

Climate and Fluid Intake

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NUMEROUS investigators have studied the physiological reaction of adults to specific temperature, humidity, and other variable climatic conditions (1, 2). These studies, initiated primarily by the U. S. Armed Forces, have been concerned largely with man's comfort, efficiency, or survival in the desert, arctic, or other places with severe climatic conditions. There have been a few investigations of the physiological response of children to heat stress under laboratory (3) and normal living conditions (4, 5), but data are too limited to describe adequately the influence of climatic factors on the amount and kind of fluid consumed by this group.

Interest in the physiological response of children to climate increased markedly with the advent of community water fluoridation. Epidemiological studies in natural fluoride areas have shown that 1 p.p.m. fluoride represents the optimum level for dental caries con-

trol in most of the United States (6). However, it has been suggested that in the practical application of the findings less than 1 p.p.m. may be sufficient to give optimum protection in very warm areas because of increased water consumption (7).

Galagan and Lamson (8) using two biological indexes (fluorosis and dental caries) found that Arizona children, living in a climate where the mean annual temperature is approximately 70° F., had a higher fluorosis index and a lower caries rate than children who used water with the same fluoride concentration but who lived in the midwest where the mean annual temperature is 50° F. They concluded that the Arizona residents drink more water than children living in the more temperate climate.

Since this finding and an earlier pilot study (5) indicated that climatic factors do influence water consumption in children, it was decided to investigate the relationship between climate and fluid intake more extensively by measuring, under normal living conditions, the actual amounts of fluid consumed by a large number of children exposed to varying climatic conditions. The study was undertaken jointly by the Public Health Service and the Contra Costa County (Calif.) Health Department, with active support from superintendents, principals, teachers, and nurses of local schools and members and officers of local parent-teacher associations.

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Dr. Henrik L. Blum, health officer of Contra Costa County, assisted in carrying out the study reported in this paper. Dewey DiMartini, Mrs. Elsie M. Green, and Mrs. Evelyn G. Ackerman served as volunteer weather observers in Brentwood, and Edward C. Jennings, in Antioch.

The Field Study

Antioch and Brentwood in Contra Costa County, Calif., were selected as study sites. Both communities experience temperatures

above 90° F. each summer, and both have mild winters, but there is enough difference between the winter and summer months to permit evaluation of seasonal change.

In a series of thirty-nine 5-day study periods during approximately 1 year, records of fluid intake were obtained for 316 Antioch and 139 Brentwood children. In Antioch, there were 27 periods, Monday through Friday, every other week, from November 30, 1953, through December 3, 1954. In Brentwood, data were obtained for one 5-day week each month from January 25, 1954, through December 10, 1954.

The participating children were divided into study groups of 12, a boy and girl in each of 6 age groups ranging from infancy through 10 years. The fluid consumed by each child was recorded for a 5-day period. No child participated for more than one period. With a few exceptions, the participants were distributed equally by sex throughout all six age groups in each study period. In a few instances records were maintained for a given child for fewer than 5 days, and occasionally fewer than 12 children participated in a group. All calculations take these irregularities into account. The age and sex distribution of participants is shown in table 1.

Table 1. Number of participants, by age and sex, Antioch and Brentwood, Calif.

Age in years	Antioch			Brentwood		
	Total	Boys	Girls	Total	Boys	Girls
All ages...	316	156	160	139	68	71
Under 1.....	54	27	27	19	8	11
1-2.....	52	25	27	24	12	12
3-4.....	54	27	27	24	12	12
5-6.....	54	27	27	24	12	12
7-8.....	51	26	25	24	12	12
9-10.....	51	24	27	24	12	12

The children studied were selected from a roster of potential participants for each town. The rosters were divided into sections according to sex and age groups, and the names of the children in each section were arranged alphabetically. In accordance with a prescribed sampling procedure, the names of possible participants were drawn from the roster. If the

parents of a selected child did not agree to participate during the full 5-day period, an alternate child was chosen. Children who were known to be ill were excluded, especially if they had fever. Since participation in the study was voluntary, the children included do not necessarily comprise a sample representative of all children in the two communities.

Each participant was visited at home at least three times. The first visit was made to obtain a firm commitment from the parents that their child would participate and to instruct the parents and the child how to measure and record fluid intake. A plastic cup, calibrated in fluid ounces, and a record book were given to the parents. For each school child, a collapsible cup, also calibrated in fluid ounces, and an additional booklet were issued to the child's teacher, who was given the same instructions as the parents. Teachers of kindergarten and first-grade children maintained the records during school hours, but children in the second grade and above usually maintained their own fluid consumption records, with some teacher supervision.

The second visit took place at the midpoint of the recording period. The child was weighed, any problems in maintaining the fluid-consumption record were discussed, and the record was checked for obvious errors or omissions. The third visit was made at the end of the recording period. The fluid-consumption records were collected from the homes and the schools and were given a final review at this time.

The amount of fluid consumed was recorded in eight categories. The first five categories included either water in its natural form or substances to which water is added in the home: drinking water, formula preparations for babies or reconstituted milk made with water, juices diluted with water, soups diluted with water, and other water-based beverages such as tea or coffee. The other three categories included beverages which do not have water added in the home: carbonated beverages, juices not diluted with water, and other beverages such as whole milk. Water used in cooking, such as that added to vegetables, was not recorded.

The United States Weather Bureau installed

Table 2. Body weight and amount of all fluids and of water consumed per child, by sex and age, Antioch and Brentwood, Calif.

Sex and age in years	Antioch						Brentwood					
	Body weight (pounds)		All fluids (ounces per day per pound body weight)		Water (ounces per day per pound body weight)		Body weight (pounds)		All fluids (ounces per day per pound body weight)		Water (ounces per day per pound body weight)	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
<i>Boys</i>												
Under 1-----	18.0	3.4	1.77	0.53	0.39	0.46	15.9	4.4	2.01	0.58	0.81	0.60
1-2-----	30.6	3.9	1.00	.35	.44	.26	29.4	3.1	.96	.23	.33	.15
3-4-----	37.6	4.1	.94	.31	.39	.19	39.4	5.6	.76	.16	.38	.15
5-6-----	53.9	9.0	.90	.29	.38	.19	49.6	8.2	1.12	.50	.53	.29
7-8-----	65.5	13.7	.80	.24	.40	.20	66.8	8.9	.72	.25	.39	.18
9-10-----	78.9	13.3	.64	.17	.34	.13	77.5	8.2	.73	.25	.42	.29
<i>Girls</i>												
Under 1-----	17.6	3.3	1.67	.53	.53	.56	16.3	1.9	2.00	.56	.80	.70
1-2-----	28.0	4.0	1.17	.53	.43	.33	27.6	5.0	1.11	.66	.44	.35
3-4-----	38.0	5.8	.97	.33	.41	.23	37.0	5.1	.70	.21	.33	.20
5-6-----	49.5	11.9	.87	.36	.39	.19	50.5	5.2	.85	.26	.31	.15
7-8-----	65.1	12.9	.74	.22	.36	.20	61.2	15.5	.76	.23	.40	.21
9-10-----	81.2	18.6	.64	.26	.33	.17	72.7	11.6	.73	.43	.38	.23

and maintained the equipment needed for recording climatologic observations in each community. The equipment consisted of maximum and minimum thermometers, wet and dry bulb thermometers, a fan, and a hygrothermograph for recording temperature and humidity continually during a 24-hour period. Since the Weather Bureau staffs its weather stations with volunteers, volunteers were recruited in each community to serve as weather observers. They read the wet and dry bulb thermometers and recorded the dew point three times each day, 9 a. m., noon, and 5 p. m. They read the maximum and minimum thermometers once each day and recorded rainfall whenever it occurred. The data from the hygrothermograph were checked against the manual observations, and any necessary changes were made in the data according to procedures outlined by the Weather Bureau climatologist.

Climatologic Findings

Two of the most common expressions of climate are temperature and humidity. However, no one of the many measures of temperature or

humidity is recognized as the best measure of these factors. Among the possible ways temperature or humidity can be expressed are the 24-hour mean, the 7 a. m. to 6 p. m. mean, the daily maximum, the mean of the maximum and the readings on the hours preceding and following the hour in which the maximum occurs, the 3 p. m. reading, and the daily mean calculated by averaging the maximum and minimum.

From a practical standpoint, all six measures could not be used in the analysis. To identify the ones that reflect most accurately the climatic conditions to which the children in the study were exposed, rank order correlations of these measures were done.

For temperature, an average of each of the aforementioned expressions was calculated for each observation period during which fluid-intake records were maintained, and each of the measures was then ranked according to the period in which the particular expression ranked highest, next highest, and so on. Coefficients of concordance were 0.986 for Antioch and 0.975 for Brentwood. Since the correlation between the rankings of the various temperature expressions is so high, it may be concluded

that any one of the measures is as good as any other to describe the temperature factor in this climatic environment. The daily maximum temperature is used here since it reflects the extremes of heat to which an individual is exposed and since it is a measure generally available wherever weather observations are recorded.

For the rank order correlation of humidity expressions, minimum humidity was used instead of maximum humidity since the latter approached 100 percent at some time nearly every day, particularly in the early morning hours. The result of the correlation is similar to that for temperature, and it is concluded that any one of these measures of humidity adequately describes the humidity factor in this climatic environment.

It has been assumed by many investigators that humidity has an important effect on fluid intake, although the extensive observations re-

Table 3. Percentage distribution of ounces of each kind of fluid consumed,¹ Antioch and Brentwood, Calif.

Kind of fluid consumed	Antioch	Brentwood
All fluids.....	² 100.0	³ 100.0
Drinking water.....	33.8	36.4
Water based beverages.....	9.6	11.2
Milk.....	47.9	39.9
Carbonated beverages.....	3.0	3.6
Other fluids.....	5.7	8.9

¹ During 1,539 child-days in Antioch and 681 in Brentwood.

² 61,810 ounces.

³ 27,044 ounces.

ported by Adolph indicate otherwise (1). It was hoped that this study would provide additional information on the subject. However, combinations of high temperature and high humidity, which would be required to detect any

Table 4. Percentage distribution of participants by ounces of all fluids, water, and all other fluids consumed per day per pound of body weight, November–March and April–October, Antioch and Brentwood, Calif.

Ounces fluid consumed per day per pound of body weight	Antioch						Brentwood					
	November–March ¹			April–October ²			November–March ³			April–October ⁴		
	All fluids	Water	All other fluids	All fluids	Water	All other fluids	All fluids	Water	All other fluids	All fluids	Water	All other fluids
Total.....	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Less than 0.2.....	0	34.3	6.4	0	15.3	8.0	0	39.7	8.6	0	13.6	9.9
0.2–0.3.....	5.0	42.9	30.8	0	34.8	24.4	3.4	32.8	36.3	2.5	33.2	32.2
0.4–0.5.....	20.0	12.1	25.7	11.9	27.8	29.0	25.9	13.8	31.1	12.3	23.5	22.2
0.6–0.7.....	27.0	4.3	17.1	21.0	11.9	17.0	32.9	5.2	6.9	19.8	14.8	13.6
0.8–0.9.....	15.0	4.3	6.4	22.1	3.4	8.0	19.0	1.7	1.7	23.5	6.2	8.6
1.0–1.1.....	8.6	0	4.3	15.3	3.4	4.5	1.7	0	5.2	14.8	2.5	11.1
1.2–1.3.....	7.9	1.4	.7	13.1	1.1	3.4	1.7	1.7	1.7	6.2	2.5	1.2
1.4–1.5.....	5.0	0	.7	4.0	.6	1.7	1.7	1.7	3.4	6.2	2.5	0
1.6–1.7.....	2.9	.7	2.9	3.4	1.7	1.7	0	3.4	3.4	2.5	0	0
1.8–1.9.....	2.9	0	.7	.6	0	0	6.9	0	1.7	4.9	0	1.2
2.0–2.1.....	3.6	0	2.9	3.4	0	.6	0	0	0	2.5	1.2	0
2.2–2.3.....	1.4	0	.7	.6	0	1.1	1.7	0	0	2.5	0	0
2.4–2.5.....	0	0	0	2.8	0	0	1.7	0	0	1.2	0	0
2.6–2.7.....	0	0	.7	.6	0	0	0	0	0	0	0	0
2.8–2.9.....	.7	0	0	.6	0	.6	1.7	0	0	0	0	0
3.0–3.1.....	0	0	0	0	0	0	1.7	0	0	1.2	0	0
3.2 or more.....	0	0	0	⁵ 5.6	0	0	0	0	0	0	0	0

¹ Number of participants; 140; mean maximum temperature: 59.7° F.; temperature range: 56.6°–62.2° F.

² Number of participants: 176; mean maximum temperature: 82.3° F.; temperature range: 74.1°–95.5° F.

³ Number of participants: 58; mean maximum temperature: 58.6° F.; temperature range: 56.8°–62.2° F.

⁴ Number of participants: 81; mean maximum temperature: 85.6° F.; temperature range: 79.2°–97.6° F.

⁵ 3.4 ounces.

possible additional effect of humidity on fluid intake, did not occur in the study communities. For example, in Antioch there were 66 hourly observations of temperatures of 90° F. or higher during the recording periods. For the same hours, humidity did not exceed 39 percent and often went below 20 percent. Analysis of the relationship between humidity and fluid intake will not be presented since a correlation between the mean maximum temperature and the mean minimum humidity in each community demonstrated an inverse relationship approaching unity. This inverse relationship between temperature and humidity is not limited to the western United States; in fact, it appears to be a common phenomenon (9, 10).

Studies of man in the tropics indicate that relative humidity up to 80 percent does not add to thermal stress (1). It is unlikely, therefore, that humidity has an important influence on fluid intake among children. However, further study of the possible independent effect of humidity on fluid intake in areas where high temperature and high humidity occur simultaneously may be indicated. One such area is adjacent to the Gulf of Mexico.

Temperature and Fluid Intake

In this report the term "temperature" refers to mean maximum temperature for the periods that data on fluid intake were recorded. The term "fluid" refers to all fluids consumed. Other types of fluids are mentioned specifically by name when comments refer to them. Data for both Antioch and Brentwood are presented in each table, but unless otherwise specified only the Antioch data are discussed. Since fewer than half as many observations were made in Brentwood as in Antioch, the Brentwood data do not have the same degree of reliability as those for Antioch. Generally speaking, the findings for Antioch hold true for Brentwood.

Both total fluid intake and water intake per pound of body weight decreased with increase in age, as shown in table 2. This decrease resulted mainly from the increase in body weight with age, not from an actual decrease in the total amount of fluid consumed. Correlations of both total fluid intake and water intake with

body weight are significant at the 1 percent level, although the correlations are not unity. Thus, a 10-year-old child drinks more fluid than an infant, but not in direct proportion to the weight difference between the two individuals. No important differences between boys and girls in the amount of fluid consumed are apparent.

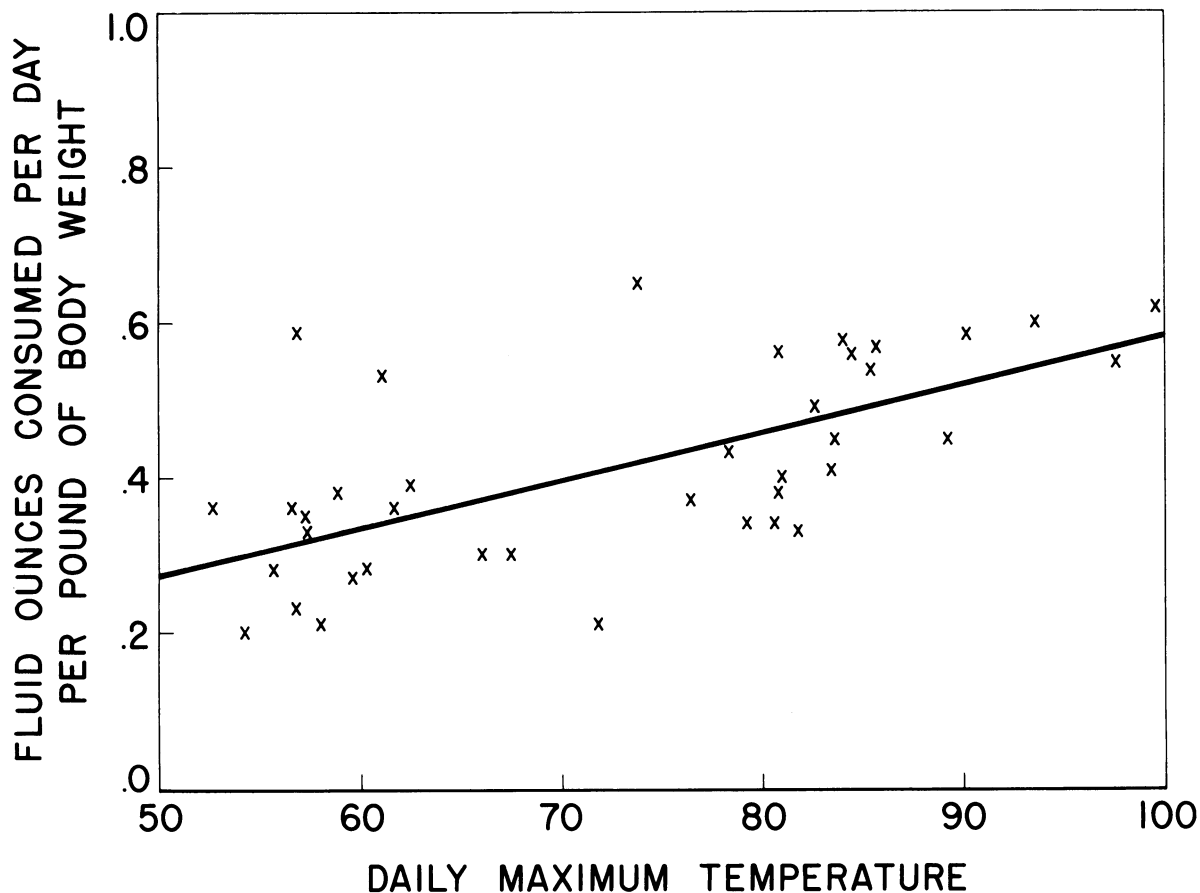
Water accounted for about 43 percent of the total fluid consumed (table 3). Slightly less than one-half of the fluid consumed was milk. This amount represents fluid milk and does not include formula preparation made with a water base or with powdered milk reconstituted with water. Carbonated beverages and other fluids combined made up less than 9 percent of the fluid intake of the children.

Table 5. Mean maximum temperature and water intake for each recording period, Antioch and Brentwood, Calif.

Mean maximum temperature for recording period	Ounces of water consumed per child per day per pound of body weight	Mean maximum temperature for recording period	Ounces of water consumed per child per day per pound of body weight
<i>Antioch</i>			
52.6-----	0.36	83.4-----	0.41
54.2-----	.20	83.6-----	.45
55.6-----	.28	84.4-----	.56
56.6-----	.36	85.4-----	.54
57.4-----	.32	90.2-----	.58
58.0-----	.21	93.6-----	.60
58.8-----	.38	99.6-----	.62
60.2-----	.28	<i>Brentwood</i>	
61.0-----	.53	56.8-----	.23
61.6-----	.36	56.8-----	.59
66.0-----	.30	57.2-----	.35
67.4-----	.30	59.6-----	.27
71.8-----	.21	62.4-----	.39
73.8-----	.65	79.2-----	.34
76.4-----	.37	80.8-----	.56
78.2-----	.44	82.6-----	.49
80.6-----	.34	84.0-----	.58
80.8-----	.38	85.6-----	.57
81.0-----	.40	89.2-----	.45
81.8-----	.33	97.6-----	.55

Correlations of temperature with total fluid, with drinking water, with water-based beverages (as defined), with total water, and with carbonated beverages were significant at the 1 percent level. Correlations were equally significant when body weight was equated to account for the possible effect that weight differences might have on fluid consumption. A

Relationship between daily maximum temperature and water intake among children, Antioch and Brentwood, Calif.



negative relationship, significant at the 5 percent level, was demonstrated between other fluids (milk and all other fluids which do not contain water added in the home except carbonated beverages) and temperature, both with and without body weight equated.

The only major differences found for Brentwood were these: Temperature did not correlate significantly with carbonated beverages or with other fluids (as defined in the preceding paragraph); correlations of temperature with total fluid and with drinking water were significant at the 5 percent level without body weight equated and at the 1 percent level with body weight equated.

The significant negative correlation demonstrated in Antioch between temperature and intake of fluids other than water, water-based beverages, and carbonated beverages may result from a decrease in intake of milk as tempera-

ture increases and water and cooling drinks are substituted for milk. This pattern of behavior has been observed previously in infants (3).

Of primary interest are the water consumption data in table 4 for two periods, November through March, when the temperature averaged 60° F., and April through October, when the temperature averaged 82° F. A decided shift to greater water intake during the higher temperature period is reflected in these data. However, under conditions of both high and low temperature, more than 90 percent of the children drank less than 1 ounce of water per day per pound of body weight. No such shift was discernible in the consumption of fluids other than water.

The relationship between temperature and water consumption is shown more precisely in table 5 and in the chart. The plotted points on this chart represent the mean amounts of water

consumed per child per day per pound of body weight for each recording period in each community. The line is derived from the estimation equation "ounces of water per pound of body weight = $-0.038 + 0.0062$ temperature," based on the data in table 5.

The findings for the two communities so closely approximate each other that data for both Antioch and Brentwood were used as the basis for deriving the equation that describes the relationship between temperature and water consumption. A straight line was calculated but the line should not be extended beyond the maximum temperature range of 50° to 100° F.

The line representing water consumption rises as temperature increases. This relationship has been described earlier by the positive correlation between water consumption and temperature. It may be concluded from these observations that the direct method of measuring water intake in children exposed to varying temperatures, under normal living conditions, confirms earlier observations obtained by using indirect biological measurements that the amount of water consumed by children increases with increases in temperature.

Summary

1. Records of fluid intake for 455 Antioch and Brentwood, Calif., children from infancy through 10 years of age were obtained during thirty-nine 5-day observation periods in a period of 1 year. Detailed temperature and humidity data also were obtained throughout the year.

2. Rank order correlations showed that any one of several expressions could be used to describe the climatic variables, temperature and humidity. Maximum temperature and minimum humidity were selected as the expressions of choice.

3. Humidity was associated negatively with temperature to such a high degree that it was

not possible to determine whether humidity might have some additional effect on fluid consumption in areas where high temperature and high humidity occur simultaneously.

4. Fluid intake per pound of body weight was highest among infants and decreased with age.

5. There were no substantial differences between boys and girls in the amount of fluid consumed per pound of body weight.

6. Under normal living conditions, water intake increased directly with increases in temperature.

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