The extensive literature available on human water requirements under different environmental conditions has recently been summarized by several authors. In spite of all the work done, several gaps in our knowledge still exist. Ledell's raised the possibility of visual acuity and accommodation being affected by body-water deficits. If this is true, then the performance of hunters, marksmen and others depending on good eyesight will suffer, unless they keep their water balance. An opportunity to test this aspect recently presented itself during extensive field studies on young men.

The aim of the present study was to observe both the physiological and physical performance of men under different water regimes, while operating in desert terrain where any liquid, apart from that issued, would be difficult to obtain. One group of men received 2 bottles/man/day, another 1 gal./man/day, and the third group drank and used water ad libitum (2 bottles = 2.04 litres, 1 gallon = 4.54 litres).

**METHODS**

Thirty men were observed over a two-day period, during which time they were required to walk a total of 25 miles in a desert-like area.

The average physical characteristics of the men are outlined in Table I. All subjects wore standard clothing and carried full packs which together weighed about 44 lb. 6 oz. on the 1st day, and 41 lb. 1 oz. on the second day. The decrease in weight was due to the consumption of rations. In order to have the rifles cleaned and ready for use at the range at the conclusion of the walk on the second day, they were stored at base camp.

The men, who were woken early in the morning, left at about 6 a.m., that is, before any beverages or food were available. Each subject was issued with two ration packs which contained mainly dehydrated and semi-dehydrated foods.

On arrival at the starting point, the men were divided into three groups of 10 each, and were given their appropriate rations of water and food. The men in group I were given one bottle of water with which to start the day, and another bottle of water on completion of the first 12½-mile walk (that is, 2 bottles/man/day). The men in group II were each given 1 bottle of water for preparing breakfast, two bottles of water for the duration of the walk and a further bottle after completion of the walk (that is, 1 gal./man/day). The men in group III received water ad libitum throughout the two-day period. On the second day, the men in group I were again given only one bottle of water up to the time of completion of the walk, and the men in group II were given two bottles each for the same period.

All the men washed and shaved on the morning of the second day, and for this purpose an additional 250 ml. of water was issued to each man in group I. This water was used and discarded under supervision. The men in group II were required to use water from their ration for this purpose.

The men slept in sleeping-bags in the open. During the night one man obtained and drank an unknown quantity of a beverage. This subject was excluded from all further observations and calculations.

The walk started at approximately 10 a.m. on both days. The groups moved off simultaneously on the first day, and at intervals of 30 minutes on the second day. The latter arrangement was necessary in order to accommodate each group on arrival at the rifle range where they were to shoot at targets at ranges of 400, 300, 200 and 100 yards, six shots being allowed at each distance. Shooting was carried out in the prone position at the first two ranges, and in the kneeling and standing positions from the latter two ranges respectively. Each group had to run from one position to the next, under supervision. Immediately on completion of this sequence, the final physiological measurements were made.

The walks were made over firm desert sand with occasional short stretches of soft sand. The groups were spaced approximately one mile apart to ensure rigid control over water intake. Only group III was accompanied by a water truck. The men walked in loose formation at an average speed of between 3.0 and 3.5 m.p.h. under the supervision of one or two observers. The pace was slowed down deliberately in order to ensure that every subject would complete the experiment.

The following observations were made:

(a) Nude weights before and after the walks on both days.
(b) Full pack and clothing weight before the commencement of each walk.
(c) Rectal temperatures before, at the midpoint of, and at the conclusion of, each walk.
(d) Heart rates at rest and hourly during the walk. Skin electrodes and transistorized transmitters and receivers were used to measure heart rates during the walk.
(e) Urinary loss and water intake, when necessary.
(f) Environmental conditions. Wet-bulb, dry-bulb and globe temperatures were taken hourly.

**RESULTS**

The average results obtained for the three groups are summarized in Table II. Because of a technical error the sweat rates of the men in group II could not be calculated accurately and are therefore omitted. Data on environmental conditions are contained in Table III.
The temperatures of three men in this latter group IOr$F$, "Partly 6·b Period. temp. '0" cloudy eF) then group I dropped to 80% and .. the highest being 103·7°F. 100%, •• performance. Only temp. Wind Cloud x--x o\<n, / 0 of their usual performance at tbe end of Period.

The mean nude weight loss in group III paralleled that showed little change in weight over the experimental period and remained within 2% of their initial weights. The results observed in group III on the first day, but tended to

follow the pattern exhibited by group I on the second day, indicating a 5% loss at the final weighing.

On the first day the average rectal temperature of group I subjects increased to over 101°F. No difference was observed between the temperatures of men in groups II and III, both groups completing the walk with average temperatures of 100·5°F. On the second day significant differences were observed between the body temperature responses of all three groups. The mean rectal temperature for group III subjects remained below 100·5°F, while in group II it rose to about 101°F and in group I to over 102°F. The temperatures of three men in this latter group exceeded 103°F, the highest being 103·7°F.

Heart rates followed a trend similar to that of the rectal temperatures. On the first day the differences between the heart rates of groups II and III subjects were slight and the rates for both were markedly lower than the rates observed in group I, especially during the latter half of the walk. On the second day there was little difference in heart rate between groups I and II during the final hours, and the heart rate for both groups was significantly higher than for group III subjects. During the last hour on both days a heart rate of over 150 beats/min. was recorded on seven occasions in group I and four times in group II, while the highest rate in group III was 136 beats/min.

On the first day there was little difference between the heart rates of groups II and III subjects were slight and the rates for both were markedly lower than the rates observed in group I, especially during the latter half of the walk. On the second day there was little difference in heart rate between groups I and II during the final hours, and the heart rate for both groups was significantly higher than for group III subjects. During the last hour on both days a heart rate of over 150 beats/min. was recorded on seven occasions in group I and four times in group II, while the highest rate in group III was 136 beats/min.

On the first day there was little difference between the sweat rates of the subjects in groups I and III. On the second day, however, the more dehydrated men in group I sweated far less, i.e. an average of 2,614 ml. as compared with a mean of 3,450 ml. for group III.

The results obtained at the rifle range were compared with those obtained on two control days. On these days the men went to the rifle range without any previous stress, and fired the same sequence at approximately the same time of day (3 p.m.). Averaging the results obtained on the control days, and comparing them with those obtained under the conditions of the experiment, shows that the men in both groups I and II were affected by water loss and its consequences. If the scores obtained under normal conditions are taken as 100%, then group I dropped to 80% and group II to 84% of their usual performance at the end of the walk. Group III maintained 100% performance. Only average results can be used because some of the men in group I obviously aimed at the targets of their fellow subjects instead of at their own, even though each target was well marked.

The adverse effect of a water deficit on the morale and drive of the subjects in group I became obvious at the end of the walk on the first day. The men were lethargic and morose, and lay or slept for most of the afternoon, and their appetites were poor. As the degree of dehydration increased on the second day, the behavioural and sympo-


Climatic effects became more pronounced. All the men complained of a feeling of generalized weakness, lassitude and overwhelming thirst. The drive to carry on walking decreased rapidly, and vigorous encouragement was necessary to keep the men going. Water bottles were jealously guarded and the men became progressively more irritable.

The men in group II were hardly affected on the first day and were active during the afternoon. On the second day, however, a pattern similar to, but not as severe as, that observed in group I, developed as these men also became 'dehydrated'.

The morale, vigour and team spirit of the men in group III remained high throughout the experiment, in striking contrast to that observed in the men of groups I and II. Group III men ate and slept well, and were more active than those in the other two groups during the first afternoon and the following morning. In fact, the men walked at too fast a pace on the second day and had to be ordered to slow down occasionally, in order to maintain the correct sequence of arrival at the rifle range.

**DISCUSSION**

The climatic conditions during this study were far from severe. The morning of the first day was decidedly cold and overcast, with a temperature of 68°F dry-bulb being registered at 10 a.m. During the two-day period of the experiment the highest globe temperature recorded was 112°F, and the dry-bulb remained below 85°F for most of the time.

These weather conditions were cooler than those under which the previous water restriction study had been carried out, and tended to negate the object of conducting this experiment in desert conditions. Despite this fact and the deliberately reduced walking speed, a severe degree of physiological stress was imposed on the men in group I, who barely managed to complete the walk. Had climatic conditions been more severe, the probability of collapse or failure in some of the subjects would have been dangerously high.

The results obtained in this study substantiate our previous findings and serve to emphasize the importance of supplying an adequate water ration to active men operating in an arid zone. The degree of dehydration observed in the men in group I who received 2 bottles/man/day was greater at the end of the second day than in the water-restricted group studied previously. The amount of water given to group I on the first day was not enough to balance the water debt or to allow the men to recover overnight. If insufficient food intake is ruled out as a contributing cause, this group started off on the second day with an average body-water deficit of 3%. Their resting temperatures and pulse rates were consequently higher than those observed on the first morning, i.e. 98·6°F and 69 beats/min, respectively for the first day, as against 99·3°F and 103 beats/min, for the second day. These increases must be seen in the light of almost no activity on the part of the men during the morning of the second day. The men of the other two groups also showed higher initial values on this morning, but they were all playing active games and running about before the measurements were made.

The high body temperatures recorded in group I during and after the walk on the second day, are directly related to the progressive increase in the state of dehydration and the concomitant decrease in sweat rate. Their final average temperature was 2·0°F higher than that of the men given an unrestricted water supply, while their mean sweat rate was about 800 ml lower. Final pulse rates differed by 30 beats/min.

The men in the group given only one gallon of water/day (group II) did fairly well during the first day and during the initial stages of the second walk. Thereafter, water deficit also took its toll. Rectal temperatures and heart rates increased and finally finished at values between the values of groups I and III. It would appear, therefore, that even in relatively cool environments an issue of water of one gallon/man/day is not sufficient to keep active men in water balance and free from the consequences of water depletion. The water intake between walks of the men in group III was unfortunately not measured.

Iadell provides a possible explanation for the decrease in marksmanship in the two water-restricted groups. He states that after two days without water in a temperate climate there may be difficulties in accommodation, and that visual acuity declines. It was obvious that the subjects in group I not only suffered from these effects, but that they also had difficulty in orientation and thus actually shot at the wrong targets. As in the case of Mackworth's findings, the effect of a water deficit on performance was more pronounced in some members than in others, and here the poor performers suffered most. The group III men maintained their control performance and were not adversely influenced by the walk.

The psychological symptoms observed in groups I and II subjects are in general agreement with those reported and commented upon previously. The fact that all the men completed the experiment must be attributed, to a large extent, to the competitive spirit among the three groups, and to the leadership of the supervisors. The loss of appetite in the men in group I agrees well with the report of Salganik, who stated that the demand for food is reduced whenever Man is deprived of water, irrespective of the climate.

A ration of two bottles of water/man/day is inadequate even for one day of activity. One gallon of water/man/day will also be inadequate during extended field operations. Should such a ration become necessary due to unforeseen circumstances, then more judicious use of rest and shelter during the heat of the day will have to be made. Activity will then have to be restricted to the cool mornings and evenings.

**SUMMARY**

Thirty men were observed over a period of two days, during which time they were required to walk a total distance of 25 miles over a desert-like area. They carried packs weighing approximately 45 lb. and walked at 3-3·5 m.p.h. At the end of the walk on the second day they had to shoot at targets at various ranges. The environmental data collected showed that the climatic conditions were not severe. The highest globe temperature recorded was 112°F, while dry-bulb temperatures remained below 85°F for most of the time. In spite of this, the group of men who were given two bottles (2·04 litres) of water/man/day became severely 'dehydrated'. As a result, the body temperatures of 4 of the 10 men rose to dangerously
high levels of 103°F or above. Their heart rates were excessively high, while sweat rates were decreased. The physiological stress imposed was so severe that these men barely managed to complete the walk on the second day.

The group provided with one gallon/man/day (4.54 litres) performed fairly well on the first day, but progressively developed a greater water deficit on the second day. At the completion of the walk on the second day, an average rectal temperature of 101°F was recorded and heart rates were similar to those of the above group. The marksmanship of these two groups was affected, resulting in 15-20% lower scores than on control days.

The men who were given water ad libitum gave by far the best performance. Their body temperatures and heart rates were comparatively low, and not higher than would be expected from subjects doing the same level of exercise in cool environments. Their marksmanship was unaffected by the walk.

The effects of a water deficit on the morale and drive of the men in the two water-restricted groups were obvious. Behavioural and symptomatic effects became more pronounced as the extent of water depletion increased on the second day. Appetites were poor, and during the intermediate afternoon and evening these men were listless and morose.

This paper is published with the permission of the Transvaal and Orange Free State Chamber of Mines.

REFERENCES

THE ATOMIC ENERGY BOARD WHOLE-BODY COUNTER AND ITS APPLICATION TO MEDICINE


A whole-body counter is essentially a gamma-detecting device capable of determining the gamma-radioactivity of large samples, e.g. humans, and often capable of identifying the individual radionuclides within the sample. It consists of (Fig. 1): (i) a gamma-sensitive detector, (ii) shielding to reduce the natural background radioactivity around the detector, and (iii) an electronic counting system, usually with some form of pulse discrimination to sort out the gamma energies of interest and, hence, to identify radionuclides.

In vivo determinations of gamma-radioactivity and bremsstrahlung arising within the sample are done with whole-body counters. The most sensitive counters can measure the natural body burdens of gamma-active radionuclides in humans, while the less sensitive can easily measure trace amounts of radio-isotopes administered in the course of medical investigations. Table I lists the detection limits for a sensitive counter for some of the more common radionuclides in vivo.1

Whole-body counters are usually classified according to the type of detector used, the geometry in which the subject is counted and the number of detectors used. Thus there are 2- and 4-crystal scintillator counters, 2- and 4-crystal scintillator counters, single and multiple crystal counters using the standard chair or stretcher techniques; the last-named types all use thallium-activated, sodium iodide crystals.

The volumes of liquid scintillator counters range from 280 to 1,800 l, while plastic scintillator volumes range from 7-8 l to 300 l and crystal detector volumes lie in the range 0.6 l - 6.8 l. In crystal whole-body counters a single crystal is used usually, but there are counters using as many as 48 crystals. The characteristics of 4 typical whole-body counters are compared in Table II.

From Table II it is obvious that the 4-crystal scintillator system is the most sensitive and the multiple crystal stretcher system the least sensitive. Furthermore, the crystal counter has a much better resolution than the other 2 types of counter. The sensitivity of the single crystal counter is such that it is possible to determine down to 10-3 of the maximum permissible body burden for most gamma-emitting radionuclides in a reasonable counting time.

Whole-body counters are usually used for any of the following determinations:

(i) Natural activity in humans, e.g. potassium-40 content (Fig. 2), special groups living in areas of excessive natural background, radium and mesothorium cases, uranium and thorium cases.

(ii) Artificial activity in humans and animals, e.g. caesium-137 burden in the population at large (Fig. 2), fission products in special groups of the population, accidental ingestion by occupationally exposed

---