discussion relate to four active days—not five.

Table 1 provides a brief summary of the climatic findings.

<table>
<thead>
<tr>
<th>Overall mean daily climatic record</th>
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<tr>
<td></td>
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<tr>
<td><strong>Temperature °C</strong></td>
</tr>
<tr>
<td>Air</td>
</tr>
<tr>
<td>---------</td>
</tr>
<tr>
<td>Tripolitania</td>
</tr>
<tr>
<td>Swaziland</td>
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<tr>
<td>Bahrain</td>
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<td>Malaya</td>
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Figures are means of half-hourly readings (0600-1800) averaged over eleven days.

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Sweat losses (including insensible perspiration and water evaporated from the lungs) were calculated from the formula:—

\[ \text{Sweat loss (c)} = (W_1 + a + b) - (d + f + r + W_2), \]

where:

- \( W_1, W_2 \) = mean body weights at the beginning and end of each twelve-hour period
- \( a \) = weight of food consumed
- \( b \) = water intake (sum of intake from water bottles and beverages)
- \( d \) = urinary output
- \( f \) = faecal output
- \( r \) = weight change (imputed) due to excess of \( \text{CO}_2 \) produced over \( \text{O}_2 \) consumed.

Water balance was computed for both twelve and twenty-four hour periods from the expression:—

\[ \text{Change in water balance} = \text{water in} - \text{water out} = (b + aw + mw) - (c + dw + fw) \]

where:

- \( aw \) = food water
- \( mw \) = metabolic water, the end result of cellular oxidation (calculated)
- \( dw \) = urinary water
- \( fw \) = faecal water.

**Findings and discussion**

Although it is axiomatic that water requirements can always be met by replacing losses, this statement cannot stand in isolation. It is necessary to study the losses themselves and to assess how far, if at all, they are depressed from the optimum by a negative water balance either at the start or during the course of a twelve-hour period. For this reason discussion of sufficiency criteria must follow rather than precede consideration of voluntary dehydration.

**12 HOUR WATER BALANCE**

Fig. 1.
Voluntary dehydration

It has long been recognised that, even when water is freely available, men having to work in the heat do not replace this as quickly as it is lost (Hunt, 1912, Adolph and Dill, 1938, Ladell, 1937). The water deficit thus incurred was termed voluntary dehydration by Adolph (1947). In the present work the cumulative balances, illustrated in Fig. 1, show that for all four experiments the largest water debt was acquired on the first day of activity after the initial rest period. The extent of these debts, both for the day-time work period and for the whole twenty-four hours, is illustrated in Table II.

<table>
<thead>
<tr>
<th></th>
<th>0600-1800 hours</th>
<th>24-hour period</th>
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<tbody>
<tr>
<td></td>
<td>Debt (g)</td>
<td>Per cent body weight</td>
</tr>
<tr>
<td>Tripolitania</td>
<td>1596</td>
<td>2.4</td>
</tr>
<tr>
<td>Swaziland</td>
<td>1659</td>
<td>2.6</td>
</tr>
<tr>
<td>Bahrain</td>
<td>2349</td>
<td>3.4</td>
</tr>
<tr>
<td>Malaya</td>
<td>528</td>
<td>0.8</td>
</tr>
</tbody>
</table>

By the end of the second day's activity the debts had been abolished for the Bahrain and Swaziland troops, and much reduced in Tripolitania and Malaya. What significance should be attributed to these deficits? Has their occurrence had any effect on either performance or sweat output? To a certain extent, assessment of these small degrees of apparent dehydration is confused by a lack of precision in defining a starting point to represent normal hydration. In Fig. 1 the balances have been adjusted to zero at the end of the first twenty-four hours on the basis that this period of rest under new conditions should facilitate stability and that thereafter, as has been shown by Robinson (1963), resting men retain an even balance. Further, it could be that the particular water debts incurred on the first exercise day are not genuine debtor balances, but rather adjustments to changed circumstances, what Ladell (1965) calls a veering towards the physiological norm for men who are habitually super-hydrated. This view is supported by Henschel (1964), who suggested that voluntary dehydration may serve a useful purpose in conserving water. But even if the deficit is more of a genuine reality than just a resetting of the hydration homeostat, there is little evidence that, at the levels encountered, voluntary dehydration had any significant effect on either performance or sweat loss. In Bahrain, where the climatic stress was greatest, the men had to work through the heat of the day in extremely arduous and trying conditions. There were a number of minor heat casualties, but fewer than on the second day, when there was a day-time water debt of only 0.4 l. There was no suggestion from the behaviour of the troops of the sluggish performance and lassitude described by Adolph (1947) and Sohar (1962) as occurring at levels of from four to five per cent deficit of body weight. While few would quarrel with the findings that best performance is maintained when intake keeps equal pace with output (Moroff and Bass, 1965, Pitts, Johnson and Consolazio, 1944) there is little to suggest either from the literature or from clinical observations during the present study that water debts up to the possible maximum of 3.4 per cent body weight deficit are prejudicial to performance.
Dehydration and sweat output

Before employing sweat losses as the guide to replacement it is prudent to assess the effect of a negative water balance on the mechanism of sweat production itself. The evidence on this is controversial. Numerous authors have argued that dehydration levels in the region of 3-5 per cent have little or no effect on sweating (Bass and Henschel, 1956, Strydom et al, 1964, Renbourn and Ladell, 1959) whereas others have shown marked reductions at very low levels of water debt (Pearcy et al, 1956, Ellis, Ferris and Lind, 1954). It is likely that an unavoidable lack of control over starting hydration confuses the results, but it seems probable that, in outdoor situations of fairly long duration as opposed to laboratory studies, Ladell (1965) was near the truth in suggesting that sweating is not affected until deficits of more than 2.5 l have been incurred. In the present series debts to this extent were only approached on the first day of exercise in Bahrain when the mean deficit was 2.3 l.

Urinary Output

The evidence adduced so far permits the recorded sweat losses to be employed as guides to water replacement. Is the same true of the other principal channel of water loss, namely the urine output? There is small doubt that daily urine flows in excess of 1000 ml indicate corrective action being taken by the kidney to prevent over-hydration, but at the other end of the scale the picture is far from clear. While no one would dispute that obligatory urine volume is governed both by the quantity of metabolic end-products requiring elimination and the concentrating power of the kidney, there is little unanimity over what constitutes a minimal acceptable output for a healthy adult on a mixed diet in the heat. The classical view that at least 1500 ml are necessary is quoted by Whittow (1956) when he suggests that outputs lower than this are indicative of habituation to mild dehydration. Such opinions do not evoke much credence, unless a state of chronic dehydration is an acceptable concept, when compared with the many reports from desert studies of daily outputs from healthy men of less than 500 ml/24 hr (Robinson, 1949, Ladell, Waterlow and Hudson, 1944). Adolph (1947) regards desert outputs between...
700 and 900 ml as usual and necessary, whereas Kenney (1963) considered 700 ml to be the obligated minimum in the presence of maximum concentration, warning of danger from uraemia and hypernatraemia when outputs fall below this figure. Weisberg (1962) considers a normal mixed diet will produce 60 g/24 hr of solids (containing 1.2 osmoles of solutes) and that, with renal concentration to a specific gravity of 1035, obligatory output will be 850 ml.

Recorded urinary outputs in the present study are displayed in Fig. 2. It is manifest that very few mean daily outputs were in excess of 1000 ml, and from Table III it can be seen that for 20 of the 40 completed experimental days outputs were less than 800 ml/24 hr. Bahrain provided the most consistently low outputs, and for this reason an appraisal of these particular results is made in some detail.

Table III

<table>
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<th>Frequency distribution of urinary outputs</th>
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<tr>
<td>Output less than (ml)</td>
</tr>
<tr>
<td>1000</td>
</tr>
<tr>
<td>Tripolitania</td>
</tr>
<tr>
<td>Swaziland</td>
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<tr>
<td>Bahrain</td>
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<td>Malaya</td>
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Table III: Number of days (out of ten) when mean urinary output was less than 1000 ml and below.

Fig. 3 illustrates the distribution of 39 individual twenty-four hour outputs during both resting and activity phases. It shows the shift from a normal to a skew distribution, limited at the lower end by the irreducible obligatory flow, during the four days of strenuous exertion. The two most oliguric days (Days 6 and 7) both produced 15 individuals (10 of whom figured in both days) with outputs of less than 400 ml. The mean specific gravity recorded for these men was 1035 and 1033 on days 6 and 7 respectively, compared with a mean of 1030 for the whole group on both days. These figures suggest, as would be expected, that the volume of output is mediated principally by the concentrating power of the kidney. In the conditions of extreme heat stress under which these men were working there was a maximal response to anti-diuretic hormone and only
the absolute minimum of fluid loss was permitted by the renal route. There remains
the unanswered question of solute excretion. With an output of less than 400 ml/24 hr,
even with concentration to 1035, it is improbable that the excretion of total solids for
these soldiers was in excess of 25-30 g/24 hr from an expected total production of about
60 g when fed on the standard diet of army composite rations. Although low urine
outputs in hot conditions have been associated with raised values of blood urea (Ladell
et al, 1944, Ladell, 1947), and while Adolph (1947) accepts a low grade uraemia as
being in no way deleterious, there is reason to suppose that for the Bahrain subjects
here was in fact no significant accumulation of unexcreted solutes. It has long been
known that considerable quantities of urea are lost through the skin, and Robinson
(1949) draws attention to the loss of significant amounts of salt and urea by this avenue
of excretion. Although sweat, and especially that of a man acclimatized to heat, is one
of the most hypotonic of body fluids it is likely to contain at least 3 g/l of total solids
(Kuno, 1956). For the two days in Bahrain at present under scrutiny the mean sweat
losses were 12.7 I and 10.7 I respectively. There seems little doubt that in these
circumstances the skin can provide an alternative route for the elimination of solutes
and so reduce the threatened risk of an accumulation of metabolic end products. This
is not to suggest that urinary flows of less than 600 ml/day should be encouraged.
Indeed they should not. There is always the possibility, as has recently been demonstrated
in Israel by Frank and de Vries (1966), that consistently low urine flows will be associated
with an increased incidence of urolithiasis.

Conclusions

The concept of voluntary dehydration as either a resetting of the hydration
homeostat or a genuine dehydration remains debatable. It has been shown in the present
series that shifts in water balance, which might be cited as evidence for the presence of
voluntary dehydration, occurred only on one day of each of the four experiments, and
then to a degree unlikely to have affected either performance or sweat production.

The low urinary outputs recorded from Bahrain are considered non-injurious, if
hardly beneficial. Where very low urinary outputs are found in combination with very
high sweat losses it is likely that the latter will facilitate the excretion of a considerable
proportion of the metabolic end-products which demand removal. This releases the
kidney from the task of secreting more waste water than is absolutely necessary and has
the effect of reducing the obligatory flow to levels otherwise considered pathological.

Summary

In a series of four experiments to fix a scale of water allowances for troops in hot
countries, the replacement of losses was taken as the criterion of requirement. This
assumption is analysed in the light of the levels of dehydration encountered and their
effects on sweat and urinary outputs. Reasons are advanced for considering the
"voluntary dehydration", observed only on the first active day of each experiment,
to have had no appreciable effect on performance or sweat output. Very low urinary
outputs were recorded in one experiment. The hypothesis is made that in conditions of
high sweat outputs (in excess of 10 1/12 hr) the skin provides an alternative route for
the excretion of metabolic end-products.
Water Requirements in Hot Countries

REFERENCES