AD-A150 942 PREPARING ALBERTO SALAZAR FOR THE HEAT OF THE 1984 OLYMPIC MARATHON(U) ARMY RESEARCH INST OF ENVIRONMENTAL MEDICINE NATICK MA L E ARMSTRONG ET AL. JAN 85 1/1

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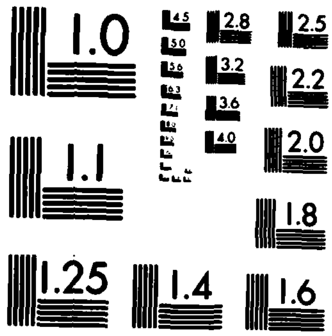
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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: M13/85	2. GOVT ACCESSION NO.: AD-A150942
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): Preparing Alberto Salazar for the heat of the 1984 Olympic Marathon	5. TYPE OF REPORT & PERIOD COVERED
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): CPT Lawrence E. Armstrong, Roger W. Hubbard, MAJ Bruce H. Jones, and Jack T. Daniels.	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: US Army Research Institute of Environmental Medicine, Natick, MA 01760-5007	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 3E162777A879 44383302122
11. CONTROLLING OFFICE NAME AND ADDRESS	12. REPORT DATE: January 1985
	13. NUMBER OF PAGES: 17
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): UNCLAS
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

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18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Heat, exercise, dehydration, heat acclimatization, rectal temperature, sweat rate, physical training, gastric emptying, body weight, iron deficiency.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Observations were made on American marathon record holder Alberto Salazar during a climatic chamber trial, heat acclimatization training, and the 1984 Olympic Marathon. Blood samples and rectal temperature data showed that hormonal and thermoregulatory mechanisms were normal. However, measurements of a very high sweat rate (2.79 liter/hr and 3.06 liter/hr) indicated that dehydration was a ptoentially serious problem. In fact, Salazar lost 5.43 kg (-8.1%) during the Olympic marathon, in 134.3 minutes of running. Although Salazar's

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PREPARING ALBERTO SALAZAR FOR THE HEAT OF THE 1984 OLYMPIC MARATHON

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IN BRIEF

Observations were made on American marathon record holder Alberto Salazar during a climatic chamber trial, heat acclimatization training, and the 1984 Olympic Marathon. Blood samples and rectal temperature data showed that hormonal and thermoregulatory mechanisms were normal. However, measurements of a very high sweat rate (2.79 liter/hr and 3.06 liter/hr) indicated that dehydration was a potentially serious problem. In fact, Salazar lost 5.43 kg (-8.1%) during the Olympic marathon, in 134.3 minutes of running. Although Salazar's decreased rectal temperature was desireable, his increased sweat rate was an unnecessary physiological adaptation to training in the heat.

INTRODUCTION

Successful distance running performance in the heat depends on many factors. Specifically, the importance of heat acclimatization (1,2) and fluid intake during prolonged exercise (3,4) have been previously documented. However, few reports have been published on the heat acclimatization and fluid consumption habits of elite athletes who are preparing for world class competition under hot, humid conditions.

The purposes of this case study were: (1) to evaluate the physiological responses of Alberto Salazar to a heat tolerance test conducted under conditions which were projected to be "worst case" for the 1984 Olympic marathon, (2) to offer heat acclimatization recommendations and to evalute the success of Salazar's heat acclimatization training, and (3) to advise Salazar on thermoregulation and fluid discipline during the Olympic marathon.

METHODS

The following selected characteristics were recorded for this subject: height - 185 cm, weight - 66.9 kg, age - 25 yr, surface area - 1.89 m^2. His maximal heart rate (188 bpm), maximal ventilation (177.1 liter/min, BTPS), and maximal oxygen consumption (78.7 $ml \cdot kg^{-1} \cdot min^{-1}$) were measured at room temperature in Eugene, Oregon. He was completely informed of all procedures and potential risks prior to giving written consent for this study.

Prior to the Olympic marathon (OM) and prior to heat acclimatization (HA) training, Salazar underwent a discontinuous running heat tolerance test (HTT) in a climatic chamber at Natick, MA. This chamber was maintained at the "worst case" conditions predicted for OM in Los Angeles, California, on August 12, 1984 (30.3°C dry bulb, 76% relative humidity, 28.0°C WBGT, and 0.1 m/min wind velocity). Twenty minutes of seated rest in the chamber (REST1) and a 12.5 minute treadmill warmup (running at 5.2, 5.6 and 6.1 m/s) (RUN1) preceeded 15 minutes of running at 6.4 m/s (RUN2). This was followed by a standing rest (REST2) of 10 minutes, and six minutes of running at 5.9 m/s (RUN3). Twenty minutes of seated recovery (REST3) completed HTT. The RUN2 treadmill velocity (6.4 m/s) was equivalent to a 5.0 min/mile race pace.

Venous blood samples were taken from the antecubital vein before RUN1, after RUN2, and 20 minutes after RUN2. All blood samples were analyzed for lactic acid (Sigma Chemical Co., St. Louis, MO), plasma renin activity (New England Nuclear, North Billerica, MA), aldosterone (International CIS, Cedex, France), and cortisol (New England Nuclear, North Billerica, MA). Urine samples were collected before REST1 and 40 minutes after RUN3, and were analyzed for sodium by flame photometry.

All respiratory exchange measurements were conducted using standard techniques of open-circuit spirometry. Samples of expired air were analyzed for carbon dioxide (Beckman LB-2) and oxygen (Applied Electrochemistry S-3A). Heart rates were recorded by an ECG telemetry system (Hewlett Packard). Sweat rates were calculated by using body weight differences, corrected for water intake. Rectal, oral and three-point skin temperatures (arm, chest, calf) were monitored by standard thermisters (Yellow Springs Inc., Yellow Springs, OH).

Prior to HA, recommendations were offered regarding site selection, water and salt intake, glucose-electrolyte replacement drinks, meterological factors, Tre monitoring, and body weight maintenance. We also designed several wide-bore drinking containers which were used during HA training and OM.

After HA workouts on the road and track, Salazar recorded Tre using a digital thermometer and rectal probe. Salazar also monitored environmental conditions using a wet globe thermometer (5), which gives a reading that can be converted to the equivalent WBGT reading by adding 1°C. This thermometer offered Salazar a relative index of the severity of daily temperature and humidity conditions.

A record was maintained of the workouts run during HA in Florida. This training log recorded daily mileage, intensity, type of workout, wet globe temperature, and Tre at the end of each training session.

Salazar recorded pre-OM and post-OM nude body weight, to allow calculation of sweat losses. Water consumption (i.e. number of aid stations, volume ingested) was recorded by Salazar following OM. Four weeks post-OM, he also completed a 27 item retrospective questionaire regarding the heat acclimatization and fluid intake recommendations which had been given to him.

RESULTS

Climatic Chamber Trial

The running HTT, conducted under "worst case" OM conditions, produced the results in Table 1. Oral temperature obviously did not accurately reflect Tre, and was noticeably affected by cool water ingestion. Salazar's skin temperature was lower than Tre because of evaporative cooling stimulated by heavy sweating and limb movements. The HTT heart rate, ventilation, and oxygen consumption (RUN2) were 89%, 87%, and 92%, respectively, of the maximal values measured in Eugene, Oregon.

The results of blood analyses are presented in Table 2. The plasma volume loss and lactic acid accumulation are typical of exercise performed at this intensity and for this duration. Plasma renin, aldosterone and cortisol levels also increased as expected (6). In accord with these aldosterone increases, the urinary Na+ concentration decreased from 104 mEq Na+/l (beginning of REST1) to 38 mEq Na+/l (40 min after RUN3). The POST-RUN3 and the REST3 values were similar for all measurements in Table 2, with the exception of lactic acid. The increased lactic acid concentration from POST-RUN3 to REST3 probably reflected a delayed release of intramuscular lactate into the blood.

Based on a maximal sweat rate of 2.79 liter/hr (Table 1), the net change in body weight during OM was calculated for different rates of water consumption. Figure 1

TABLE 1 - RESULTS OF CLIMATIC CHAMBER TRIAL[1]

STAGES OF HEAT TOLERANCE TEST[2]

TRIAL SEGMENT:	REST1	RUN1	RUN2	REST2	RUN3	REST3
DURATION (min):	20	12.5	15	10	6	20
VELOCITY (m/s):	0	5.2-6.1	6.4	0	5.9	0
PACE (min/mile):	0	6:15-5:15	5:00	0	5:30	0
MEASUREMENT(unit)						
Rectal temperature (°C)	37.3	37.9	39.4	40.0	40.2	39.9
Skin temperature (°C)	34.7	35.5	36.7	36.3	36.7	36.2
Oral temperature (°C)	37.0				38.6	37.5
Heart rate (beats/min)	57	102	167	122	150	73
Ventilation (1/min, BTPS)	11.8		155.0		109.5	21.6
Oxygen Consumption (ml/kg/min)	4.7		72.4		60.9	7.1
Sweat Rate (1/hr)	0.37		2.35		2.79	2.08

NOTES: 1. conducted at 30.3°C dry bulb, 76% RH, 28.0°C WBGT, 0.1 m/min wind velocity

2. values were recorded at the end of each trial segment, except REST2 (at midpoint)

TABLE 2 - RESULTS OF BLOOD ANALYSES

	CHAMBER TRIAL SEGMENT		
MEASUREMENT (unit)	CONTROL[1]	POST-RUN3	REST3[1]
Plasma volume (Δ %)		-16.2	-16.8
Lactic acid (mg%)	5.4	12.8	17.1
Plasma renin activity (ng/ml/hr)	1.55	10.08	9.92
Aldosterone (ng/dl)	12.15	18.75	17.11
Cortisol (ug%)	18.01	30.86	30.29

1. samples taken after 20 min of sitting in the heat

illustrates these projected body weight losses during OM, based upon water consumption rates of 0.5, 0.375, 0.25, and 0.0 liter per 5 km. Aid stations were located at 5 km intervals on the OM course. These projections indicated that Salazar stood to lose 5.93 kg (-8.9%) during OM, if he drank no fluids (line D, Figure 1). Dehydration was considered to be a serious problem.

Heat Acclimatization Training

The meteorological records (dry bulb temperature, relative humidity, wind velocity, rainfall, and per cent cloud cover) of Los Angeles, CA, Norfolk, VA, Gainesville, FL, and Miami, FL were compared. Gainesville, FL was selected as the site for HA training; the weather conditions anticipated for HA in Gainesville were very similar to those projected for OM in Los Angeles, CA on August 12, 1984.

Salazar ran 509 km between June 29 and July 17, 1984 (26.7 km per day). Thirty-three workouts were run during these 19 days--6 on the track (intervals) and 27 on the road (continuous). Daily body weight was stable at 67 kg during HA.

Rectal temperature (Tre) was measured by Salazar after five of his most intense training sessions, but never exceeded $39.2^{\circ}C$ (average: $38.5^{\circ}C$). Salazar reported that, during equivalent track workouts, Tre decreased $0.7-1.0^{\circ}C$ after one week of HA. For example, on Day 5 of

HA, Salazar ran an intense track workout under 26°C WBGT conditions and measured a final Tre of 39.2°C. Salazar ran a nearly identical track workout on Day 19 of HA, under 27.2°C WBGT conditions, and measured a final Tre of 38.7°C. Based on these data, we believe that Salazar successfully achieved heat acclimatization.

For eight weeks prior to OM, Salazar experimented with liberal hydration before exercise, and with a variety of consumption volumes during long (30-34 km) steady runs. Favorable drinking behavior modifications were reported, in that Salazar typically drank very little during previous marathons.

The Olympic Marathon

Five minutes prior to the start of OM, Salazar consumed one liter of cool water. He had practiced this every day for 2 months prior to OM, and it caused him no discomfort. During OM, a mean running velocity of 314 m/min (5.2 m/s) was maintained for 134.3 minutes, at approximately 85% of his maximal oxygen consumption. Although Tre was not measured, the coastal breeze on the marathon course stimulated evaporative cooling, and Salazar did not feel overheated during any segment of OM. Body weight loss was measured at 5.43 kg (-8.1%), in spite of total fluid consumption estimated at 1880 ml (223 ml/5 km). This body weight loss equates to a sweat rate of 3.06 liter/hr.

Although environmental conditions varied along the OM course, measurements ranged from 23.9-27.8 °C dry bulb and 2.2-5.4 m/s wind velocity (75% RH). Calculations (7) of the maximal evaporative capacity of the environment, the sweat equivalent of radiation and conduction factors, and wasted (dripping) sweat indicated that Salazar used only 62% of his total sweat output for evaporative cooling. In the HTT described above, this same calculation indicated that Salazar similarly used only 64% of his total sweat output to cool the body. This finding was supported by visual observations of wet skin, dripping sweat and saturated running gear.

Post-Olympic Evaluation

Four weeks after OM, Salazar completed a 27 item written questionaire, at our request. He believed that he was maximally heat acclimatized at OM, but that HA training adaptations were not enough to offset his inherent tendency to dehydrate. Salazar reported that he was in such excellent physical condition that he would have won a medal if he had entered the Olympic 10,000 m race. He reportedly plans to avoid hot weather marathons in the future and will probably concentrate on the 10,000 m race in the 1988 Olympics because, "in such a short race, sweat rate will not be a factor."

DISCUSSION

Realizing that laboratory testing and marathon running are two separate domains, our research team offered recommendations to Salazar which were freely accepted or rejected, as they met the realities of intense daily training and world class competition. Following OM, Salazar stated that his 2:14:19 performance was disappointing, compared to his OM goals. Considering the many factors which contribute to athletic performance (i.e. training, disease, psychological state, environmental conditions), Salazar's atypical OM effort does not indicate that our recommendations were inappropriate or that these research findings are invalid.

There were no indications of impaired thermoregulation during HTT or HA. The Tre of 40.2°C observed during RUN3 of HTT (Table 1) was attributed to the near absence of air flow across the skin (chamber wind velocity: 0.1 m/min). Outdoor measurements of post-exercise Tre never exceeded 39.2°C, during HA in Florida. In fact, because of Salazar's high level of fitness ($\dot{V}O_2max$ = 78.7 ml • kg^{-1} • min^{-1}), he should have achieved a low Tre more rapidly than less fit individuals (8).

Salazar's pituitary-adrenal axis responded normally to rest and exercise (Table 2), and normal fluid-electrolyte adjustments during HA and OM were expected. Plasma renin and aldosterone typically exhibit increases during exercise which are proportional to the relative exercise intensity (6).

Figure 1 illustrates the projections used by Salazar to plan his water intake prior to OM. Several previous investigators have demonstrated that performance decrements usually accompany body weight losses exceeding 5% (9). Because of Salazar's high sweat rate (2.79 liter/hr, Table 1), he theoretically should have consumed 375 ml at each 5 km aid station (see line B, Figure 1) to avoid BW losses greater than 3%. Gastric emptying is delayed by high intensity exercise, however, and we estimated Salazar's gastric emptying rate at approximately 250 ml/5 km (10). This estimate was empirically verified when Salazar experimented with a range of fluid consumption rates, during training runs. Thus, we realized prior to OM that Salazar's net body weight loss would fall between lines C and D in Figure 1. In fact, the actual body weight loss experienced by Salazar is represented by the dashed line in Figure 1, in spite of an estimated average water intake of 223 ml/5 km.

The fact that Salazar's actual body weight loss during OM fell closer to line D than line C (Figure 1) is best explained by an increased sweat rate--an expected outcome of HA training (11). The calculated sweat rate during OM was 3.06 liter/hr, compared to 2.79 liter/hr

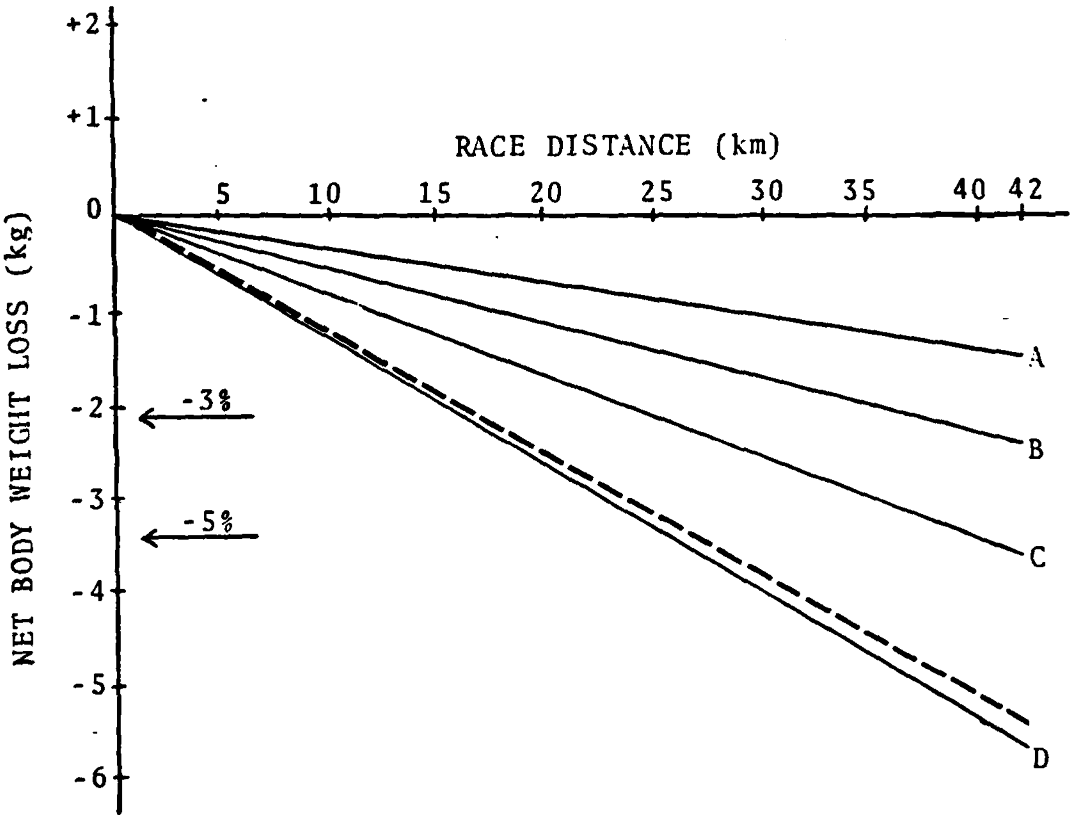

FIGURE 1 - Projected net body weight loss, based on 2.79 l/hr sweat rate and "worst case" OM conditions. Lines A, B, C and D represent water consumption rates of 0.5, 0.375, 0.25 and 0.0 liter/5km, respectively. Dashed line illustrates Salazar's actual OM body weight loss (3.06 l/hr sweat rate), in spite of water intake of 0.223 l/5km.

prior to HA (during HTT). Unfortunately, this post-HA increase in sweat rate was unnecessary because Salazar sweat profusely before HA; it also acted to accelerate dehydration during training and racing. This does not mean that Salazar should not have undergone HA in Gainesville, FL, however. In attempting to achieve the lower Tre, lower heart rate, and lower sweat electrolyte losses so often observed following HA (11), Salazar had to accept the undesirable increase in sweat rate. We believe that Salazar's training in the mild environment of Eugene, Oregon would not have prepared him properly for OM. Gisolfi (1) has previously demonstrated that HA training can be improved, but not replaced, by training in a cool environment.

Figure 2 was published by Costill in 1972 (3). It compares running speeds and sweat rates of marathon runners under environmental conditions which were milder than OM (17-24°C, 2.5-4.2 m/s wind velocity 23-54 % RH). We have added the symbol S at the top of Figure 2 to represent Salazar's OM sweat rate; clearly, it is one of the highest sweat rates ever reported. Pugh's observations of 56 marathoners (12) racing under environmental conditions (23°C dry bulb, 58% RH) similar to those in Costill's study, demonstrated sweat losses of 1-5.23 kg. Salazar's net body weight loss was 5.43 kg during OM. Pugh's top four finishers had surface

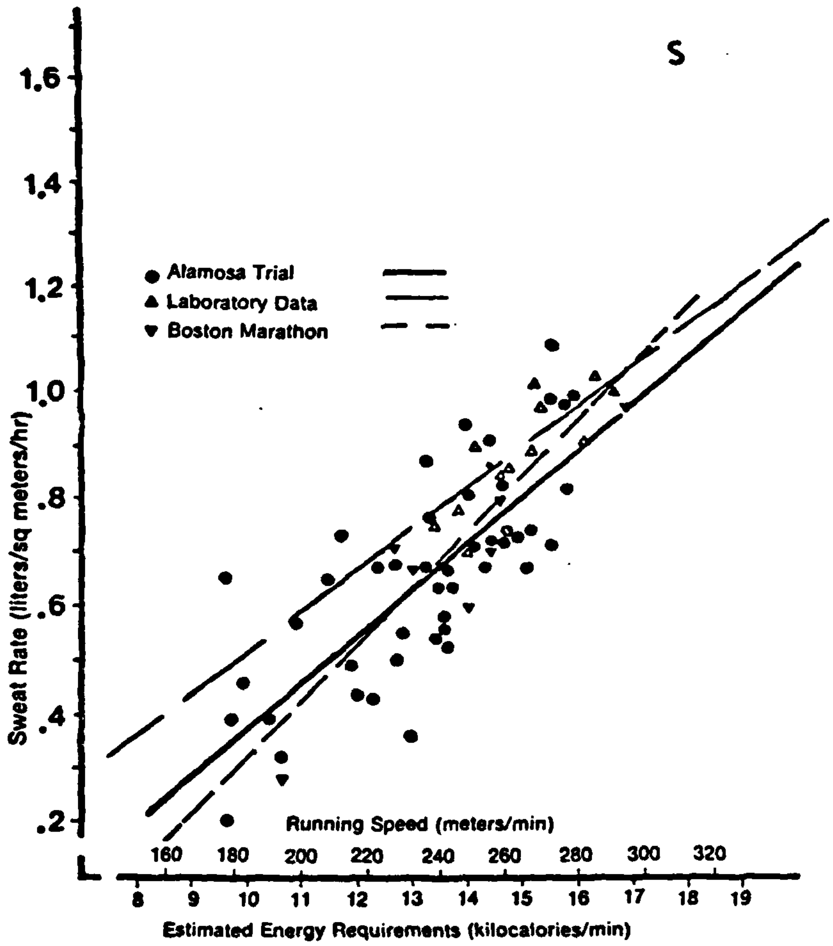

FIGURE 2 - Relationship between running speed and sweat rates, as measured by Costill (3). The symbol S represents Salazar's mean race velocity and sweat rate during OM. Reproduced by permission, Journal of American Medical Association 221(9): 1024-1029, 1972.

area-to-mass ratios (SAM) of 26, 29, 28, and 27 m^2/kg; Salazar's SAM was calculated at 35.4 m^2/kg (1.89 m^2 surface area). This large SAM indicated a high capacity for evaporative cooling as well as a potentially large number of sweat glands. Once again, dehydration was anticipated to be a more serious problem than hyperthermia.

Ferritin, an iron complex stored mainly in bone marrow, may be used or discharged by distance runners faster than it is replaced. A normal serum ferritin value for distance runners is 60 ng/ml (13), but iron deficiency is diagnosed if serum levels fall below 30 ng/ml. More than one year prior to OM, Salazar had nonanemic ferritin deficiency diagnosed when his serum ferritin level was measured at 17 ng/ml. This condition was treated by oral iron supplements, and by April, 1984 the symptoms of this ailment were absent. We now realize that Salazar's nonanemic ferritin deficiency may have been influenced by his capacity to sweat profusely (13,14). In fact, Vellar (15) has reported that as much as 40 μg iron/100 ml sweat might be lost during heavy sweating.

Fine-mist showers were erected so that marathoners could run through them during OM. Although we would recommend that most runners make use of such showers on hot days, we advised Salazar to avoid these showers for the following reasons: (a) he was concerned about thigh chafing and blisters on his feet; (b) dehydration--not hyperthermia-- was expected to be the limiting factor; (c) Sweating at approximately 3 liter/hr, Salazar's skin would already be wet; (d) although a temporary psychological euphoria could be gained by running through these showers, this same euphoria could be derived by pouring a cup of cool water over his head and shoulders; and (e) Salazar would produce approximately 1400 Kcal of metabolic heat per hour during OM and a brief exposure (0.5-1.5 seconds) to a fine-mist spray would not lower Tre measureably. Pugh (12) similarly considered sponging the body to have only a minor impact on heat balance during a marathon.

As distance runners train in hot weather, two unique factors--physical training and heat exposure--contribute to the heat acclimatization process. Our initial interest in this project arose when it was recognized that Salazar's HA training would involve a small physical training gain and a relatively large heat acclimatization component. Thus, the improvements observed during Salazar's HA in Gainesville, FL were essentially due to heat exposure and offered a measure of the relative contribution of both factors to HA. We plan to pursue this research problem with marathon runners in our laboratory.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the technical assistance of William Matthew, Dr. Patricia Szlyk, Dr. Ralph Francesconi, Dr. Michael Durkot, Candace Matthew, Jane Deluca, Pamela Evans, Denise McQuade, and Karie Jo Feingold. The support of Mr. Jose' Salazar, COL Ernest M. Irons and Dr. James Vogel also is appreciated.

Human subjects participated in this study after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research.

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