AD-A162 728 HEAT ACCLIMATIZATION DEVELOPED DURING SUMMER RUNNING IN NORTHEASTERN UNITED STATES(U) ARMY RESEARCH INST OF ENVIRONMENTAL MEDICINE NATICK MA L E ARMSTRONG ET AL. 1/1

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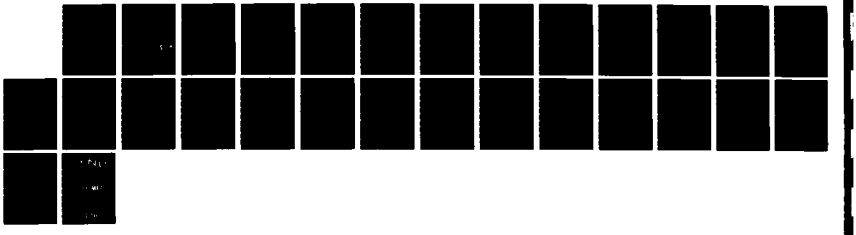

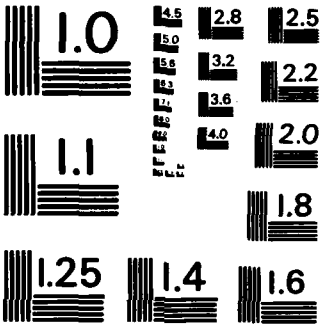

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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

Five highly trained distance runners (DR) were observed during controlled 90-min thermoregulation trials in spring (T_1) and late summer (T_2) to document the extent of heat acclimatization (HA) developed during summer running in Northeastern United States. These trials simulated environmental (30.3 ± 0.1°C DB, 34.9 ± 0.5 % RH, 4.47 m/sec wind speed) and exercise (treadmill running at 80, 120, 160, and 200 m·min^{-1}) stresses encountered by DR during daily training. Between T_1 and T_2, DR trained outdoors for 14.5 ± 0.4 wk but consequently showed few physiological adaptations classically associated

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with HA. Statistical comparison of T_1 and T_2 indicated no significant differences in mean heart rate, rectal temperature, sweat Na^+ and K^+, plasma Na^+ and K^+, or change in plasma, volume during exercise; mean weighted skin temperature was unchanged (except at 50 min of exercise) and sweat rate was also unchanged (except during the initial 30 min segments, 73 ± 6 vs 93 ± 8 $ml \cdot m^{-2} \cdot h^{-1}$), indicating an earlier onset of sweating during T_2. Significant decreases ($p < .05$) in submaximal oxygen uptake were observed. T_1 vs T_2 values were 13.97 ± 0.27 vs 10.19 ± 1.19, 31.38 ± 1.15 vs 27.91 ± 1.45, and 44.97 ± 0.85 vs 41.24 ± 0.97 $ml \cdot kg^{-1} \cdot min^{-1}$ at treadmill speeds of 80, 120, and 200 $m \cdot min^{-1}$ respectively. We conclude that DR did not require summer heat exposure to adequately thermoregulate during the spring trial (T_1), which simulated the hottest summer days recorded during this study.

HEAT ACCLIMATIZATION DEVELOPED DURING SUMMER RUNNING IN NORTHEASTERN UNITED STATES

5 tables, 3 figures

Abstract

Five highly trained distance runners (DR) were observed during controlled 90-min thermoregulation trials in spring (T_1) and late summer (T_2) to document the extent of heat acclimatization (HA) developed during summer running in Northeastern United States. These trials simulated environmental (30.3 $\pm$ 0.1°C DB, 34.9 $\pm$ 0.5 % RH, 4.47 m/sec wind speed) and exercise (treadmill running at 80, 120, 160, and 200 $m \cdot min^{-1}$) stresses encountered by DR during daily training. Between T_1 and T_2, DR trained outdoors for 14.5 $\pm$ 0.4 wk but consequently showed few physiological adaptations classically associated with HA. Statistical comparison of T_1 and T_2 indicated no significant differences in mean heart rate, rectal temperature, sweat Na^+ and K^+, plasma Na^+ and K^+, or change in plasma volume during exercise; mean weighted skin temperature was unchanged (except at 50 min of exercise) and sweat rate was also unchanged (except during the initial 30 min segment: 73 $\pm$ 6 vs 93 $\pm$ 8 $ml \cdot m^{-2} \cdot h^{-1}$), indicating an earlier onset of sweating during T_2. Significant decreases ($p<.05$) in submaximal oxygen uptake were observed: T_1 vs T_2 values were 13.97 $\pm$ 0.27 vs 10.19 $\pm$ 1.19, 31.38 $\pm$ 1.15 vs 27.91 $\pm$ 1.45, and 44.97 $\pm$ 0.85 vs 41.24 $\pm$ 0.97 $ml \cdot kg^{-1} \cdot min^{-1}$, at treadmill speeds of 80, 120 and 200 $m \cdot min^{-1}$ respectively. We conclude that DR did not require summer heat exposure to adequately thermoregulate during the spring trial (T_1), which simulated the hottest summer days recorded during this study.

KEY WORDS: heat acclimatization, running, rectal temperature, oxygen uptake, sweat, plasma volume, sodium, potassium

Introduction

Untrained, unacclimatized individuals entering a hot environment require 7-12 days of heat exposure for successful heat acclimatization (11). In contrast, highly trained distance runners exhibit physiological characteristics which enable them to perform well in the heat during any season. Two investigations (10,15) independently observed the effects of high-intensity cool weather interval training (70-90% $VO_{2\ max}$) and reported that collegiate distance runners responded to winter heat tolerance tests as though they were heat acclimatized, although they had not been exposed to heat since the preceeding summer. Two unique factors interact during heat acclimatization in distance runners: physical training and heat exposure. Gisolfi (8) experimentally isolated physical training and heat exposure in an attempt to measure the contribution of each to heat acclimation. He reported that eight weeks of intense intermittent treadmill running in cool conditions (21°C) produced approximately 50 % of the total heat tolerance resulting from heat acclimation trials. Yet, Gisolfi and Cohen (9) cautioned that heat acclimation responses are highly dependent upon the conditions of standard heat tolerance tests as well as the duration and intensity of training programs. Therefore, data involving physical training and heat exposure must be applied to highly trained athletes with caution.

No research to date has focused on the natural heat acclimatization of athletes involved in daily outdoor training

programs. The purpose of the present investigation was to measure the extent of heat acclimatization developed by highly trained distance runners during summer training in the Northeastern United States. Classical heat acclimatization adaptations (e.g. rectal temperature, heart rate, sweat rate, sweat electrolytes) were measured during controlled thermoregulation trials in the spring and late summer; these trials were designed to simulate environmental and exercise stresses which marathoners and ultramarathoners encounter during daily training. Between spring and summer trials, subjects trained and competed in road races for 14.5 $\pm$ 0.4 weeks. This investigation is unique among heat acclimatization investigations because responses were observed in athletes using their own coaches and training/racing schedules, and because it measured long-term physiological adaptations resulting from more than three months of summer running.

Methods

The subjects of this investigation were four male and one female highly trained distance runners. The female was a nationally-ranked ultramarathoner; two of the males also competed in ultra-marathons during the course of this investigation. The mean best marathon time for DR was 2:38:00 $\pm$ 0:06:00 (n=4). Selected characteristics of these athletes are listed in Table 1. Subjects followed their normal training schedules throughout the entire investigation, keeping daily training logs for three months prior to each thermoregulation trial.

TABLE 1

Thermoregulation trials were conducted in the Spring (T_1) and summer (T_2). The mean number of weeks between trials was 14.5 ± 0.3. Ambient temperature data for March through August (National Climatic Data Center, Asheville, N.C.) is presented in Figure 1. Between T_1 and T_2, the maximum daily temperature of only three days (3 % of the total days) exceeded the 30.3°C chamber conditions (Fig. 2).

FIG. 1

FIG. 2

Three-day dietary records were completed prior to T1 and T2. Subjects were instructed to drink large quantities of water on the day before the trial to ensure adequate hydration. A pre-trial urine sample was analyzed for specific gravity. If any subject had urine specific gravity over 1.030, that subject consumed more water until specific gravity was below 1.030. Heights were recorded, skin thermistors were placed on the forearm, calf and chest, and EKG electrodes were applied. Immediately before testing, subjects showered without soap, inserted a rectal probe 8 cm beyond the anal sphincter, and dressed in electrolyte-free running gear.

Trials (Fig. 2) were conducted in an environmental chamber at 30.3 ± 0.1°C, 34.9 ± 0.5% RH with a 4.47 m sec^{-1} wind speed. Subjects stood in the chamber for a 20 minute body fluid equilibration period, after which an antecubital blood sample and a body weight were taken. Subjects completed 30 minutes of continuous treadmill exercise at belt speeds of 80, 120 and 160 m·min^{-1}. The final 60 minutes were run at 200 m·min^{-1}. Subjects stepped off the treadmill briefly for a body weight (Sauter Balance, accuracy ± 10 g) after 30, 50, and 70 min of exercise.

A semi-automated data collection system was used to monitor rectal and skin temperatures and to analyze expired gases. A gasmeter (Parkinson-Cowan), oxygen analyzer (Applied Electrochemistry, model S3A), and carbon dioxide analyzer (Beckman, model LB2) were part of this system. Temperatures from rectal and skin thermisters (Yellow Springs, Inc.) were monitored at two minute intervals throughout the trial, and heart rates were monitored continuously with an EKG telemetry system (Hewlett-Packard, Inc.). A blood sample and body weight were taken immediately at the end of exercise. Subjects stood for 20 minutes, after which the final blood sample and body weight were taken. Blood samples were analyzed for microhematocrit and hemoglobin (Hycel Inc.). These values were used to calculate percentage plasma volume changes (4). Plasma sodium and potassium were also analyzed using a flame photometer (Ranin Instruments Inc., model FLM3).

Body weight differences were used to calculate sweat rate, after correction for water intake and urine output. Sweat electrolyte losses were measured after the post-exercise blood sample, using the whole body washdown technique of Vellar (19). During work bouts all dripping sweat, which was minimal because of dry conditions, was blotted from the hair and skin with electrolyte-free towels. The subjects, clothing and towels were washed using a known volume of deionized water (7.66 L) and aliquots were analyzed for sodium and potassium on a flame photometer.

The paired two-tail t-test and one-way ANOVA were used to compare spring and summer trials. The .05 level of confidence was used throughout.

Results

TABLE 2

Table 2 presents a comparison of subject pre-trial status for the spring (T_1) and summer (T_2) trials. No significant differences were found in training habits (except for number of interval workouts per month), dietary intake, or measures of pre-trial body water status. Rectal temperature and mean

FIG. 3

weighted skin temperature (MWST) for T_1 and T_2 appear in Figure 3. The only significant differences appeared after 50 min of exercise, when MWST was significantly higher during T_2. Heart

TABLE 3

rate (Table 3) exhibited no T_1 vs T_2 differences at all measured trial segments. A significant ($p<.05$) between-season difference in oxygen uptake was observed during exercise at 80, 120, and 200 $m \cdot min^{-1}$ (Table 3). Sweat rates and sweat electrolyte losses for each trial are shown in Table 4. Sweat

TABLE 4

rate (Table 4) was higher only during the initial 30 min of exercise (80-160 $m \cdot min^{-1}$) during the summer. There were no T_1 vs T_2 differences in either sweat concentration or total mEq

TABLE 5

lost. Plasma electrolytes and plasma volume changes (Table 5) also indicated that there were no T_1 vs T_2 differences.

Discussion

When advising highly trained distance runners (DR) about training-racing in hot environments, one must recognize that these athletes perform well in heat tolerance tests during any season of the year (10,15). Although previous research

indicates that heat acclimatization is incomplete unless untrained subjects do some work in the heat (2,6,9,17), the results of this investigation indicate that DR demonstrated essentially the same ability to thermoregulate in a 30.3°C environment in the spring as they did after 14.5 weeks of summer training. Although exercise during thermoregulation trials T_1 and T_2 stimulated 1.1-1.4 liters of sweat per hour and resulted in average peak rectal temperatures between 38.3-38.4°C, there were no statistical differences between T_1 and T_2 in peak rectal temperature, mean weighted skin temperature (except at 50 min of exercise), heart rate, sweat rate (except during the initial 30 min of exercise), sweat Na+ and K+ concentration, plasma Na+ and K+, or plasma volume change (Table 5).

These findings do not indicate that distance runners should omit heat exposure from their training when preparing for hot environments, because these data are specific to northern areas of the United States (Figure 1), to exercise intensities typical of ultramarathon and marathon training (60-65 % $VO_{2\,max}$), and to thermoregulation at or near 30.3°C. Drinkwater (5) noted that optimal acclimatization procedures involve training in an environment which is comparable to the one in which competition will occur. Indeed, a similar approach was utilized to successfully acclimatize a marathon runner prior to the 1984 Summer Olympic Games (1). Had the DR of the present investigation trained in the Southern United States, it is likely that they would have developed physiological adaptations

indicative of greater heat tolerance (14), in spite of their high level of fitness and great cardiovascular stability at T_1.

Numerous studies have appeared in the literature concerning the effects of physical training on heat tolerance (8,9,10,14,15). The results of the present investigation contribute to this body of information by (1) demonstrating that DR met the summer thermoregulatory requirements of the Northeastern United States (exemplified by T_1 and T_2) before training during June, July and August, and (2) by supporting those studies which observed that DR responded to winter heat tolerance trials as though they were already heat acclimatized (10,15). This "preacclimatization" of distance runners has been attributed to stimulation of sweating and cutaneous blood flow during strenuous workouts (15), high maximal oxygen consumption, increased evaporative cooling, greater cardiovascular stability, expansion of blood volume (10), more favorble body fluid dynamics (17), and earlier onset of sweating (13). The present investigation supports the concept of an earlier onset of sweating (see initial 30 min in Table 4), but it is improbable that this small increase in sweat production between T_1 and T_2 (20 $ml \cdot m^{-2} \cdot hr^{-1}$) significantly altered rectal temperature during exercise (1).

The MWST (Figure 3) during spring and summer trials indicated that cutaneous circulation generally decreased during exercise, while working muscles received increased blood flow to meet the metabolic demands of exercise. The mean rectal temperature peaked at 38.3-38.4^{o}C and decreased during the

final 20 min of exercise, indicating that DR thermoregulated successfully. The only T_1 vs T_2 statistical difference ($p<.05$) was observed after 50 min of exercise, when the summer MWST was higher than the spring. Because rectal temperatures (Figure 3) and sweat rates (Table 4) were not different at that point, this T_1 vs T_2 difference was probably due to a greater cutaneous circulation during T_2. Heart rate data (Table 3) also may be interpreted to support this hypothesis, in that increased peripheral circulation reduces central blood volume and acts to increase heart rate in an effort to maintain cardiac output.

Table 3 indicates that the 14.5 weeks of summer training between T_1 and T_2 resulted in changes in submaximal oxygen consumption. Because there were no T_1 vs T_2 differences in mean body weight or surface area, this decreased oxygen consumption meant that 8 % less metabolic heat (M) had to be dissipated (while running at 200 $m \cdot min^{-1}$) during T_2 than during T_1. Sawka et al. (16) have observed similar 3 % and 5 % reductions in cool and hot environments when submaximal exercise was performed before and after 10 days of heat acclimation. We propose that there are four likely explanations for such reductions in M. First, the DR of the present investigation ran nearly the same number of workouts per month, km per day, and competitive events per month, prior to T_1 and T_2 (Table 2). Although no measure of daily training intensity was undertaken (e.g. field measurements of oxygen uptake), the number of interval workouts per month (Table 2)

was significantly higher prior to T_1 (2.0 $\pm$ 0.6) than prior to T_2 (0.7 $\pm$ 0.2). Differences in exercise intensity and in the aerobic-anaerobic nature of training prior to T_1 and T_2 may have resulted in the reduced M reported in Table 3. Second, daily elevation of rectal temperature (1) during summer training (not measured) also may have resulted in the significantly lower M during T_2. Third, heat acclimatization may have altered muscle motor unit recruitment patterns during locomotion (16). Fourth, it also has been suggested that improved metabolic efficiency is responsible for the decreased M elicited by exercise after heat acclimatization (18).

The T_1 vs T_2 responses of the female ultramarathon runner in this investigation (not shown separately) were qualitatively and quantitatively similar to those of her male counterparts, with respect to heart rate, rectal temperature, MWST, sweat rate, sweat electrolytes, change in plasma volume during exercise, and submaximal oxygen consumption. In this respect her physiological responses were different from the responses of sedentary females, as reported by Fortney and Senay (7); sedentary females in their study exhibited greater cardiovascular strain, lower evaporative cooling, greater peripheral distribution of blood, higher MWST, and greater reduction of plasma volume than males. Because physical training lowers the threshold for sweating, increases plasma volume, decreases heart rate, decreases MWST, and decreases rectal temperature (3,9), the female DR in the present investigation (estimated $\dot{V}O_{2\ max}$ of 72 $ml \cdot kg^{-1} \cdot min^{-1}$) provides

evidence that previously reported male-female thermoregulatory differences (7) may have been due to differences in fitness levels between subjects. A recent review paper (12) supports this position by concluding that few differences in male and female responses to heat stress exist when groups are matched for maximal oxygen consumption.

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The views, opinions, and/or findings contained in this report are those of the authors and should not be construed as an official department of the Army position, policy, or decision, unless so designated by other official documentation. Human subjects participated in these studies 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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Figure Titles

FIGURE 1 - Mean (± SE) outdoor maximum and minimum temperatures at the location of this investigation.

FIGURE 2 - Design of thermoregulation trials T_1 and T_2 in the environmental chamber. Arrows denote body weight measurements (± 10g). Symbols: V - oxygen uptake, S - pre-trial shower, U - urine sample, B - venous blood sample, W - whole body washdown.

FIGURE 3 - Rectal temperatures and mean weighted skin temperatures during T_1 and T_2 (mean ± SE).

TABLE 1 - Selected subject characteristics (mean ± SE)

SUBJECT	SEX	AGE (yr)	HEIGHT (cm)	WEIGHT (kg)
A	M	40	181	71.628
B	M	25	166	69.903
C	F	29	167	59.000
D	M	36	180	64.850
E	M	30	183	73.060
MEAN		32	175	67.688
± SE		3	4	2.577

TABLE 2 - Mean (± SE) training, dietary and body water parameters prior to T_1 and T_2.

MEASUREMENT	UNIT	SPRING	SUMMER	STATISTICAL SIGNIFICANCE
Training				
Training	km/day	13.7 ± 1.1	13.3 ± 1.1	NS
Training	days/month	26 ± 1	25 ± 2	NS
Interval workouts	days/month	2.0 ± 0.6	0.7 ± 0.2	$p<.05$
Competition	races/month	1.2 ± 0.3	1.3 ± 0.3	NS
Dietary Records*				
Energy	Kcal/day	2299 ± 170	1998 ± 187	NS
Sodium	mg/day	2650 ± 294	2607 ± 415	NS
Protein	%	18.2	20.2	NS
Carbohydrate	%	61.7	56.6	NS
Fat	%	20.1	23.2	NS
Body Water Indices				
Body weight	kg	67.688 ± 2.577	67.803 ± 3.143	NS
Urine specific gravity		1.023 ± 0.004	1.018 ± .002	NS
Hematocrit	%	43.5 ± 0.9	42.8 ± 0.4	NS

* - three-day dietary records completed within one week of spring and summer trials

TABLE 3 - Mean (± SE) oxygen uptake and heart rate during T_1 and T_2 at run velocities of 80, 120, 160 and 200 m/min. All measurements were taken after a minimum of 10 min steady-state exercise.*

MEASUREMENT	UNIT	RUN VELOCITY (m/min)	T_1	T_2	STATISTICAL SIGNIFICANCE
Oxygen Uptake	$ml \cdot kg^{-1} \cdot min^{-1}$	80	13.97 ± 0.27	10.19 ± 1.19	$p<.05$
		120	31.38 ± 1.15	27.91 ± 1.45	$p<.05$
		160	35.89 ± 1.93	35.00 ± 1.29	NS
		200	44.97 ± 0.85	41.24 ± 0.97	$p<.05$
Heart rate	$beats \cdot min^{-1}$	80	74 + 4	84 + 11	NS
		120	102 ± 6	113 ± 5	NS
		160	117 ± 6	120 ± 8	NS
		200	135 ± 7	143 ± 8	NS

* - each mean represents five data points, except 200 m/min values which represent 15 data points

TABLE 4 - MEAN (± SE) whole body sweat rate and sweat electrolyte values during T_1 and T_2.

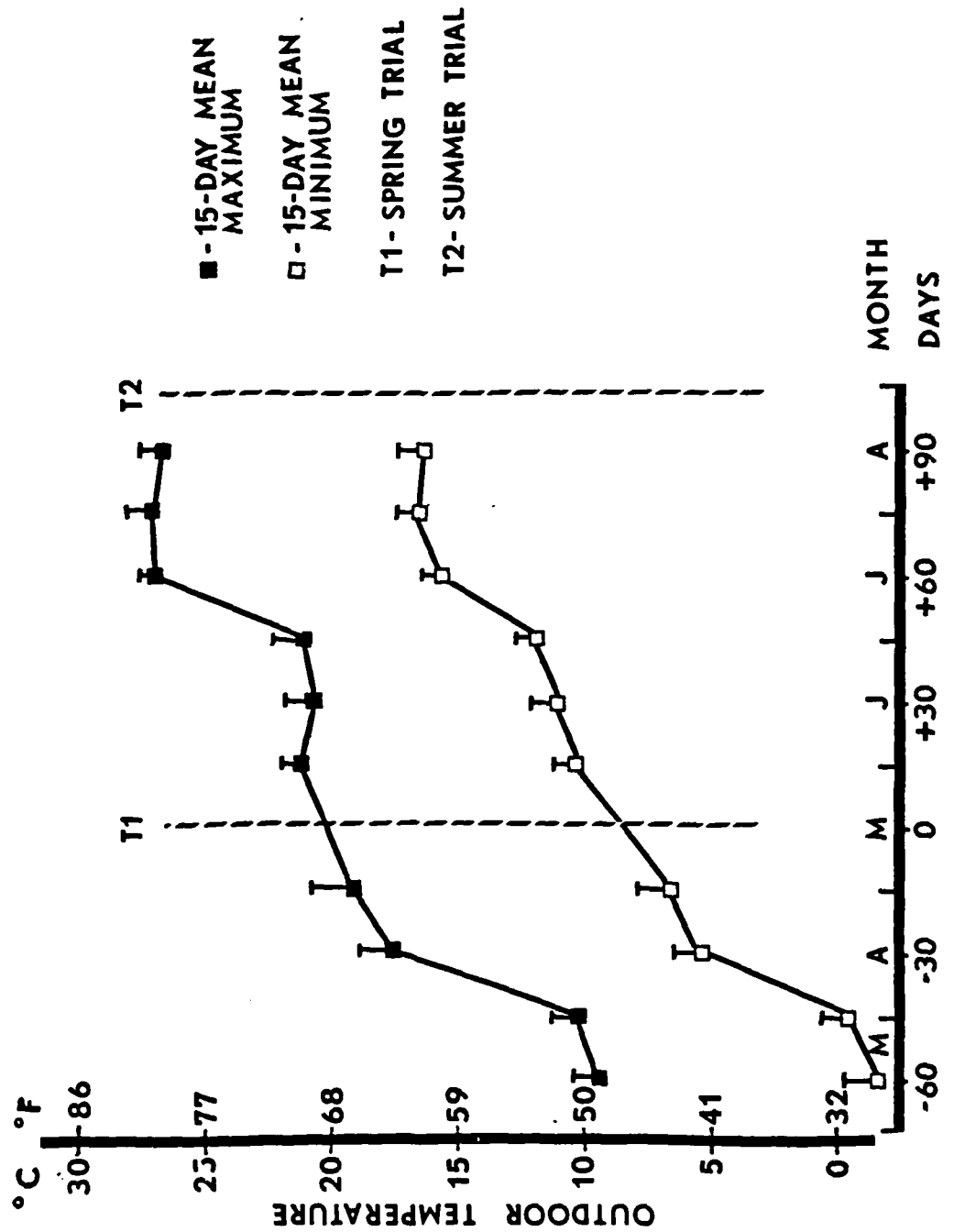
MEASUREMENT	UNIT	RUN VELOCITY (m/min)	TIME (min)	T_1	T_2	STATISTICAL SIGNIFICANCE
Sweat rate	$ml \cdot m^{-2} \cdot hr^{-2}$	80-160	30	73 ± 6	93 ± 8	$p<.05$
		200	20	636 ± 42	683 ± 71	NS
		200	20	754 ± 87	669 ± 109	NS
		200	20	592 ± 35	662 ± 63	NS
		POST	20	231 ± 23	262 ± 32	NS
Sweat Na+ conc.	mEq/L	*	*	21 ± 6	31 ± 4	NS
Sweat K+ conc.	mEq/L	*	*	4.1 ± 0.2	4.1 ± 0.2	NS
Sweat Na+ loss	total mEq	*	*	34 ± 9	51 ± 6	NS
Sweat K+ loss	total mEq	*	*	6.4 ± 0.3	6.7 ± 0.4	NS

* - represents entire trial

TABLE 5 - Mean (± SE) plasma volume change, plasma Na+, and plasma K+ during T_1 and T_2.

MEASUREMENT	UNIT	TIME INTERVAL	T_1	T_2	STATISTICAL SIGNIFICANCE
Plasma volume change	Δ %	Pre	- 4.7 ± 2.0	- 2.1 ± 1.9	NS
		Pre - 20 min post	- 0.6 ± 2.1	- 0.1 ± 1.6	NS
Plasma Na+	mEq/L	Pre	140 ± 0.2	140 ± 0.7	NS
		Post	142 + 0.4	142 + 0.7	NS
		20 min post	140 + 0.4	141 + 0.9	NS
Plasma K+	mEq/L	Pre	4.5 ± 0.1	4.3 ± 0.1	NS
		Post	4.7 ± 0.1	4.3 ± 0.1	NS
		20 min post	4.5 ± 0.1	4.5 ± 0.1	NS

FIGURE 1


■ - 15-DAY MEAN MAXIMUM
□ - 15-DAY MEAN MINIMUM
T1 - SPRING TRIAL
T2 - SUMMER TRIAL
T1
T2
°C °F
30 86
25 77
20 68
15 59
10 50
5 41
0 32
OUTDOOR TEMPERATURE
M A M J J A
-60 -30 0 +30 +60 +90
MONTH
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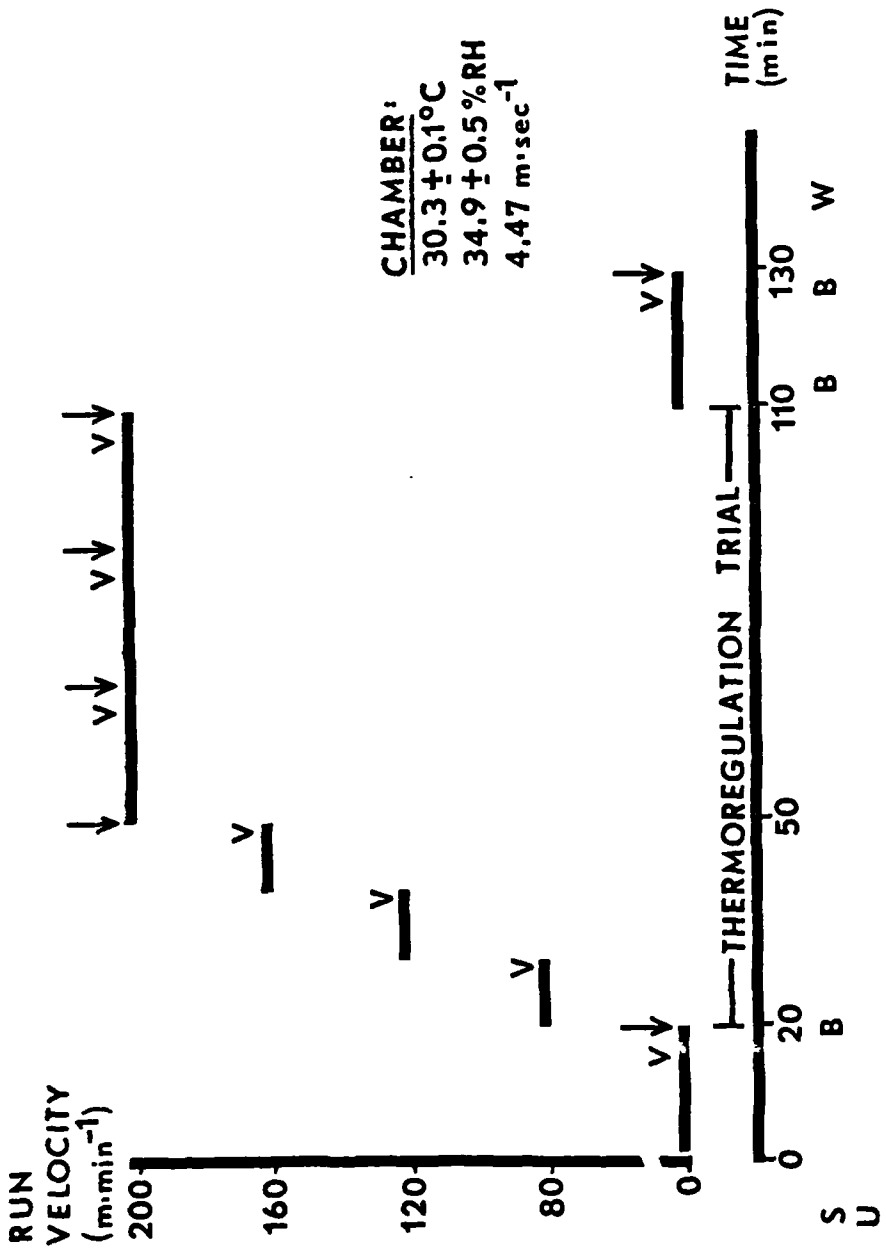
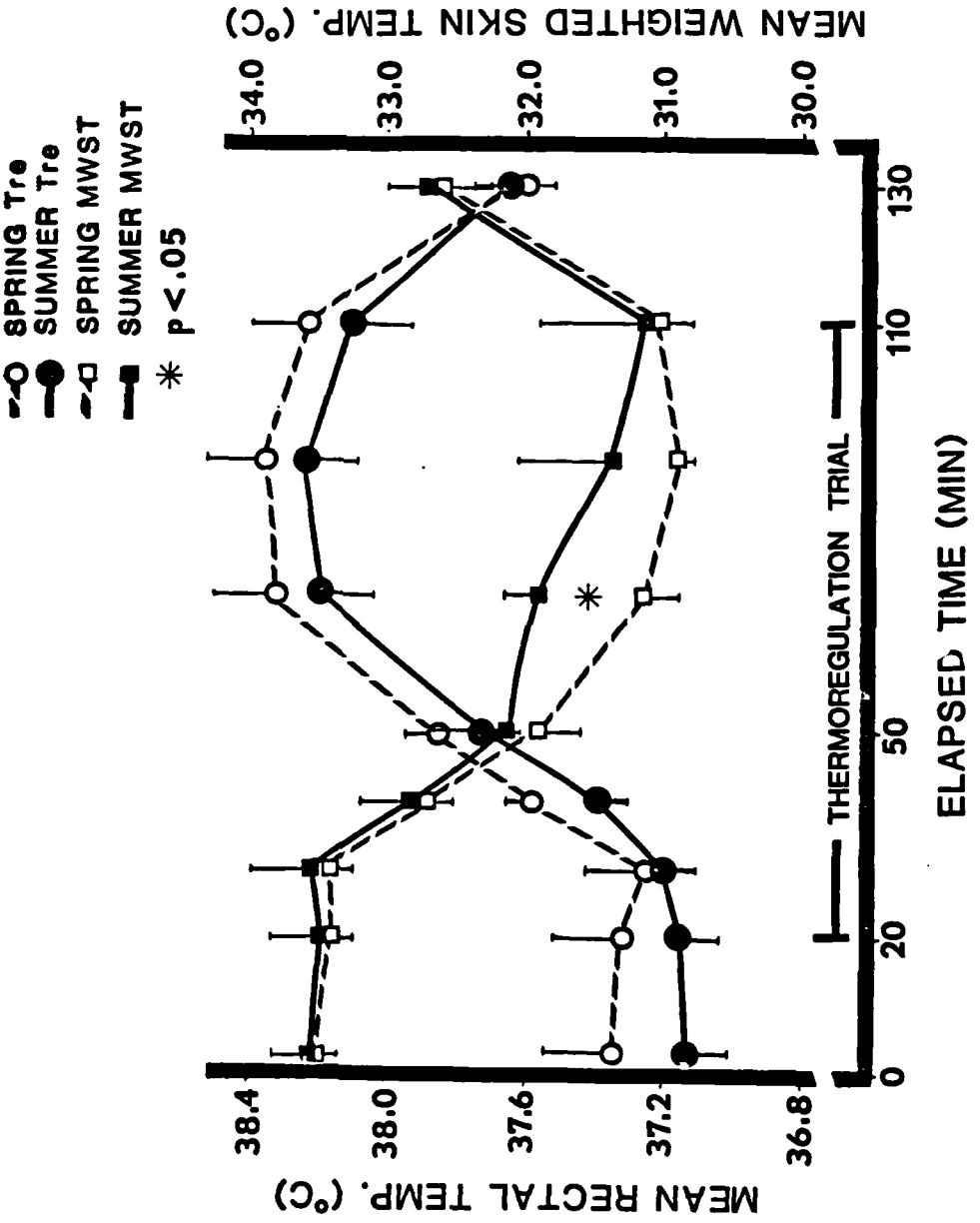

RUN VELOCITY (m·min⁻¹)
200
160
120
80
0
CHAMBER:
30.3 ± 0.1°C
34.9 ± 0.5% RH
4.47 m·sec⁻¹
THERMOREGULATION TRIAL
TIME (min)
0
20
50
110
130
S B
U B
W

FIGURE 3


MEAN WEIGHTED SKIN TEMP. (°C)
34.0
33.0
32.0
31.0
30.0
SPRING Tre
SUMMER Tre
SPRING MWST
SUMMER MWST
* p<.05
THERMOREGULATION TRIAL
0
20
50
110
130
ELAPSED TIME (MIN)
MEAN RECTAL TEMP. (°C)
38.4
38.0
37.6
37.2
36.8

END

FILMED

1-86

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