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# *Work Performance After Dehydration: Effects of Physical Conditioning and Heat Acclimatization*

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ABSTRACT

BUSKIRK, E. R., P. F. IAMPIETRO AND DAVID E. BASS. *Work performance after dehydration: effects of physical conditioning and heat acclimatization.* J. Appl. Physiol. 12(2): 189–194. 1958.—Three groups of five men each were dehydrated overnight in the heat (115°F) on two occasions ($D_1$ and $D_2$) to approximately 5.5% of their starting body weight. During the 3-week period between $D_1$ and $D_2$, one group (*AC*) was acclimatized to heat and physically conditioned, the second group (*C*) was physically conditioned and the third group (*S*) remained sedentary. The response to work after dehydration was assessed by the following criteria: pulse rate (P), rectal temperature ($T_r$) and maximal oxygen intake (Max. $\dot{V}O_2$). Pulse rates during and after walking and after running were elevated with dehydration. This elevation was reduced in *groups AC* and *C* at $D_2$ as compared to $D_1$, but not in *group S*. An elevation in $T_r$ with walking also occurred with dehydration, but this elevation was not significantly different at $D_2$ as compared with $D_1$ in any group. Physical conditioning elicited an elevation in Max. $\dot{V}O_2$ (*group AC* and *C*), but the elevation was no greater in *group AC* than in *group C*. Dehydration was associated with an equal decrement in Max. $\dot{V}O_2$ at $D_1$ and $D_2$ in all groups, but the conditioned men (*AC* and *C*) maintained a relatively higher Max. $\dot{V}O_2$ than *group S*. Thus, physical conditioning was associated with enhanced work performance during dehydration (assessed by the above criteria), whereas acclimatization to heat did not appreciably supplement this effect.

ACUTE dehydration apparently limits man's ability to work, largely through impaired cardiovascular function (1). The circulating blood volume is particularly affected with the result that work which was performed easily when adequately hydrated becomes extremely difficult when dehydrated. Rapid elevations in pulse and rectal temperature occur even with moderate work, and early exhaustion ensues.

Both physical conditioning (2, 3) and heat acclimatization (4, 5) appear to be associated with improvement of cardiovascular function during work, particularly in the heat, with the result that work performance is enhanced.

The present study was designed to determine whether the above two treatments might ameliorate the impaired ability to do work when dehydrated. Work during dehydration consisted of grade walking and grade running on the treadmill.

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## PROCEDURE AND METHODS

Three groups of five men each were dehydrated in the heat overnight (115°F D. B., 80°F W. B., 3 mph wind) on two different occasions, (1st dehydration = $D_1$ and 2nd dehydration = $D_2$). When dehydrated, they were asked to perform two bouts of work, a walk followed by a run. Various physiological measurements were made during work and recovery. The general plan for the experiment is given in table 1.

During the 3-week period between $D_1$ and $D_2$, one group (*AC*) was acclimatized to heat and physically conditioned; a second group (*C*) was physically conditioned and a third group (*S*) remained sedentary. Two men were lost from *group S* at $D_2$, therefore, the results for *group S* are given for only three men.

TABLE 1. GENERAL PLAN FOR THE EXPERIMENT

| Weeks | Events |
|---|---|
| 1 | Preliminary observations all groups |
| 2 | Dehydration I ($D_1$) |
| | Each group* starts appropriate regimen on the day following $D_1$ |
| 3 | Regimens continue |
| 4 | Regimens continue |
| 5 | Dehydration II ($D_2$) |

* *Group AC*—acclimatized to heat and physically conditioned; *C*—physically conditioned; *S*—sedentary.

TABLE 2. SCHEDULE OF EVENTS DURING DEHYDRATION PERIODS

| Time | Activity | Mesurements |
|---|---|---|
| 6 P.M. | Rest in 78°F air | $T_r$, wt., P |
| 8 P.M. | Rest in 115°F air | $T_r$, wt. |
| 3 A.M.—(Time dependent on rate of weight loss) | Rest in 78°F air | $T_r$, wt. |
| 7 A.M. | Walk in 78°F air | $T_r$, P, $\dot{V}O_2$, wt. |
| 7:30 A.M. | Rest in 78°F air | $T_r$, wt. |
| 7:35 A.M. | Run in 78°F air | Max. $\dot{V}O_2$ |
| 7:38 A.M. | Rest in 78°F air | $T_r$, P, wt. |
| 7:40 A.M. | Allowed to drink ad libitum | |

Windspeed 3 mph; wet bulb 80°F for all conditions; $T_r$ — rectal temperature; P — pulse; wt.—weight; $\dot{V}O_2$—oxygen consumption; max. $\dot{V}O_2$—maximal oxygen intake.

Acclimatization to heat was accomplished by the performance of daily bouts of work in the heat (90°F D.B., 80°F W.B., 3 mph wind during the 1st week, 120°F D.B., 80°F W.B., 3 mph wind during the 2nd and 3rd weeks). The work consisted of three 30-minute walks with 30-minute rest periods between walks. Thus, the men remained in the hot room for 2.5 hours each morning. Although the men were permitted free week-ends between the 1st and 2nd and between the 2nd and 3rd weeks, they worked through the last week-end just prior to $D_2$.

Physical conditioning consisted of cross-country runs each afternoon over the surrounding terrain. The cross-country course was approximately 4 miles long and the men ran the course from 2–4 times each afternoon. In addition, they were given routine formal exercises and participated in team games such as touch football and volley ball. At least 3 hours per afternoon were spent on the conditioning phase.

The men who remained sedentary engaged only in sedentary recreational activities, i.e. pool, cards, movies, reading, etc.

The schedule of events during the dehydration periods ($D_1$ and $D_2$) is given in table 2. The men entered the chambers at 6 P.M. and spent 2 hours resting in 78°F air. Water was withheld during this period. At 8 P.M. the men entered the hot chamber, 115°F D.B., 80°F W. B., and reclined on beds or participated in recreational activities, e.g. throwing rubber horseshoes, until they had lost 5% of their 8 P.M. weight. Rectal temperature ($T_r$), pulse and body weight were measured at 1-hour intervals until body weight loss approached 5%. Then weights were taken at more frequent intervals until 5% was achieved.

When the 5% loss was reached, the men were removed to the comfortable chamber (78°F) and remained there until treadmill work was started at approximately 7 A.M. This meant that each man rested or slept from 3–5 hours prior to the start of his work period. During this resting period, just prior to working on the treadmill, the men were awakened and the measurements listed in table 2 were made. The men were no longer hyperthermic (elevated $T_r$) at the time of measurement.

At approximately 7 A.M. the work periods were initiated. The men went on the treadmill at 15-minute intervals in the approximate order that they had been removed from the hot chamber the previous night. Each man walked 30 minutes (3.5 mph, 10% grade), rested 5 minutes, ran 3 minutes (7 mph, grade for maximal oxygen intake procedure), and rested 12–15 minutes in sequence. The measurements listed in table 2 were made during the indicated periods. The times of measurement are also apparent from the appropriate figures in the results section.

A portable thermistor apparatus was used to measure rectal temperature. Body weight was measured with a Toledo platform scale sensitive to ±10 gm.

Urine was voided on occasion by several individuals during the course of both dehydrations. In no case did the 12–16-hour urine volume exceed 400 cc/man. Four individuals vomited a small amount of material which was collected and weighed. Fecal weights were also determined. In each case all of the above weights were excluded and did not contribute to what was called the 'dehydration' weight loss. Weight loss during the night hours was not corrected for the weight of $CO_2$ expired over the weight of $O_2$ inspired.

Pulse was counted by auscultation over the apex or by radial palpation. Metabolic rate during walking was determined by collecting expired air in a Tissot spirometer. The fraction of $O_2$ in expired air ($F_{EO_2}$) was determined with a Beckman $O_2$ Analyzer. The equation of Weir (6) was used to calculate metabolic rate from this information. Maximal oxygen intake (Max. $\dot{V}O_2$) was determined by the method of Taylor, Buskirk and Henschel (7). In addition, $F_{EO_2}$ and $F_{ECO_2}$ were obtained by analyzing the expired air samples collected during the walk and run in a Micro-Scholander apparatus.

Each man was given a subjective performance evaluation during work on the treadmill at $D_1$ and $D_2$. The technique of analysis of variance was used where possible. Further delineation of differences was attempted (where appropriate) with sign tests.

## RESULTS

*Group AC* men were demonstrably acclimatized to heat as evidenced by the usual indices, i.e. work pulse, sweat rate and rectal temperature (fig. 1). Evidence for improved physical condition after the physical conditioning program is provided by the elevation in maximal oxygen intake (table 3) and an improvement in cross-country running time.

The extent of dehydration, estimated as percentage of weight loss from the 8 P.M. body weight, averaged 5.55%/man for all groups and varied between 5.18 to 6.33% at both $D_1$ and $D_2$, table 4.

During the night hours in the heat, the rate of weight loss was approximately 550 gm/hr. and varied from 430 to 1030 gm/hr. During the morning exercise periods at 78°F, the men lost 350 gm/hr. when hydrated normally and 250 gm/hr. when dehydrated. Weight loss during work was slightly higher at $D_2$ than $D_1$, particularly in *group AC*, because some difficulty was experienced with the speed regulating device for the treadmill; the metabolic rates during walking also tended to be higher at $D_2$ than $D_1$, indicating a walking speed slightly greater than 3.5 mph. Because of this difficulty, the higher walking sweat rates (wt. loss) at $D_2$ in *group AC* cannot be specifically associated with acclimatization to heat and/or physical conditioning. No change in sweat rate occurred in *group C* or *group S*, when sweat rate was expressed as grams per Kcal. of energy expenditure during walking.



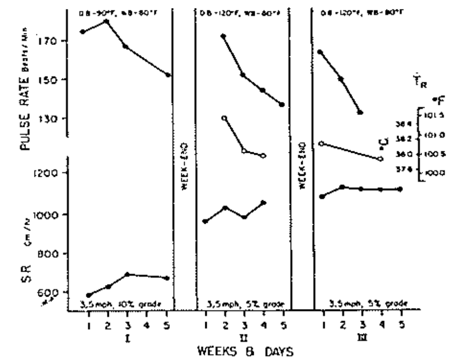



FIG. 1. Change in walking pulse, rectal temperature ($T_r$), sweat rate (*SR*) during 3 weeks of acclimatization to heat.

TABLE 3. CHANGE IN MAXIMAL OXYGEN INTAKE WITH DEHYDRATION, PHYSICAL CONDITIONING AND COMBINATION OF ACCLIMATIZATION TO HEAT AND PHYSICAL CONDITIONING

| Group | Man | Δ ($D_1 - N_1$) | Δ ($D_2 - N_2$) | Δ ($N_2 - N_1$) | Δ ($D_2 - D_1$) |
|---|---|---|---|---|---|
| Conditioned (C) n = 5 | *Ca* | 0 | −0.09 | +0.09 | 0 |
| | *Che* | −0.15 | −0.25 | +0.07 | +0.08 |
| | *Mu* | −0.10 | −0.28 | +0.02 | −0.16 |
| | *Per* | −0.07 | −0.06 | +0.53 | +0.43 |
| | *Da* | −0.14 | −0.24 | +0.39 | +0.29 |
| $\bar{x}$ | | −0.09 | −0.18 | +0.22 | +0.19 |
| Acclimatized and Conditioned (AC) n = 5 | *Wi* | −0.32 | −0.34 | +0.70 | +0.68 |
| | *Cha* | −0.21 | −0.25 | +0.34 | +0.30 |
| | *Gr* | −0.55 | −0.22 | +0.06 | +0.39 |
| | *Co* | −0.45 | −0.29 | +0.27 | +0.43 |
| | *Mc* | −0.18 | −0.16 | +0.15 | +0.17 |
| $\bar{x}$ | | −0.34 | −0.25 | +0.31 | +0.39 |
| Sedentary (S) n = 3 | *Bu* | −0.06 | −0.12 | +0.42 | +0.36 |
| | *Ke* | −0.16 | −0.18 | −0.02 | −0.10 |
| | *Pea* | −0.30 | −0.32 | −0.05 | +0.05 |
| $\bar{x}$ | | −0.17 | −0.21 | +0.11 | +0.10 |
| $\bar{\bar{x}}$ (n = 13) | | −0.21 | −0.22 | +0.27 (AC&C) | +0.26 (AC&C) |

$N_1$ and $N_2$ = max. $\dot{V}O_2$ when normally hydrated; measured the day before $D_1$ and $D_2$, respectively.

$D_1$ and $D_2$ = max. $\dot{V}O_2$ at 1st and 2nd dehydrations, respectively.

TABLE 4. EXTENT OF DEHYDRATION ESTIMATED FROM PER CENT BODY WEIGHT CHANGE

| Group | Man | % Wt. Loss | |
|---|---|---|---|
| | | $D_1$ | $D_2$ |
| Conditioned (C) n = 5 | *Ca* | 5.83 | 5.64 |
| | *Che* | 5.33 | 5.55 |
| | *Mu* | 5.81 | 6.04 |
| | *Per* | 5.62 | 5.20 |
| | *Da* | 6.33 | 5.60 |
| $\bar{x}$ | | 5.78 | 5.61 |
| Acclimatized and Conditioned (AC) n = 5 | *Wi* | 5.20 | 5.72 |
| | *Cha* | 4.59* | 5.58 |
| | *Gr* | 5.18 | 5.73 |
| | *Co* | 5.63 | 5.55 |
| | *Mc* | 5.24 | 6.09 |
| $\bar{x}$ | | 5.17 | 5.73 |
| Sedentary (S) n = 3 | *Bu* | 5.89 | 5.90 |
| | *Ke* | 5.75 | 6.00 |
| | *Pea* | 5.73 | 5.30 |
| $\bar{x}$ | | 5.79 | 5.73 |

$D_1$ = first dehydration; $D_2$ = second dehydration.

$$\%\text{ wt. loss} = \frac{\text{evening weight} - \text{final weight}}{\text{evening weight}} \times 100$$

where evening weight is the weight at the start of each dehydration (8 P.M.)

final weight is the weight at the end of each dehydration.

* Man drank water after removal from hot room.

The change in $T_r$ during work and recovery with normal hydration and with dehydration is presented as figure 2. Work and recovery $T_r$'s were elevated with dehydration. The magnitude of this elevation was approximately 0.5°C greater than with normal hydration in most instances.

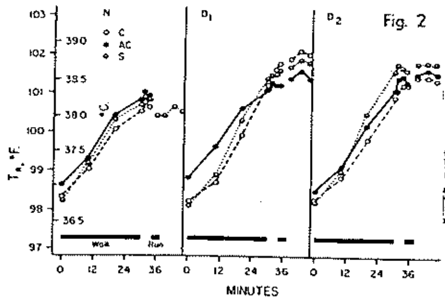
Acclimatization to heat and/or physical conditioning did not alter the $T_r$ response to walking on a 10% grade at 3.5 mph while dehydrated; this was also true of the $T_r$ during recovery after walking and running. $T_r$ at the end of walking appeared to be markedly less at $D_2$ than at $D_1$ in *group C*; however, this is more apparent than real, since appreciable decreases occurred in only three of the five men in *group C*. $T_r$ at the end of walking in *group AC* was the same at $D_2$ as at $D_1$. As already noted, the walking speed was faster at $D_2$ than at $D_1$; nevertheless, $T_r$ at $D_2$ was not elevated in proportion to the greater energy expenditure. It is possible, therefore, that $T_r$ at the end of the walk might have been less at $D_2$ than at $D_1$, if energy expenditures had been the same, and that acclimatization to heat and/or physical conditioning may have had an effect (that was missed) on $T_r$ in *group AC*.

It is interesting to note that the 3-minute run during dehydration produced an elevation in $T_r$ from 0.1–0.2°C above the $T_r$ measured 3 minutes after walking. By comparison, if *group S* when normally hydrated is used as a reference, $T_r$ actually fell during recovery from the walk and then rose 0.1°C after the run.

Pulse rates during work and recovery are shown in figure 3. It can be seen that dehydration is associated with a distinctly higher pulse rate in all groups. Although the pulse rate response in *group S* did not change at $D_2$ as compared to $D_1$, the 30-minute walking pulse rate decreased in 9 out of the 10 men in *groups AC* (5 of 5) and *C* (4 of 5). The same finding was observed for the 1-minute recovery pulse after walking and the 1- and 4-minute recovery pulse after running. When *groups AC* and *C* are compared with themselves between $D_2$ and $D_1$, it would seem that physical conditioning lessened the cardiovascular strain, (indicated by the pulse rate) resulting from dehydration. Acclimatization to heat appeared to lessen further the cardiovascular strain, but a significant difference in pulse response between *groups AC* and *C* could not be determined. Thus, an effect of acclimatization to heat on pulse response was not demonstrated.

The change in max. $\dot{V}O_2$ with acclimatization to heat and/or physical conditioning and dehydration is shown in table 3. An increase in max. $\dot{V}O_2$ occurred in *groups AC* and *C* between $D_1$ and $D_2$, (see column $N_2$-$N_1$); this increase was associated with the physical conditioning program. Acclimatization to heat did not appear to augment this effect. Dehydration was associated with a decrement in max. $\dot{V}O_2$ in both $D_1$ and $D_2$ ($D_1$-$N_1$ and $D_2$-$N_2$, table 3); this amounted, on the average, to 210 cc/man on $D_1$ and 220 cc/man on $D_2$. The decrement at $D_1$ and $D_2$ was approximately the same for all groups, although the conditioned men maintained a higher max. $\dot{V}O_2$ with dehydration. Thus, physical conditioning did not ameliorate the adverse influence of dehydration, but the conditioned individual was in a better state (in terms of reserve) to cope with the dual stress of dehydration plus running.





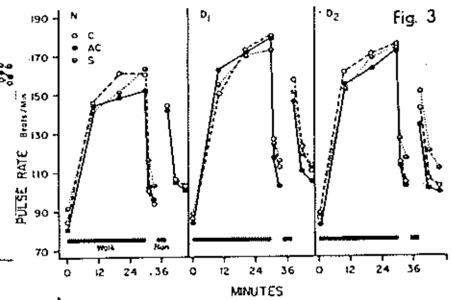




FIG. 2. Change in rectal temperature ($T_r$) during work and recovery with normal hydration (*N*) or dehydration ($D_1$, $D_2$).

FIG. 3. Change in pulse rate during work and recovery with normal hydration (*N*) or dehydration ($D_1$, $D_2$).

One individual in *group S* had a significant increase in max. $\dot{V}O_2$ between $D_1$ and $D_2$ while in the other two men max. $\dot{V}O_2$ remained unchanged. We have no reason for excluding this individual from *group S*, although his max. $\dot{V}O_2$ elevation at $D_2$ looks suspicious and a change of this magnitude rarely occurs.

Expressed subjective discomfort during work with dehydration included the same symptoms observed by Adolph *et al.* (1). Major complaints were nausea, dizziness, abdominal and muscular pain. In general, these complaints disappeared by $D_2$ in the men who were acclimatized to heat and/or physically conditioned, but not in *group S*.

## DISCUSSION

The results of this study indicate that work performance during dehydration is enhanced by physical conditioning; and that acclimatization to heat, superimposed on physical conditioning, does not further enhance performance. Apparently, the altered physiological state of the physically conditioned individual, e.g. enlarged respiratory cardiovascular reserve, plays a major role in counteracting the deleterious effects of acute dehydration on work performance.

The physical conditioning used in this study, i.e. cross-country running, was not considered to be sufficient in amount and duration to prepare a man for competition in athletic circles. In evaluating the conditioning program, it should be borne in mind that the subjects did not participate in recreational sports, marches or other forms of moderate to severe activity for approximately 6 weeks prior to the initiation of the study. At $D_1$, all subjects were considered to be relatively unconditioned because of this enforced 6-week period of sedentary existence. With initiation of the conditioning program, therefore, the step was one from a relatively unconditioned to a better conditioned state. In terms of physiological adaptation to exercise, however, it is felt that the step referred to above produced a clear separation of groups in terms of conditioning for running. The elevation in max. $\dot{V}O_2$ found with the conditioning program used here and the increase in duration of running supports this view.

Acclimatization to heat was defined in terms of response of heart rate, sweat rate, rectal temperature, etc., to a specific heat and work load. The procedure for heat acclimatization used in this study may be regarded as rendering acclimatization to 120°F at the specific work load used and substantially more acclimatization to lesser heat loads (8). Further experimentation is required to determine whether different levels of heat acclimatization are important with respect to man's ability to tolerate dehydration.

The relationship between performance decrement and the magnitude of dehydration hinges to some extent on the index used for assessing dehydration. In this study, dehydration was interpreted as a net loss in body weight from the 8 P.M. body weight. Obviously, other measurements must be made to estimate 'true' water loss. The uncorrected weight loss is no doubt releated to a 'true' water loss and on this basis can, in turn, be related to alterations in work performance. The 8 P.M. body weight was chosen as reference for convenience and because it was felt that it would provide as valid a reference point as any other.

An expansion of the circulating blood volume with physical conditioning (9) and heat acclimatization (8, 10) has been reported by others; however, the changes in cardiovascular and/or respiratory function in this study could not be associated with changes in basal blood volume. These data, (blood and plasma volumes) are reported separately (11).

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