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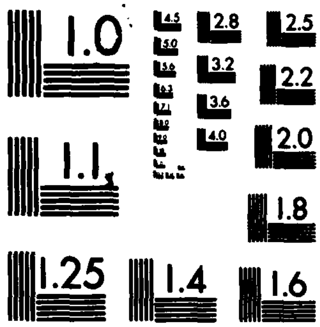

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The purpose of this experiment was to explore the complex relationship between fluid consumption and consumption factors (thirst, voluntary dehydration, water alliesthesia, palatability, work-rest cycle) during a simulated, 14.5 km (9 mile), desert walk (treadmill, 1.34 $m.sec^{-1}$ (3.0 mph), 5% grade, $40^{o}C$ d.b./26^{o}w.b. and wind speed of 2.5 mph). Twenty-nine Ss were tested (30 $min.h^{-1}$, 6 h) on each of two nonconsecutive days Ss were randomly assigned to 1 of 3 groups: tap water (n=8), iodine-treated tap water (n=11) or iodine-treated, flavored, tap water (n=10). The temperature of the water was $40^{o}C$ during one trial and $15^{o}C$ on the other. Mean sweat losses

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(6 h) were similar and averaged 3.9 ± 0.06 kg. Fluid consumption (6 h) varied between 1.4 kg (warm, iodine-treated; 232 ± 44 $g.h^{-1}$) and 3.0 kg (cool, iodine-treated, flavored; 509 ± 50 $g.h^{-1}$). Warm drinks were consumed at a lower rate than cool drinks (negative and positive alliesthesia). This decreased consumption resulted in the highest percent body weight losses (2.8 and 3.2%). Cooling and flavoring effects on consumption were additive and increased the rate of intake by 120%. The apparent paradox between reduced consumption concomitant with severe dehydration and hyperthermia is attributed to negative alliesthesia for warm water rather than an apparent inadequacy of the thirst mechanism. The reluctance to drink warm, iodine-treated water resulted in significant hyperthermia, dehydration, hypovolemia and in two cases, heat illness.

Voluntary Dehydration and Alliesthesia for Water

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Index Term: Voluntary Dehydration, Rehydration, Water Alliesthesia, Taste, Temperature and Thirst

Abstract

The purpose of this experiment was to explore the complex relationship between fluid consumption and consumption factors (thirst, voluntary dehydration, water alliesthesia, palatability, work-rest cycle) during a simulated, 14.5 km (9 mile), desert walk (treadmill, 1.34 m/sec (3.0 mph), 5% grade, 40°C d.b./26°C w.b. and wind speed of 2.5 mph). Twenty-nine Ss were tested (30 min/h, 6 h) on each of two nonconsecutive days. Ss were randomly assigned to 1 of 3 groups: tap water (n=8), iodine-treated tap water (n=11) or iodine-treated, flavored, tap water (n=10). The temperature of the water was 40°C during one trial and 15°C on the other. Mean sweat losses (6 h) were similar and averaged 3.9 ± 0.06 kg. Fluid consumption (6 h) varied between 1.4 kg (warm, iodine-treated; 232 ± 44 g/h) and 3.0 kg (cool, iodine-treated, flavored; 509 ± 50 g/h). Warm drinks were consumed at a lower rate than cool drinks (negative and positive alliesthesia). This decreased consumption resulted in the highest percent body weight losses (2.8 and 3.2%). Cooling and flavoring effects on consumption were additive and increased the rate of intake by 120%. The apparent paradox between reduced consumption concomitant with severe dehydration and hyperthermia is attributed to negative alliesthesia for warm water rather than an apparent inadequacy of the thirst mechanism. The reluctance to drink warm, iodine-treated water resulted in significant hyperthermia, dehydration, hypovolemia and in two cases, heat illness.

INTRODUCTION

The body's solute composition and the volume of the extracellular fluid are maintained in dynamic balance, and partially controlled by antidiuretic hormone and thirst (2). The drive to drink compensates for unavoidable water losses via respiration, urination, and perspiration. However, Pitts and coworkers (12) emphasized that during work in the heat men never voluntarily drink as much water as they lose and usually replace only two-thirds of the net water loss. Over a six hour period, inadequate fluid intake results in progressive dehydration, steadily rising core temperatures, elevated pulse rates, declining sweat rates and an increased risk of heat exhaustion (12). Similarly, Rothstein et al. (14) observed that men working in the desert became dehydrated even when water was available and called this phenomenon voluntary dehydration. The inadequacy of the thirst mechanism to detect precisely the severity of the deficit and to stimulate sufficient drinking was offered as an explanation.

Adolph's (14) research characterized other factors concerned in voluntary dehydration. It was reported that hypohydration equivalent to 2 to 3 percent of body weight was a common occurence during military activity in the desert. A 5 percent reduction in body weight as body water was the maximum expected on any one day because of intense thirst. However, body water deficits representing 6 to 10 percent of an athlete's body weight can occur during prolonged strenuous sporting events (5). The intensity of voluntary dehydration increases with sweat rate and, thus, is effected by higher ambient temperatures or work rates. It also increases with the temperature of the water available as men drank less water at 43°C than they do at 15°C. Dehydration increased with the effort involved in obtaining water and a high percentage of the total deficit occurred during the interval between meals (14). Adolph also noted that under certain circumstances flavoring the water was preferred and that sufficient time must be allowed for "retanking". Lee et al. (11) reported on the benefits, in hot dry environments, of frequent drinking of small amounts of fluid instead of the infrequent drinking of larger amounts. Curiously, the duration of dehydration is also a factor. Men reported being intensely thirsty at an initial 2 percent dehydration but not after seven hours at a deficit of 2.5 percent (14).

What factors suppress the urge to drink during voluntary dehydration is not known but there is a wealth of scientific information on the dangers of dehydration which limits sweating, adversely affects cardiovascular and thermoregulatory functions, and predisposes to heat illness. Emphasis on drinking by command in the absence of thirst has reduced casualty rates during military operations in both hot-dry (9) and hot-wet environments (10). During an experimental march of 370 miles traversing Israel, nineteen fully acclimatized young men averaged 17 miles per day carrying a load of 35 lb each (16). The young men overcame voluntary dehydration and maintained a sufficient fluid intake by being supplied either water at 20-30°C or a variety of canteen drinks at 10-13°C. The men preferred a cold (10-13°C), sweetened, fruit flavored drink that was readily available throughout the day and especially at mealtimes. At least 15-20 minutes of rest were necessary to insure adequate time for consumption. More recently, because of the paucity of information on the influence of water temperature on water intake in humans, Boulze, et al. (3), measured this intake using a wide range of fluid temperatures. Volunteers were dehydrated without access to food and water by mountain climbing or sweating in a vaporarium. Body weight losses of these two groups averaged 1660 and 289 g, respectively. Maximal fluid intake was observed for drinking water at 15°C. Colder and warmer water was ingested to a lesser extent. When volunteers were allowed to mix water to their preferred temperature, they chose 14.9 $\pm$ 1°C. The intake for mountain climbers (223 ml at 15°C) represented only 13 percent of the water deficit (3). These results confirmed Adolph's earlier assertion that 15°C water was preferred. Restricting fluid intake to a test period after dehydration, however, resulted in incomplete rehydration (voluntary dehydration) in the mountain climbers. This experimental design did not allow an investigation of the complex relationship between thirst, palatability of the drink (coolness, flavor) and the work-rest cycle.

Potable water is free from disease producing organisms or treated to the degree required for human consumption. In some cases potable water is safe to drink but it is not palatable because of disinfecting agents (chlorine or iodine) and high temperature. The purpose of this experiment was to measure the extent of voluntary dehydration during a prolonged walk under desert conditions with warm (105°F) or warm-disinfected (iodine) tap water to drink. Additionally, the effect of cooling and/or flavoring the drinks on consumption during the experimental interval was also determined.

MATERIALS AND METHODS

Subjects: A total of 31 male volunteers were recruited from the local test subject population. Two subjects became ill with symptoms of heat exhaustion during the warm beverage evaluations and withdrew from the test. Their data is not reported. Twenty-nine healthy male subjects (Ss) completed participation in this investigation. Before the initial test session, each subject was informed of the purpose of the study, the extent of their involvement, any known risks, and their right to terminate participation at will. Each expressed understanding by signing a statement of informed consent.

Table 1

Protocol: All testing was carried out on ten test days between mid-September and mid-November in a climatic chamber facility. The air temperature was 40°C d.b./26°C w.b., relative humidity 32%, and wind speed 2.5 mph. Each subject spent 6 hours in the climatic chamber on each of two nonconsecutive days. During the test Ss walked on one of two treadmills set at a 5% grade and operating for 30 min each hr at a rate of 1.34 m • sec^{-1} (3.0 mph). During the 30 min each hr that the Ss were sedentary, they were periodically given various oral or written psychological tests. Subjects rated their beverages on a 9-pt category scale which ranges from "like extremely" (9) to "dislike extremely" (1). Rating on the category scale was done both before the first walk and after the last. At the end of 6 hrs, each subject had walked 14.5 km (9 miles) and climbed 724 m (2376 ft) under simulated desert conditions. Ss were instrumented (T_{re}, T_{sk}, ECG) and clothed only in shorts, socks and sneakers.

Ss were randomly assigned to one of three exprimental groups differing in the water available for drinking during the 6 hr in the chamber as follows:

Group 1: Tap water (Natick, MA), n=8.

Group 2: Tap water treated with standard military issue iodine tablets, 8 mg per liter (Wisconsin Pharmacol, Milwaukee, WI), n=11.

Group 3: Tap water treated with iodine tablets and a commercially available cherry flavored beverage powder mixed at one-half strength, n=10. Major ingredients were citric acid, ~6% sucrose, monocalcium phosphate, ascorbic acid, artificial flavor and color.

Each subject received the water or beverage at a temperature of 40°C on one test day and at 15°C in a second session. The liquid was contained in coded canteens placed within reach of each subject and refilled every 30 minutes. Subject grouping (four subjects per treadmill) and the order of warm versus cool drink days were randomized and carried out in a double blind fashion.

Measurements and Techniques: Following a breakfast of military rations (Meal, Ready to Eat, Individual), Ss reported to the climatic chambers between 0715 and 0730 h. After voiding a pretest urine sample, nude body weights were measured on an electronic platform balance accurate to ± 50 g. Urine was collected for each subject throughout the test interval. Ss had skin thermocouples affixed, rectal probes inserted and electrocardiogram sensors attached, then donned the assigned clothing (underpants, shorts, socks, and sneakers; no shirts or hats) and were reweighed to calculate the combined clothing and equipment tare weight. Prior to entering the environmental chamber, all instrumentation was tested and Ss were required to drink 250 ml of tap water. Ss entered the chamber and were seated for 20 min after which a baseline blood sample was drawn. All subjects were reweighed within 2-3 min of the beginning and end of each exercise bout. A second blood sample was similarly drawn at the end of the test.

A three point (chest, arm, leg) thermocouple skin temperature harness and a thermistor rectal probe were connected to a digital voltmeter via a Hewlett Packard (HP) scanner system to a HP 9825 computer system which automatically plotted and recorded individual core and mean weighted skin temperatures (4) every 4 min. Heart rate and electrocardiogram were continuously displayed for each subject by means of a 10-channel HP system which received telemetered data from a transmitter carried in a belt pouch by each individual subject. Plasma volumes were estimated using the blood volume formula of Hidalgo (8) and pre-test hematocrit. The percentage change in plasma volume following the six hour experiment was calculated as net % change (from the pre-test sample) according to the formula of Dill and Costill (7) using measured hematocrit (corrected for trapped plasma) and hemoglobin concentration. Commercial test kits were used to determine hemoglobin (Hycel Cat.#116C) on a Perkin-Elmer Lambda 3 UV/VIS spectrophotometer.

Fluid intake and body weight (clothed and instrumented) were measured every 30 min, i.e., at the end of each period of walking or resting. Each coded canteen was replaced with a fresh one, when empty or every 30 min, and weighed on an electonic balance (Sartorius 1403-M70) accurate to $\pm$ 1 g. Sweat rate was determined as the net body weight loss, corrected for food and fluid intake anu urinary water loss. Lunch consisted of a second Meal, Ready to Eat weighed to the nearest gram and served following the third walk (2.5 h post start). After the sixth cycle of walking, Ss remained seated for 20 min prior to blood sampling, provided a final urine specimen and were weighed clothed and nude.

RESULTS

Each subject spent 6 h in the climatic chamber on each of two nonconsecutive days. When subjects were presented warm beverages, both the average rate of consumption as well as the total (6 h) consumption were significantly reduced (Table 2). However, cooling alone increased the voluntary 6 h intake between 640 and 1079 g. Quite apart from the cooling effects are the rather striking influences of flavor on consumption. For example, the flavoring of either warm or cool disinfected (I_2) drinks increased consumption between 584 and 870 g. Consumption rates for cool, flavored iodine-treated water were significantly greater than for all other beverages tested including cool water and cool iodine-treated water. Thus, the combined effect of cooling and flavoring (cool, flavored iodine solution; 3052 g) versus warm iodinated water (1389 g) increased consumption 1663 g. The cooling and flavoring effects, therefore, appear additive. On the average, 45 percent of total intake occurred during rest periods (data not shown).

Table 2

In contrast to the average hourly fluid consumption rates which varied with the composition, taste and temperature of the beverage (Table 3), average hourly sweat rates were similar and constant throughout the 6 h exposure. Approximately two thirds of the hourly sweat rate occurred during the 30 min work periods. Thus, 6 h sweat losses were similar for all groups and were independent of the total fluid consumed. Consequently, there were substantial differences in total weight losses.

The striking impact of palatability factors on percent body weight loss is depicted in Figure 1. The percent body weight loss (1.03 ± 0.18%) in men consuming the cool-flavored beverage was significantly lower than that of any other test. For each of the three fluids, consumption of the cool (vs warm) beverage resulted in significantly less body weight loss (Table 3). The difference in weight loss averaged between 0.7 and 0.9 kg. Flavoring (Fig 1, number 4) significantly lowered the percent body weight loss associated with the consumption of the warm, disinfected drink (Fig 1, number 6). Thus, flavoring a warm-disinfected beverage was nearly as effective in preventing body weight loss as cooling the same drink (1585 vs 1486 g loss; Table 3). Warm or warm disinfected water resulted in the highest percent body weight losses observed (2.85 ± 0.29 and 3.21 ± 0.38%, respectively). Compared to the group with the lowest body weight loss (cool, iodinated, flavored drink), the group consuming the warm-disinfected water had a highly significant ($p < 0.0005$) increase in maximum core temperature (100.1 ± 0.1 vs 100.9 ± 0.2°F and a highly significant ($p < 0.0125$) decline in plasma volume (-1.5 vs -7.6%).

The ratings on the 9-point hedonic scale showed that subjects having cooled water showed a net increase in their acceptance of the drink after six hours. On the other hand, subjects having the warm drinks showed a net decrease on average in acceptance (data not shown).

DISCUSSION

Despite recent advances in understanding the regulation of drinking in experimental animals, relatively little is known about thirst in humans (13). Adolph and Wills (1) ascribed at least three meanings to the term "thirst" including: 1) sensations related to a need for water - the amount drunk is believed to index the intensity of sensations; 2) urges to drink meaning an integration of all of the complex peripheral and central stimulation which evoke the drinking behavior; and 3) deficit of water referring to a state of hypohydration. Rendering a subject thirsty would be accomplished by dehydration to some degree. Cabanac (6) has defined sensation as a phenomenon of consciousness brought about by the reception and integration of neural inputs from the existence of a certain variable in the external environment. Sensation is both descriptive and affective implying pleasure or displeasure. Furthermore, the stimuli can induce a pleasant or unpleasant sensation depending upon the intensity of the stimulus and the internal state of the subject. Cabanac has proposed that the word alliesthesia be used to describe this phenomenon (6). For example, a cold stimulus would be pleasurable and useful during hyperthermia but unpleasant during hypothermia. Recently, Rolls et al (13) demonstrated alliesthesia for water during the course of post-drinking satiety following prolonged water deprivation. Since then Boulze et al (3) have explored the complex relationship between water intake, pleasure and water temperature in exercised-dehydrated or heat-exposed humans. Their results verified the earlier observations of Adolph (14) and Sohar et al (16) that 15°C (59°F) water represents a preferred temperature for consumption. Moreover, they demonstrated dehydration resulted in a negative alliesthesia for warm water while the positive alliesthesia for cold water was probably the result of hyperthermia rather than dehydration. The usefulness of measuring an alliesthetic shift combined with the recognition that pleasure-displeasure is a determinant of adaptive behavior represents an insightful and exciting theoretical guide for research on set points for regulated variables such as water consumption.

In the experiment reported here, the urge to drink was initiated by the dehydrating effects of exercise in the heat. The average hourly sweat rates of the three groups were nearly identical. The average 30 min exercising sweat rates, if doubled are in excellent agreement with values ($465 \pm 19\ g \cdot m^{-2} \cdot h^{-1}$) reported by Shapiro et al (15) for men working under similar conditions. The 6 h sweat losses were similar for all groups and were independent of the total fluid consumption. This suggests that sweat losses were affected primarily by the consistent work/rest cycles and the environmental heat stress. The thirty min rest periods were chosen to insure that subjects had sufficiently long intervals for compensatory water consumption (retanking). Surprisingly, on the average, 55 percent of the fluid intake was consumed during exercise (data not shown). This could reflect the increased emphasis during military training on preventing heat disorders by drinking more frequently during work in hot weather. Notwithstanding the nearly equal distribution of each group's average hourly fluid consumption between exercising and resting periods, smaller volumes of warm drinks were consumed (Table 2). This observation is supportive of Cabanac's proposal that during work in the heat there is a negative and positive alliesthesia for warm and cool water, respectively. As a result of the negative alliesthesia for warm water, groups consuming warm or warm iodine-treated beverage had the highest percent body weight losses (Fig. 1); this confirms Adolph's observation that dehydrations of 2 to 3 percent body weight are common. During the course of the experiment two subjects withdrew because of symptoms of heat illness, and the common factors appeared to be the reduced drinking of warm beverages and the resulting hypohydration (-2.6 and -2.3% change in body weight). Whereas either cooling or flavoring enhanced water consumption, the greatest increase occurred when both were employed. This is demonstrated as percent voluntary rehydration in Fig. 2. Consumption of cold flavored iodine-treated water elicited over twice the percent voluntary rehydration than when warm iodine-treated water (80.5 vs 37.0%) was ingested. The apparent continuum of group rehydration values suggests that palatability factors such as flavoring agents or disinfectants can enhance both positive and negative water alliesthesia. It seems reasonable to assume that ultimately the thirst in the group consuming cool, iodine-treated, flavored water (509 ± 50 g $\cdot$ h^{-1}) would be less intense than that of the group drinking warm iodine-treated water (232 ± 44 g $\cdot$ h^{-1}). The trends of the hedonic ratings of the various drinks during the experiment support this generalization. The apparent paradox of less thirst and greater consumption could then be explained as a positive alliesthesia for cool-flavored water. Likewise, the second apparent paradox of less intense thirst (consumption) in more severely dehydrated and hyperthermic individuals is likewise explained by negative alliesthesia rather than an apparent inadequacy of the thirst mechanism.

In conclusion, this experiment demonstrates that water temperature and flavor are important determinants of fluid balance during a 6 hour, 9 mile simulated, desert walk. Flavoring significantly increases the consumption of either cool or warm, idodine-treated water. The enhancement with flavoring is quantitatively similar to that of cooling (positive alliesthesia) and their combined effects appear additive. The reluctance to drink warm, iodine-treated water resulted in significant hyperthermia, dehydration, hypovolemia and in two cases, heat illness. These results suggest that the availability of only warm, chlorine or iodine-treated unflavored water would reduce voluntary fluid consumption during hot weather activities and thereby increase the risk of dehydration and/or heat illness. It is further hypothesized that this reluctance to drink warm, halogen treated water during a 6 hour period of progressive dehydration is a striking manifestation of a negative alliesthesia for water rather than a putative failure of the thirst mechanism.

FIGURE LEGENDS

Fig. 1. Effect of palatability factors (water temperature and/or taste) on percent body weight loss. Mean ± S.E.
Code: C = cool; I = iodine-treated; F = flavored; W = warm or water. Significance testing by paired or unpaired t test; $p < 0.05$.

Fig. 2. Effect of palatability factors (water temperature and/or taste) on percent rehydration calculated from 6 hour sweat losses and 6 hour water consumption. Mean ± S.E. See Legend Fig. 1 for code.

DISCLAIMER

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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Table 1

Physical Characteristics

Group[1]	n	Age(yr)[2]	Height (cm)	Weight (kg)	Body Surface Area (m^2)	Blood Volume (ml)
1 (W)	8	22 ± 2	181 ± 6	76 ± 11	1.958 ± 0.145	5205 ± 479
2 (W-I)	11	24 ± 3	177 ± 11	73 ± 8	1.898 ± 0.157	5005 ± 515
3 (W-F-I)	10	22 ± 3	176 ± 10	72 ± 9	1.878 ± 0.165	4942 ± 527
Cumulative	29	23 ± 3	179 ± 9	74 ± 9	1.9 ± 0.2	5039 ± 516

[1] W - tap water; W-I = water plus iodine; W-F-I = water plus iodine plus flavoring.

[2] mean ± S.D.

Table 2

Effect of Cooling and/or Flavoring Water on Voluntary Consumption

Group	Code	Drink Temp (°C)	Subject n	Avg Consumption Rate $g \cdot h^{-1}$	Avg 6 h Consumption (g)	Difference Due To To Cooling (g)	Difference Due To Flavoring (g)	Difference Due To Cooling and Flavoring (g)
1	CW	15	8	426 ± 51	2558 ± 208			
	WW	40	8	322 ± 54+	1918 ± 276+	640 (CW-WW)		
2	CIW	15	11	364 ± 51	2182 ± 195			
	WIW	40	11	232 ± 44+	1389 ± 296+	793 (CIW-WIW)		
3	CIFW	15	10	509 ± 50	3052 ± 128		870* (CIFW-CIW)	1663* (CIFW-WIW)
	WIFW	40	10	355 ± 43+	1973 ± 294+	1079 (CFIW-WFIW)	584* (WIFW-WIW)	

[1]mean ± SE

+Significant difference ($p < 0.05$) by Student's paired t test between the mean the the mean above it.

*Significant difference ($p < 0.05$) by Student's unpaired t test.

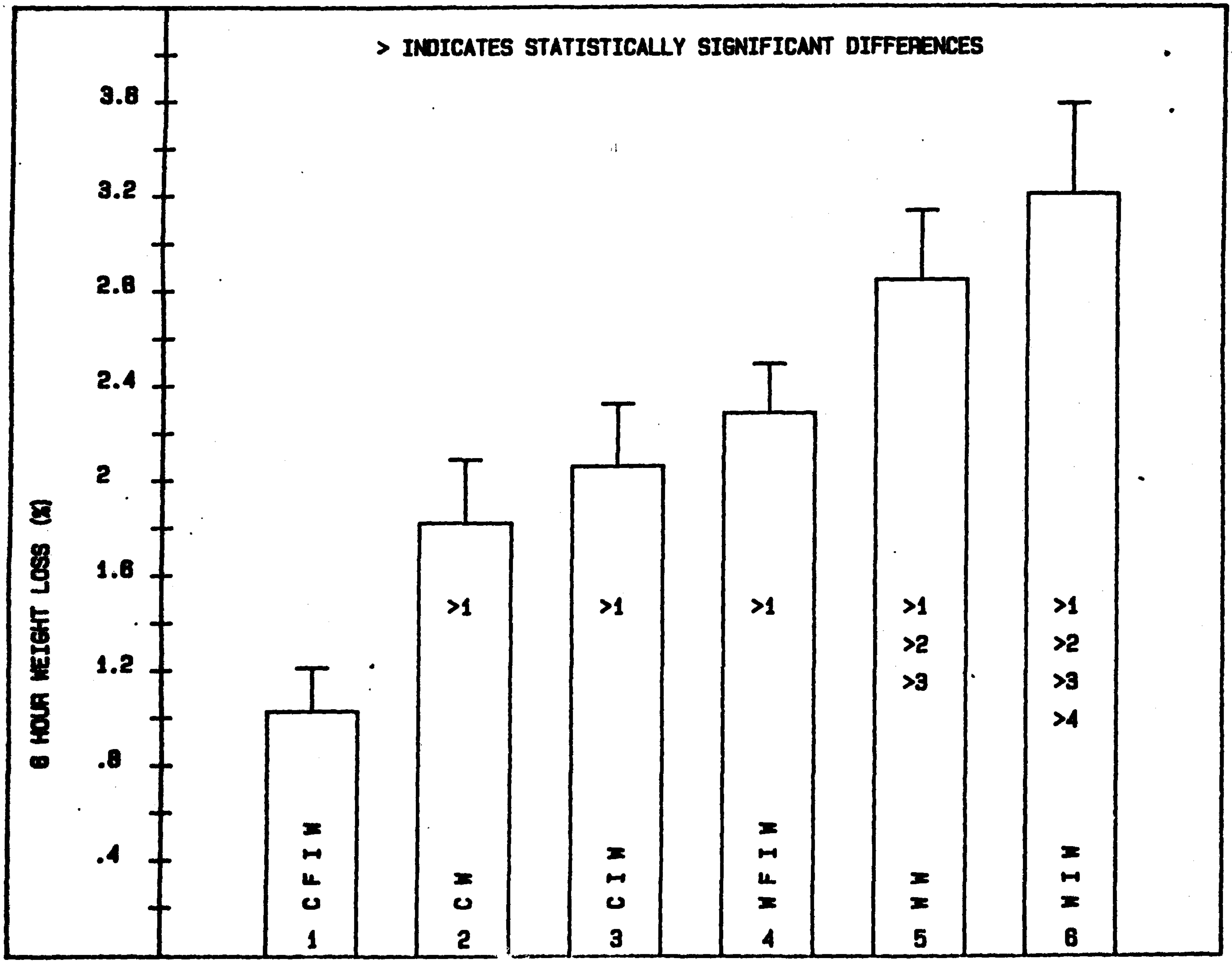
Code CW = Cool water; WW = warm water; CIW = cool, iodinated water; WIW = warm iodinated water; CIFW = cool, iodinated, flavored water; WIFW = warm iodinated flavored water.

Table 3

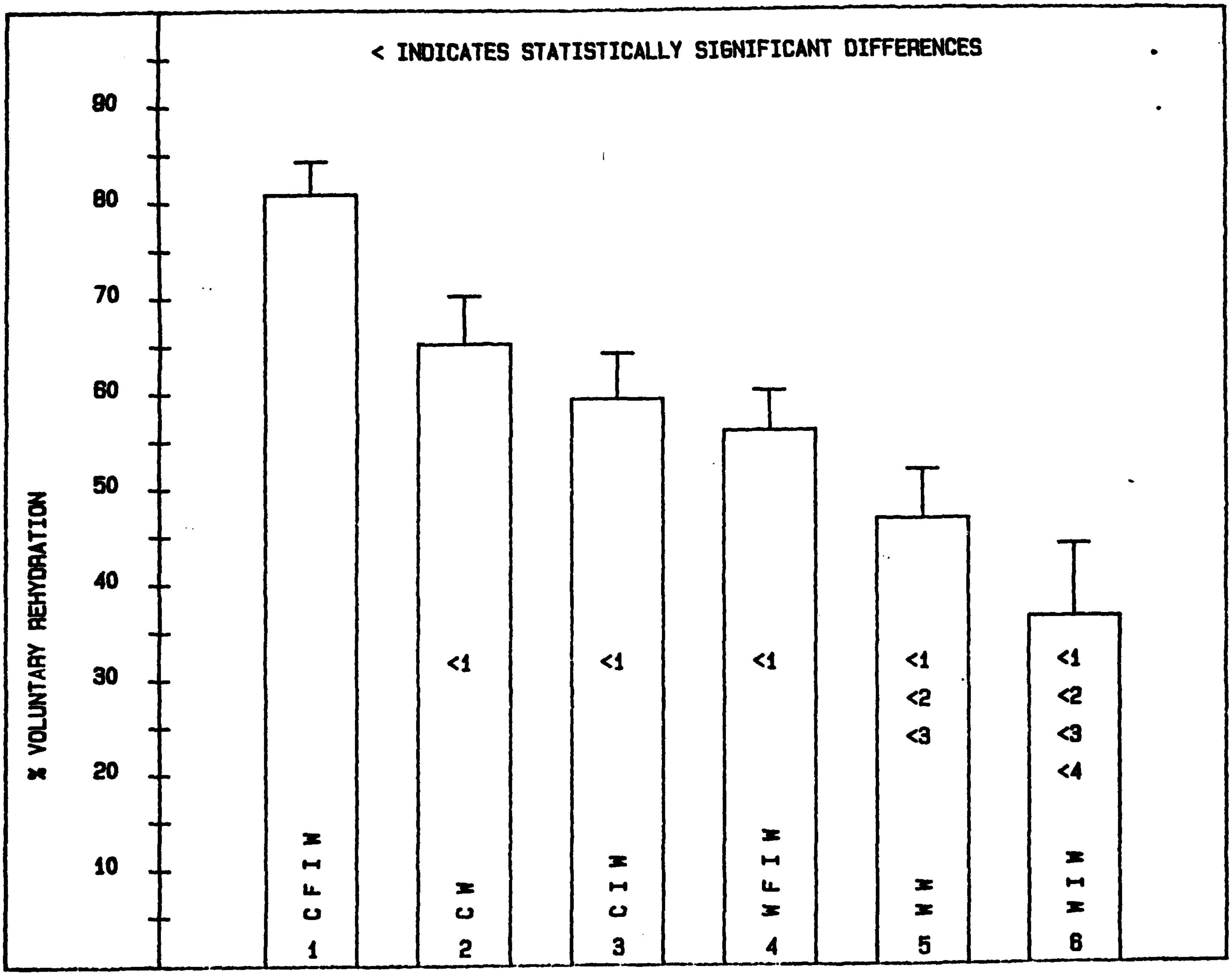
Effect of fluid intake and sweat production on body weight loss

Group	Code	Drink Temp (^oC)	Subject n	6 h Sweat Loss (g)	Average 30' Resting Sweat Rate $g \cdot m^{-2} \cdot 0.5\,h^{-1}$	Average 30' Exercising Sweat Rate $g \cdot m^{-2} \cdot 0.5\,h^{-1}$	Average Hourly Sweat Rate $g \cdot m^{-2} \cdot h^{-1}$	6 h Weight losss (g)
1	CW	15	8	4066 ± 200	98 ± 11	229 ± 3	327 ± 12	1381 ± 202
	WW	40	8	4103 ± 171	100 ± 7	232 ± 5	332 ± 10	2119 ± 184+
2	CIW	15	11	3782 ± 141	92 ± 6	227 ± 6	319 ± 10	1486 ± 172
	WIW	40	11	3785 ± 160	111 ± 16	219 ± 5	330 ± 18	2364 + 300+
3	CIFW	15	10	3920 ± 129	101 ± 9	230 ± 5	331 ± 11	740 ± 137
	WIFW	40	10	3785 ± 160	97 ± 9	226 ± 6	324 ± 11	1585 ± 147+

+ Mean ± SE significantly different ($p < 0.05$) from mean above it.



> INDICATES STATISTICALLY SIGNIFICANT DIFFERENCES
6 HOUR WEIGHT LOSS (%)
3.8
3.2
2.8
2.4
2
1.6
1.2
.8
.4
>1
>1
>1
>1
>2
>3
>1
>2
>3
>4
C F I W
C W
C I W
W F I W
W W
W I W
1
2
3
4
5
6



< INDICATES STATISTICALLY SIGNIFICANT DIFFERENCES
% VOLUNTARY REHYDRATION
90
80
70
60
50
40
30
20
10
<1
<1
<1
<1
<2
<3
<1
<2
<3
<4
CFIW
1
CW
2
CIW
3
WFIW
4
WW
5
WIW
6