

University of Queensland

PAPERS

DEPARTMENT OF PHYSIOLOGY

Volume 1

1941

Number 6

The Effect of Exercise in Hot Atmospheres
upon the Pulse Rate

BY

DOUGLAS H. K. LEE, M.Sc. (Queensland), M.D., B.S., D.T.M. (Sydney),

AND

G. P. B. BOISSARD, B.Sc. (London).

REPRINTED

from

THE MEDICAL JOURNAL OF AUSTRALIA

DECEMBER 21, 1940

DEPARTMENT OF PHYSIOLOGY.

VOLUME I.

1941.

NUMBER 6.

THE EFFECT OF EXERCISE IN HOT ATMOSPHERES
UPON THE PULSE RATE.

By

DOUGLAS H. K. LEE, M.Sc. (Queensland), M.D., B.S., D.T.M. (Sydney),
Department of Physiology, University of Queensland,

and

G. P. B. BOISSARD, B.Sc. (London),
Department of Physiology, University of Queensland.

[Reprinted from *The Medical Journal of Australia*, December 21, 1940.]

THE EFFECT OF EXERCISE IN HOT ATMOSPHERES
UPON THE PULSE RATE.

By DOUGLAS H. K. LEE, M.Sc. (Queensland), M.D., B.S.,
D.T.M. (Sydney),

AND

G. P. B. BOISSARD, B.Sc. (London).

(From the Department of Physiology, University of
Queensland.)

PROBABLY no single item of bodily reaction to hot atmospheres has received more attention in the literature than the pulse rate. This has been summarized elsewhere.⁽¹⁾ In spite of this, however, it is not possible to compile a table from which to predict the average reaction to given conditions of atmosphere and exercise. When the experimental examination of hot atmospheres in relation to tropical settlement was proposed it was necessary on this account to include observations on the pulse rate, as such measurements are both easy to make in the field and valuable as indices of bodily reactions.

These observations form part of an extensive experimental inquiry carried out under the auspices of the National Health and Medical Research Council,⁽²⁾ the results of which are now in process of compilation.

Conditions of the Experiments.

The subjects were all males between the ages of eighteen and forty-five years, in good health, who were either members of the militia forces or students. Seven subjects were used in these experiments, but not all took part in all the trials. Each subject reported daily, on five days a week, for four weeks. The different experiments were scattered throughout the period to distribute the effects of acclimatization. The time of rising, of passing urine and of having breakfast were noted. Upon arrival the subject had a shower bath, dressed in the clothes provided, and sat down in the anteroom. Fifteen minutes before he entered the air-conditioned room a full set of "zero" readings was made

of the various items to be followed. These were completed by weighing the subject immediately upon his entering the room. The subject remained in the air-conditioned room for seven and a half hours. During this time readings were periodically made of the various items being followed and fluid was administered at stated intervals. Exercise of the type and for the duration required was performed in the morning and again in the afternoon. Lunch of a light character was taken between the exercise periods. The clothing worn in the hot room consisted of woollen pants, woollen socks, woollen gloves and sand-shoes.

Two atmospheres were used: "hot wet" (dry bulb, 87.5° F., wet bulb, 83.5° F.), giving a relative humidity of 87% and an effective temperature of 83° F.; and "hot dry" (dry bulb, 101° F., wet bulb, 79° F.), giving a relative humidity of 38% and an effective temperature of 84.5° F. (Effective temperatures are calculated from the chart for subjects stripped to the waist.)⁽³⁾

Three different levels of water administration were tried: none, half replacement of fluid lost (40 cubic centimetres in the hot wet room, 60 cubic centimetres in the hot dry room) at fifteen minute intervals, and full replacement of fluid lost (double the previous quantities). Water administration was also compared with saline solution administration at half replacement quantities, (i) at intervals of fifteen minutes, (ii) at intervals of two hours.

Two types of exercise were used. In the first, the subject marched up and down the room at the rate of three miles per hour for two hours, pausing for three minutes every fifteen minutes to have readings taken. A rifle was carried during the exercise. In the second, the subject lifted a weight of 36.5 pounds once every fifteen seconds through forty-two inches. An automatic device returned the weight to the subject's feet after each lift, without the subject's intervention. The exercise was continued for thirty minutes with a three minutes' interval for readings in the middle.

The pulse rate was counted once every fifteen minutes, except immediately after the conclusion of an exercise period, when a continuous count was made and progressive figures were taken out every fifteen seconds, and during the lunch period, when no readings were taken.

Normal Reactions.

Normal reactions will be seen in those experiments in which full water replacement is given. If these (Figure I) are examined in detail, the reactions under other conditions can be compared with these as the norms.

Hot Wet Atmosphere: Marching.—The first exercise raises the pulse rate from an average of 88 to 102 per minute, and this falls slightly towards the end of the period. With the cessation of exercise recovery rapidly occurs. During the rest interval and during lunch the rate falls off a little to 85 per minute. In the second exercise period the rate rises to a definitely higher level of 110 per minute during the first half, but falls to 104 in the second half. Recovery rapidly occurs to a level only slightly higher than in the morning.

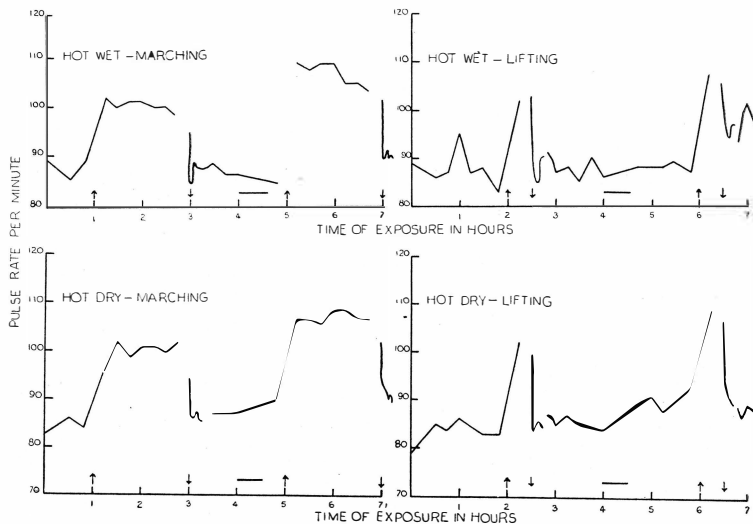


FIG. 1. NORMAL REACTIONS TO EXERCISE IN HOT ATMOSPHERES
(ARROWS INDICATE STARTING AND STOPPING OF WORK, LINE INDICATES LUNCH PERIOD)

Hot Wet Atmosphere: Lifting.—The first exercise raises the pulse rate to 102 per minute from an average level of 88. Recovery rapidly occurs and the rate fluctuates about the previous resting level of 88 throughout the rest and lunch. The second exercise period results in a somewhat higher level of 107 per minute, with a slower recovery to a higher figure of 93, which is, moreover, unstable.

Hot Dry Atmosphere: Marching.—The first exercise period raises the pulse rate from an average of 85 to 101 per minute, which remains fairly steady. Recovery is rapid, but the rate in the rest period is slightly higher at 87 per minute, and rises to 90 after lunch. The afternoon work period maintains an average rate of 107 per minute.

Recovery from this is rapid at first, but slows down later, to finish at the pre-exercise level of 90 per minute.

Hot Dry Atmosphere: Lifting.—The first exercise lifts the average resting pulse rate of 84 per minute to 102. Recovery is rapid, but this is followed by a slight temporary rise, which disappears by lunch-time. After lunch the pulse rate is raised to an average of 90 per minute. Exercise then raises it to 110. Recovery is slower and the rate reaches only 89 per minute.

Summary.

If comparisons between the two atmospheres and the two types of exercise are set aside for later consideration, the outstanding observation is that the afternoon exercise results in a greater rise of cardiac rate than the morning exercise. While this is due almost certainly in part to the accumulating fatigue of the day's activities, the taking of lunch seems to play an important part, as is indicated in the "hot dry" curves. This is in keeping with observations previously made in hotter climates with resting subjects.⁽⁴⁾ Hot dry atmospheres are more important in this respect than are hot wet atmospheres.

Significance of Variations.

In the counting of an individual pulse rate an error of four could be made. The average deviation of the average from this cause is therefore ± 2 . Differences between the level of two curves which consistently differ by more than this amount call, therefore, for examination. If the differences cannot upon inspection of individual curves be attributed to an unusual reaction of any one subject, then the differences become of significance in the experimental comparisons being made. The same criterion applies when trends in the same curve are being compared.

It has been made possible by the design of these experiments to compare experimental sets which are identical in composition except for the variable to be studied. The only partial exception to this is in the average degree of acclimatization possessed by the subjects of the experiments. In most cases the average degree of acclimatization in the sets being compared is very similar, but in order to appreciate the possible influence of such differences as do occur it is desirable first to examine the influence of acclimatization as seen in these experiments. The knowledge is also desirable for its own significance.

Two subjects were exposed to the same hot wet conditions on two occasions, once near the beginning of the series of experiments on that subject, once near the end. On each

occasion marching exercise was undertaken and water was given to half replacement of fluid lost at intervals of fifteen minutes. The comparisons reveal the following:

Subject A1.—Observations were made on the seventeenth day and on the sixth day. The pulse rate remained moderately low throughout; no essential difference was noted.

Subject B1.—Observations were made on the nineteenth day and on the eighth day. The pulse rate remained low throughout. In the less acclimatized the rate is slightly higher in the rest period.

Four subjects were exposed to the same hot dry conditions on two sufficiently separated occasions. Marching exercise was undertaken and half water replacement was given on each occasion. The comparisons (Figure II) reveal the following:

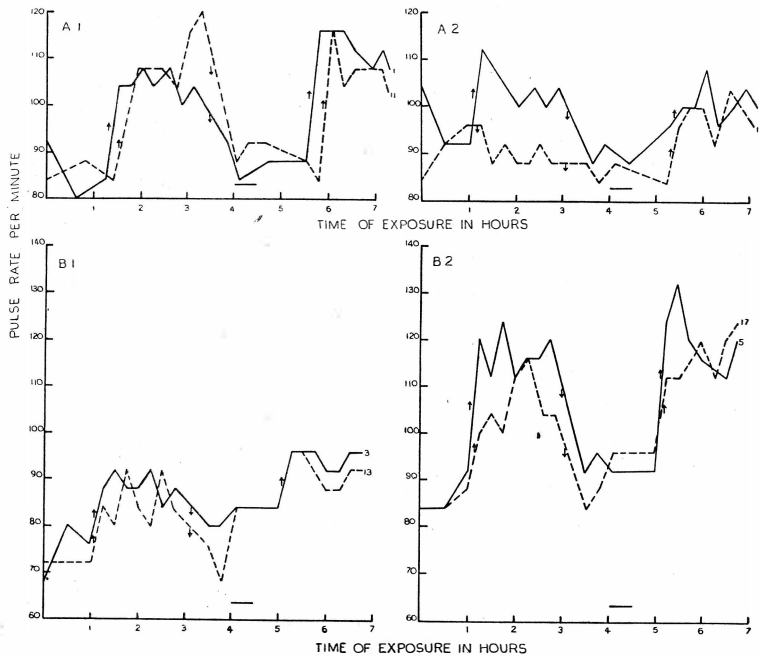


FIG. 2. EFFECT OF ACCLIMATISATION IN HOT DRY ATMOSPHERE

(— LESS ACCLIMATISED ----- MORE ACCLIMATISED, NUMBERS INDICATE SERIAL POSITION)

Subject A1.—Observations were made on the eleventh day and on the first day. The pulse rate remained moderately low throughout. In the less acclimatized the rate is lower throughout except in the afternoon exercise, in which it is higher.

Subject A2.—Observations were made on the fifteenth day and on the third day. The pulse rate remained moderate throughout. It was much higher in the less acclimatized in the morning exercise period, only a little higher in the afternoon exercise period. The recovery rates were not significantly different.

Subject B1.—Observations were made on the thirteenth day and on the third day. The pulse rate remained low throughout. It was somewhat higher throughout in the less acclimatized.

Subject B4.—Observations were made on the fifth day and on the seventeenth day. The pulse rate remained high throughout. It was much higher in the less acclimatized in the morning work period and somewhat higher in recovery: it was higher in the first part of the afternoon work period.

It would seem, therefore, that acclimatization has only a minor effect in hot wet atmospheres with the grade of exercise employed, but that it may play a significant role in hot dry atmospheres, especially in the subjects with higher pulse rates, and that the effect is greater with the morning than with the afternoon work.

Effect of the Level of Hydration.

Previous investigations⁽⁴⁾ have shown the importance of maintaining bodily hydration at an adequate level in hot atmospheres. It is important to know to what extent this factor enters into the economy of troops and labourers in tropical parts. The experiments in this series yield the following information when no replacement, half replacement, and full replacement are compared:

Hot Wet Atmosphere: Marching.—Hydration produces no improvement during the morning work or recovery. In the rest interval and in the afternoon work period half replacement, as compared with no replacement, progressively improves the rate up to seven beats per minute, and the recovery by five to ten beats. Full replacement gives no further improvement. [See Figure III (A).]

Hot Wet Atmosphere: Lifting.—Half replacement of lost fluid improves the rate by two to six beats per minute over the whole period up to lunch. While this disappears after lunch, it reappears as an improvement of six beats in the afternoon recovery from the work period and six to ten beats in the subsequent rest period. Full replacement gives no further improvement. [See Figures III (B) and III (C).]

Hot Dry Atmosphere: Marching.—Half replacement of lost fluid gives a pronounced improvement by three to ten beats

per minute over the whole morning work period, and by fourteen beats in recovery. This improvement declines to seven beats over the lunch interval. The improvement effected is five to eighteen beats per minute in the afternoon work period and thirteen beats in recovery. Full replacement gives no further definite improvement. [See Figure III (D).]

Hot Dry Atmosphere: Lifting.—Half replacement of lost fluid gives some improvement before the morning work, an

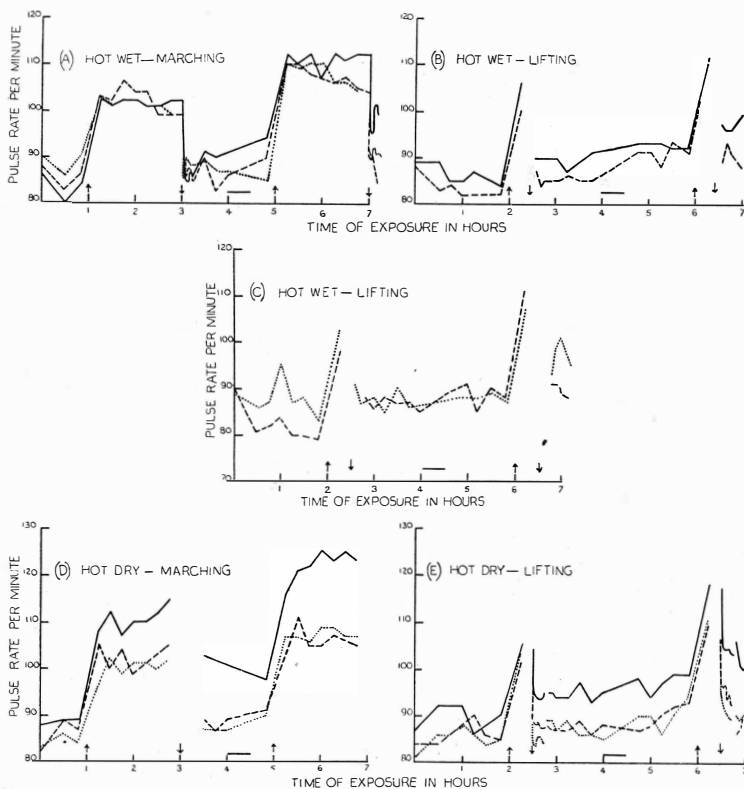


FIG 3 EFFECT OF HYDRATION LEVEL

(— NO REPLACEMENT - - - - HALF REPLACEMENT FULL REPLACEMENT)
 (IN THIS AND FIG. 4 COMPARISONS ARE MADE ONLY BETWEEN CURVES FOR GROUPS COMPRISING THE SAME INDIVIDUALS)

improvement of four beats per minute during that work, and an improvement of seven beats in recovery. The improvement continues at this level until lunch and rises to eleven beats per minute after lunch. During the afternoon work period the improvement continues at nine beats per minute, rising to eleven to sixteen in recovery. Full replacement gives no further improvement. [See Figure III (E).]

Summary.

Full replacement of water lost gives no definite improvement over half replacement. Half replacement gives some improvement over no water in the hot wet atmospheres and pronounced improvement in the hot dry atmospheres—an improvement which becomes proportionately greater as the day progresses.

Comparative Effects of the Administration of Water and of Saline Solution.

It is well known that replacement of salt as well as of water is necessary when sweating is free. Such replacement is sometimes carried out by the giving of saline drinks in place of plain water. It has been reported that the effects of work have been reduced by the administration of saline solution during the work period. It is desirable to know whether this is so for the atmospheres and exercise employed in these experiments. The following information comes from an examination of the corresponding curves in these series. Marching was the exercise employed in each case, and half replacement quantities of water or saline solution were given.

Hot Wet Atmosphere: Quarter-Hourly Administration.—Trials with saline solution cause the pulse rate to be lower by four beats per minute during the morning exercise period and recovery, but are not essentially different after that.

Hot Dry Atmosphere: Quarter-Hourly Administration.—Trials with saline solution cause the pulse rate to be somewhat higher during the morning work period and recovery, but are not essentially different after that.

Hot Wet Atmosphere: Two-Hourly Administration.—After the first administration the pulse rate during work falls to a somewhat lower level with saline solution than with water, but recovery is unchanged. After the second administration the pulse rates at rest are equal, but the pulse rate at work rises five to six beats higher after water. After the third administration the pulse rates at work are equal, but recovery is to a somewhat lower level with saline solution.

Hot Dry Atmosphere: Two-Hourly Administration.—The pulse rates after each administration lie at a somewhat higher level after saline solution than after water.

Summary.

Saline solution gives something of an improvement in the hot wet atmospheres, but appears to be something of a disadvantage in hot dry atmospheres. This is somewhat unexpected.

Effect of the Frequency of Fluid Administration.

It is not always convenient to give fluid at very frequent intervals. It is necessary, therefore, to know what stresses may be entailed by the administration of larger amounts at less frequent intervals instead of small amounts at quarter-hourly intervals. The following information comes from an examination of the curves obtained in corresponding trials. Marching exercise and half replacement quantities were employed in each case; a period of two hours was the delay used.

Hot Wet Atmosphere: Water Administration.—When administration is delayed the pulse rate before administration rises three to eight beats per minute higher [Figure IV (A)].

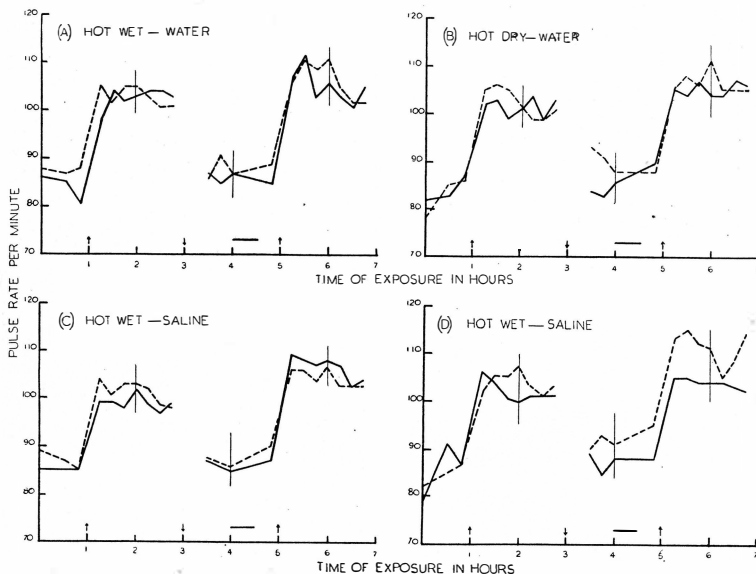


FIG. 4. COMPARISON BETWEEN FREQUENT AND INFREQUENT FLUID ADMINISTRATION
(— EVERY 15 MINUTES ---- EVERY 2 HOURS)

Hot Dry Atmosphere: Water Administration.—The pulse rate before delayed administration is higher by three to six beats during the morning work period, by eight or nine beats during the rest period, and by nought to seven beats during the afternoon work. After administration the discrepancies disappear and the rate in the delayed administration trials may become somewhat lower than in the frequent administration trials [Figure IV (B)].

Hot Wet Atmosphere: Saline Solution Administration.—The pulse rate before delayed administration is two to five beats higher in the morning exercise period, but somewhat lower in the afternoon exercise period. Disappearance of the discrepancy after delayed administration is slow [Figure IV (C)].

Hot Dry Atmosphere: Saline Solution Administration.—The pulse rate is higher in the delayed administration trials at all points except immediately after the delayed administration; it is three to ten beats higher before and nought to twelve beats higher after administration [Figure IV (D)].

Summary.

When administration of fluid is delayed the pulse rate in all cases rises higher. With the administration of saline solution the recovery is delayed or transient.

Comparison of Types of Exercise.

At first sight lifting may seem to be more strenuous than marching; but a comparison of the pulse rate curves does not support this view. Comparisons were made under several different conditions. The following results emerge:

Hot Wet Atmosphere: No Fluid Intake.—Lifting causes a pulse rate higher by four beats per minute in the first work period and by six beats per minute in immediate recovery, but otherwise there is no essential difference.

Hot Wet Atmosphere: Half Replacement Water Intake.—Lifting causes a slightly lower pulse rate than the average of marching in the first work period, but a rate of three to four beats per minute higher in the second period and recovery therefrom.

Hot Wet Atmosphere: Full Replacement Water Intake.—Lifting causes a rate slightly above the average of marching in the morning, but otherwise there is no difference.

Hot Dry Atmosphere: No Fluid Intake.—Lifting causes a pulse rate five beats less per minute than the average of marching in the morning, and eight beats less in the recovery therefrom. This discrepancy is lost by the end of the lunch period. The discrepancy returns at a level of five beats per minute in the afternoon and in the recovery. Acclimatization differences may account for a part of this discrepancy.

Hot Dry Atmosphere: Half Replacement Water Intake.—Lifting causes a pulse rate slightly lower than the average of marching in the morning, slightly higher in the afternoon.

Hot Dry Atmosphere: Full Replacement Water Intake.—There is no essential difference between the curves for the two types.

Summary.

In the hot wet atmospheres lifting tends to produce a somewhat higher pulse rate; but in the hot dry atmospheres it tends to be less exacting, particularly when water is withheld.

Comparison of the Hot Wet and Hot Dry Atmospheres.

The atmospheres used correspond to 86° F. effective temperature on the scheme drawn up by the Pittsburgh workers⁽³⁾ for men normally clothed and carrying out light work. On the scheme for men stripped to the waist, however, which would be expected to apply more to our subjects, the hot wet atmosphere has an effective temperature of 83° F. and the hot dry atmosphere one of 85° F. Our experiments were designed to afford a comparison between these two atmospheres under all the experimental conditions used. The resulting curves yield the following information:

Marching: Half Replacement Water Intake—Quarter-Hourly Administration.—This series occurs twice. In one the only essential difference is in the late afternoon work and recovery, in which the pulse rate is four to ten beats per minute higher in the hot dry atmosphere. In the other the only essential difference is in the recovery from the afternoon work, in which the pulse rate in the hot dry atmosphere is about seven beats per minute higher.

Marching: Half Replacement Saline Solution Intake—Quarter-Hourly Administration.—The pulse rate in the hot dry atmosphere is nought to eight beats per minute higher in morning work, seven beats higher in recovery, and nought to six beats higher in the rest period. It is not significantly higher in the afternoon.

Marching: Half Replacement Water Intake—Two-Hourly Administration.—The pulse rate in the hot dry atmosphere is two to eight beats per minute higher in the rest period and the second half of the afternoon work period.

Marching: Half Replacement Saline Solution Intake—Two-Hourly Administration.—The pulse rate in the hot dry atmosphere is higher practically throughout, nought to seven beats per minute in the morning work period, three to eight beats during the rest period, and six to fifteen beats in the afternoon work period. Immediately following the administration of fluid the discrepancy is temporarily somewhat reduced.

Marching: No Water Intake.—In both work periods the pulse rate in the hot dry atmosphere becomes progressively higher by six to thirteen beats per minute, and the recovery rates are higher by fourteen beats. During the rest and lunch period the discrepancy is progressively reduced to four beats per minute.

Marching: Full Replacement Water Intake—Quarter-Hourly Administration.—There is no essential difference between the two curves.

Lifting: No Water Intake.—There is no essential difference in the first work period. The pulse rate in the hot dry atmosphere is five beats per minute higher in rest period, eight beats in the second work period, and four to seven beats in recovery therefrom.

Lifting: Half Replacement Water Intake—Quarter-Hourly Administration.—The pulse rate in the hot dry atmosphere is slightly higher (three beats per minute) in both recovery periods; otherwise there is no essential difference.

Lifting: Full Replacement Water Intake—Quarter-Hourly Administration.—There is no essential difference until the afternoon work period, when the peak is three beats per minute higher in the hot dry atmosphere; but the recovery rate is six to fourteen beats per minute higher in the hot wet atmosphere.

Summary.

While there is no difference between the effects of the two atmospheres when ample water is given, the hot dry atmosphere has some heightening of effect when only half quantities are given, especially with the longer periods of marching. When no water is given, the greater effect of the hot dry atmosphere is very apparent. The administration of saline solution shows up the preponderant effect of the hot dry atmosphere more than does the corresponding administration of water.

Practical Applications.

Exercise, particularly more prolonged exercise, makes less demands upon the cardio-vascular system when undertaken in the morning than in the afternoon, especially in hot dry atmospheres.

While there is little need to pay attention to the acclimatization of subjects in hot wet atmospheres with the levels of exercise here employed, it may be of importance in hot dry climates if the cardio-vascular system is to be spared unnecessary stress. This is specially true of those subjects who have a labile pulse rate, of whom there seem to be an unusual proportion in Queensland, if the reports⁽⁵⁾⁽⁶⁾ of Commonwealth medical officers and Royal Australian Air Force recruit examiners are

examined. These experiments were conducted upon Queenslanders. If men from colder climates are being transferred to tropical parts it is probable that acclimatization will be an even more important factor. Such transfers should be made, if possible, in the cooler season, and exercise after transfer should be graded over the first two weeks.

While it is best at all times to maintain bodily hydration at its normal level, there is a certain margin of reserve which can, if necessary, be traded upon. Four hours' marching without water in the hot wet climate here employed, which is the highest summer average found in Australia, takes the body just beyond this reserve. Half replacement of the water lost (160 cubic centimetres per hour) brings the body back into this zone. With marching in the hot dry climate, which is again the highest summer average occurring in Australia, failure to replace the water lost results in a pronounced deterioration of cardiovascular reactions. In this case replacement of half the water lost (240 cubic centimetres per hour) almost, but not quite, restores the body to its margin of reserve.

In the hot dry climate the administration of saline solution during the day does not, contrary to expectation, improve cardio-vascular reactions, but actually interferes with them. In the hot wet climate some improvement results. There would seem to be no reason for the administration of saline drinks on the march in preference to water. This does not mean, of course, that the salt lost in sweating should not be replaced; but it can be left to meal-times, when it is much easier to administer. In fact, the dislike for saline drinks by our subjects may have had something to do with the heightened pulse rate. It must be realized further that these strictures do not apply to very heavy work in very hot dry atmospheres, such as that performed by stokers.

It is undoubtedly preferable to administer fluid frequently in small quantities rather than infrequently in large quantities; but if administration is delayed, although the cardiac response is raised for the time being, it returns fairly quickly to normal after adequate fluid has been administered.

The lifting exercise here employed seems to be on the same physiological level as marching without kit.

The two atmospheres here employed are equivalent in their resultant effects upon the pulse rate, provided that all other conditions are normal; but if other stresses are introduced, such as dehydration, the hot dry atmos-

there becomes proportionately more exacting. For normal conditions and moderate work the nomogram for the stripped subject for effective temperature shows no advantage over that of the clothed subject. For abnormal conditions allowance must be made for the preponderant action of the hot dry climate; that is to say, we go further and further away from the commonly accepted interpretation of Haldane's statement⁽⁷⁾ that in hot environments the temperature on the wet bulb thermometer is more important than that on the dry bulb thermometer.

Acknowledgements.

Grateful acknowledgement is made of the financial help given to these investigations by the National Health and Medical Research Council, and of the seconding of two officers to take a leading part in the work by the Director-General of Health, Commonwealth Department of Health. Gratitude is also expressed to the other members of the team whose names do not appear in the authorship of this report. We are all also indebted to our subjects, who stood with fortitude the somewhat trying and monotonous conditions of the experiment.

References.

⁽¹⁾ D. H. K. Lee: "A Basis for the Study of Man's Reactions to Tropical Climates", *Queensland University Papers*, Volume I, Number 5, 1940.

⁽²⁾ National Health and Medical Research Council, Report of the Fourth Session, 1938, Appendix I, page 15.

⁽³⁾ C. P. Yaglou: "The Thermal Index of Atmospheric Conditions and its Application to Sedentary and to Industrial Life", *The Journal of Industrial Hygiene*, Volume VIII, Number 5, 1926, page 5.

⁽⁴⁾ R. A. Gregory and D. H. K. Lee: "Effect of Water Intake upon Human Reactions to Reduced Cooling Powers", *The Journal of Physiology*, Volume LXXXVI, February 8, 1936, page 204.

⁽⁵⁾ D. A. Dowling: Personal communication.

⁽⁶⁾ P. Benjamin: Personal communication.

⁽⁷⁾ J. S. Haldane: *The Journal of Hygiene*, Volume V, 1905, page 494.