HYPERTHERMIA IN MARATHON RUNNERS IN A TROPICAL ENVIRONMENT

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OBJECTIVES :

1. To evaluate the ability of athletes to regulate body temperature despite the combined thermal stresses of sustained, vigorous exercise (marathon running) the high ambient temperature of a tropical climate, and to assess the impact of thermoregulation on race performance.

2. To correlate post-race abnormalities of blood counts, serum electrolytes, serum enzymes, and total body fluid balance with post-race rectal temperature.

INTRODUCTION :

Running on level surfaces at competitive marathon speeds (15-20 km/hr) athletes expend approximately 15 kcal of energy per kilogram of body weight per hour; during a marathon race lasting three hours, a 60 kilogram runner will expend approximately 2700 kcal. As the mechanical efficiency of running is only 20-25%, a runner during a marathon generates in excess of 2000 kcal, a large proportion of which is retained as heat. In cool and moderate environments runners are generally able to respond adequately to this internal heat stress through normal heat dissipation mechanisms, and under these conditions thermoregulation is not thought to be a limiting factor of performance. However, under thermally stressful environmental conditions of high temperature, high humidity, or high solar radiation, thermoregulation may be a critically limiting factor. Indeed, heat stroke is a well recognized complication of marathon racing in hot environments, and rectal temperatures in excess of 41°C have been recorded in apparently healthy competitive runners at the end of the races in even mildly thermally stressful conditions.

The staging of a full 42.4 kilometer marathon in Hua Hin, Thailand, in November 1979 afforded an opportunity to examine the ability of runners to regulate their body temperatures under tropical environmental conditions.

MATERIALS AND METHODS :

Race organization and course : The 1st Hua Hin marathon, started at 0630 AM on 18 November 1979 in the town of Hua Hin, Thailand (latitude 12 36') on the Gulf of Siam. The race route was a relatively flat out and back road through pineapple fields with 11 water points at approximately 3 kilometer intervals. The race was run with the wind for the first half, then into the wind the second half. Two medical vans, each staffed with a physician, continually patrolled the race course.

Meteorologic conditions : The dry bulb ambient temperature at the start of the race, approximately ½ hour after dawn, was 28°C and 4 hours later 34°C. The sky was virtually cloudless and the sunlight was intense; solar radiation was not directly measured.

Subjects : No qualifying times were required for entry into the race. At race registration all runners were requested to submit to some simple pre-race physiologic measurements (resting heart rate, blood pressure, and weight) and to complete a simple questionnaire about age, nationality, previous marathon experience, and average number of kilometers run per day in the preceding 6 weeks. Also at the registration volunteers were sought to submit to post-race measurements of heart rate, weight, and temperature, and to have 10 ml of blood drawn. Agreement to participate was virtually universal. 119 runners started the race. The first fourteen finishers (all the runners who finished in less than 4 hours 31 minutes) constituted the study group.

Measurements on study group : A study tent was situated approximately 40 meters from the finish line, and the first fourteen finishers were escorted into the study tent within 2 minutes after finishing, where measurements of weight, heart rate, rectal temperature, and blood drawing were completed within 5 minutes. Pre and post race weights were recorded on a single bathroom scale. Rectal thermometers were inserted by a physician, kept in place for at least 1 minute, and read immediately.

Blood samples were obtained from the antecubital vein within 1 minute of applying the tourniquet. One ml was put into tubes containing sodium oxolate, and 9 ml were put into clean glass tubes and allowed to clot at ambient temperatures until shortly after the 14th runner was examined, when they were chilled on wet ice for 6 hours, during transportation to Bangkok. Clot tubes were then centrifuged to separate serum from clot, and all specimens maintained at 4°C overnight until laboratory tests were done the following day.

Laboratory tests : Red blood cell counts, packed cell volumes, and hemoglobin concentrations were determined with JTB 700A automatic blood counting machine. White blood cell counts were determined microscopically; differential white blood cell counts were read microscopically on smears stained with Wright's stain; and platelets were counted with the Mk-4/HC platelet counting system.

Serum sodium and potassium were measured by flame photometry, and chloride blood urea nitrogen, and serum glutamate-oxaloaceate transaminase with commercial kits (Sigma).

Control specimens were tested simultaneously with the study specimens; abnormal results were confirmed by repeat tests.

RESULTS : Pre-race questionnaire and physical examination data of the study group subjects (13 of the top 14 finishers) are compared to the data from all other starters in Table 1. Through administrative error one of the top finishers did not fill out a pre-race questionnaire nor submit to a pre-race examination, but did agree to post race measurements. As only 22 women started,

5 finished, and none were among the top 14 finishers, only data on males is analyzed in the remainder of this report.

Of the total of 97 male starters, 40 runners finished the full 42 km course (slowest time 6:34:45). It can be seen that the fastest marathoners were slimmer had lower resting pulse rates, had more marathon experience, and had trained more intensely than the slowest runners. (See Table 1).

Post-race physiologic measurements are presented in Table 2 along with individual questionnaire data, place and times. Post-race weights are presented for the first through ninth place finishers only; for the tenth through fourteenth place finishers the scale was not brought to zero between runners.

The mean % body weight loss was 4 ± 2%, the mean post race heart rate 114 ± 26 beats/minute, and the mean rectal temperature 39.7 ± 0.7°C. The following variables were significantly correlated ($\leq .05$).

1. Place vs experience (# of previous marathons)
2. Time vs experience
3. Temperature vs place
4. Temperature vs time
5. Temperature vs experience

Results of blood tests are presented in Table 3. Mean values for the 14 study subjects for total WBC, % polymorphonuclear leukocytes serum sodium, and SGOT were all mildly elevated; mean values for red blood cell count, packed cell volume, hemoglobin, platelets, % lymphocytes, potassium, chloride, and blood urea nitrogen were all within normal limits with occasional individuals showing mild abnormalities.

Serum sodium did show a positive correlation with rectal temperature. This correlation was in large measure due to the fact that one runner had both a strikingly elevated rectal temperature (41.1°C) and an even more strikingly elevated serum sodium (167 meq/L). Although there was not a statistically significantly linear quantitative correlation between the platelet count and rectal temperature ($r = .337$, $p > .10$), the runners with the three lowest platelets counts were the three runners with the highest rectal temperature ($X^2 = 14.0$, $p < .0002$). The mean temperature of the 5 runners with abnormally low platelet counts (40.2 ± 0.8°C) was higher ($p < .05$) than the mean temperature of the 9 runners with normal or elevated platelet counts (39.5 ± 0.5°C).

None of the slower runners or non-finishers developed clinically evident heart related injury (heat stroke) during the race. One runner who quit at the 21 kilometer mark with weakness and nausea had a Tr of 40.8°C, but he was mentally appropriate and recovered quickly.

Table 1. Pre-race questionnaire and physical examination data.

	Study group (n = 14)	Slower male runners and non-finishers (n = 83)
Number (%) with complete pre-race questionnaire	13 (93%)	52 (100%)
Number (%) Native to S.E. Asia	11 (86%)**	48 (92%)**
Age (years)	31 ± 8	31 ± 10
Ht (centimeters)	166 ± 7	166 ± 15
Wt (kilograms)	57 ± 5	60 ± 10
HR (beats/minute)	67 ± 6	80 ± 14
# marathons previously completed	4 ± 5	0.4 ± 1
Average kilometers/day training last 6 weeks	18 ± 10	10 ± 6

* Means ± 1 S.D.

** The four slower runners and non-finishers who were not native had resided in Thailand for 36, 24, 24, and 1 month; the 2 not-native top finishers for 72 and 7 months.

Table 2. Individual questionnaire responses and post-race physiologic measurements of top fourteen finishers

Place	Questionnaire data					Physiologic measurements							
	Time	Age (years)	Nationality	Training (km/day)	Experience (# previous marathons)	Wt (Pre/kg)	Wt (Post/kg)	Wt (kg)	% wt Loss	HR pre (beats/min)	HR post (beats/min)	HR Δ (beats/min)	T rectal (degree)
1	2:52:46	24	Thai	20	8	58.2	56.8	1.4	2.3	62	120	58	39.6
2	2:55:06	23	Thai	20	5	61.4	60.0	1.4	2.2	72	90	18	40.6
3	3:02:29	25	Thai	15	5	49.1	47.7	1.4	2.8	60	80	20	40.1
4	3:11:09	25	Thai	20	15	61.4	57.7	3.7	5.9	72	90	18	41.1
5	3:18:22	52	U.S.A.	15	0	62.7	59.5	3.2	5.1	66	96	30	39.3
6	3:20:45	24	Thai	16	2	55.0	50.9	4.1	7.4	68	120	52	40.4
7	3:23:54	31	Thai	15	10	49.5	47.3	2.2	4.6	60	160	100	39.4
8	3:32:34	22	Thai	10	1	57.3	55.0	2.2	4.0	64	120	56	40.0
9	3:37:25	32	Thai	20	1	52.3	51.8	0.5	0.9	76	120	44	39.0
10	3:47:46	30	Thai	50	2	61.4	NA	NA	NA	60	165	105	40.2
11	3:53:31	31	Austral.	8	0	63.6	NA	NA	NA	64	88	24	39.1
12	4:08:40	37	Thai	15	1	57.3	NA	NA	NA	72	104	32	39.3
13	4:20:23	NA	Thai	NA	NA	NA	NA	NA	NA	NA	108	NA	39.6
14	4:31:35	37	Thai	14	1	50.0	NA	NA	NA	76	132	56	38.8
Mean ± 1 S.D.		31 ± 8 (N=13)		18 ± 10 (N=13)	4 ± 5 (N=13)	124 ± 11 (N=9)	119 ± 1 (N=9)	5 ± 3 (N=9)	3.9±2.1 (N=9)	67 ± 6 (N=13)	114 ± 26 (N=14)	47 ± 29 (N=14)	39.7 ± 0.7 (N=14)

NA = Data not available

Table 3. Results of blood tests of top fourteen finishers

Place	RBC ($\times 10^6$ per mm^3)	Hct (%)	Hbg (gm/100 ml)	WBC ($\times 10^3$ per mm^3)	Plt ($\times 10^3$ per mm^3)	Na (Meq/L)	K (Meq/L)	Cl (Meq/L)	BUN (mg/100 ml)	SGOT (S.F. units)
1	5.03	48	15.0	9.9	210	150	5.0	104	19	65
2	4.53	45	15.9	10.2	110	150	5.5	99	22	62
3	5.50	48	15.6	14.2	396	145	4.8	96	14	65
4	5.73	52	17.0	12.1	81	167	5.6	96	16	68
5	4.93	51	16.9	9.4	158	156	5.4	103	17	57
6	5.81	51	17.2	5.9	95	147	5.5	96	11	128
7	5.31	48	16.4	15.7	115	146	5.3	98	14	61
8	5.01	44	15.8	9.1	254	146	4.5	93	14	80
9	4.22	39	14.8	20.8	462	146	5.3	96	15	56
10	4.75	45	15.9	8.5	209	150	5.4	99	22	52
11	4.72	48	17.3	15.6	169	147	5.2	99	17	76
12	5.56	49	15.7	15.2	119	140	5.5	104	14	94
13	5.23	56	18.2	18.8	224	150	5.6	104	14	36
14	5.21	52	16.1	13.3	183	142	5.6	93	21	65
Mean±1S.D.	5.11±0.46	48±4	16.3±0.9	12.8±4.2	200±112	149±6	5.3±0.3	99±4	16±3	69±22
Normal range	5.4±0.8	47±5	16±2	7.8±3.0	150-450	135-145	3.5-5.5	95-105	10-20	0-40
# Abnormal	1	2	1	8	6	11	0	2	3	13
Low	1	1	0	0	5	0	0	2	0	0
High	0	1	1	8	1	11	0	0	3	13