Fluid Consumption Related to Climate among Children in the United States

Woosung Sohn, DDS, MS, PhD; Keith E. Heller, DDS, MPH, DrPH; Brian A. Burt, BDS, MPH, PhD

Abstract

Objective: *Recommended fluoride concentrations in US public water systems are between 0.7–1.2 ppm, depending on the mean daily maximum temperature. This range assumes that water intake is higher in warmer than in cooler climates, based on research from the 1950s. The aim of this analysis is to relate fluid consumption among American children aged 1–10 years to the local climate under modern conditions.* ***Methods:*** *The quantities of daily total fluid intake per body weight (ml/kg) and plain water intake per body weight (ml/kg) of children were calculated from the 24-hour recall diet survey in the third National Health and Nutrition Examination Survey (NHANES III, 1988–94). The mean daily maximum temperature from 1961 to 1990, averaged for the month during which the NHANES III exam was conducted, was obtained for each survey location from the US Local Climate Historical Database. Multiple regression analysis was conducted using SAS and SUDAAN.* ***Results:*** *Fluid intake was significantly associated with age, sex, socioeconomic status (SES), and race and ethnicity. No significant association could be found between the amount of either total fluid or plain water intake and mean daily maximum temperature, either before and after controlling for sex, age, SES, and race or ethnicity.* ***Conclusions:*** *Results indicate that there is no evidence that fluid consumption among children is significantly related to mean temperature in modern conditions. This suggests that the national temperature-related guidelines for fluoride concentration in drinking water may be due for reevaluation. [J Public Health Dent 2001;61(2):99-106]*

Key Words: fluid consumption, water intake, temperature, climate, children, fluoride concentration, drinking water.

The history of early fluoride research and subsequent development of the recommended range of water fluoride concentration have been well described in the literature (1,2). The "optimum" fluoride concentration of 1.0 part per million (ppm) was suggested by Dean et al. (3,4) from the "21 Cities" study as the trade-off between maximum caries prevention and an "acceptable" level of dental fluorosis. A few years later, Arnold (5) suggested that some factors that might affect children's fluid intake, such as climate, should be considered in setting public policy for fluoridation.

In the 1950s, Galagan and Lamson (6) measured the prevalence and severity of fluorosis of children in Arizona and compared the results with those of Dean's studies in the Midwest. They found more severe endemic fluorosis among the children from the southwestern communities and concluded that the higher fluorosis levels might be due to differences in water consumption. The design of these studies was somewhat crude by today's standards because no consideration was given to potential confounders such as socioeconomic status. The results, nevertheless, provided indirect evidence for a relationship between temperature and fluid intake.

In a later study, Galagan and colleagues directly measured water consumption among children aged 1 to 10 years old and daily maximum temperature in two California cities at different seasons. The relationship between water consumption and temperature was subsequently proposed as the following equation (7): Water intake per body weight (oz/lb)= –0.038+0.0062 x mean daily maximum temperature (°F). Using this equation and the conclusion from Dean's studies that 1.0 ppm of fluoride was the optimum concentration in the Chicago area cities where mean maximum daily temperature was 61.6°F, Galagan and Vermillion (8) derived an equation to assess the optimum fluoride concentration in relation to local temperature: Optimum fluoride (ppm F)=0.34/(–0.038+0.0062 x mean daily maximum temperature (°F)). Finally, a range of optimum fluoride concentration of 0.7–1.2 ppm F was suggested based on an approximate temperature range of 50°F–90.5°F for the United States. The US Public Health Service adopted this range in 1962 for its guidelines for appropriate fluoride levels for the prevention of dental caries (9), and it remains in force today (10).

Only a few studies have investigated fluid intake of children with its relationship to climate since Galagan's studies (11-14). The findings from these studies were equivocal. Crosby and Shepherd (11) reported a marked increase of fluid intake in kindergartners and schoolgirls during summer in Australia. More recently, Ershow and Cantor (12) reported a slightly higher fluid consumption in summer in the United States based on the 1977–78 Nationwide Food Consumption Survey (NFCS) data. However, they also reported that regional differences were much bigger than seasonal differences and that the seasonal pattern

Send correspondence and reprint requests to Dr. Sohn, Department of Cariology, Restorative Sciences, and Endodontics, School of Dentistry, University of Michigan, 1101 North University Street, Ann Arbor, MI 48109-1078. E-mail: woosung@umich.edu. Drs. Heller and Burt are with the Program in Dental Public Health, Department of Epidemiology, School of Public Health, University of Michigan. This paper was awarded second place in the 1999 Leverett Graduate Student Merit Award and presented as a poster at the 62nd AAPHD meeting on October 6, 1999, in Honolulu, HI. Manuscript received: 12/6/99; returned to authors for revision: 2/18/00; accepted for publication: 10/2/00.

was not consistent over age groups. They did not report seasonal variation after controlling for geographic region.

In contrast, Walker et al. (14) found no difference in fluid intake among children by season in various areas in the United States. McPhail and Zacherl (13) actually found an increase of fluid intake with temperatures below 50°F and an overall U-shaped fluid intake–temperature relationship from their study in northern Canada. They suggested a possible alteration of the effect of climatic temperature on fluid intake by artificial temperature regulation, such as indoor heating and warm clothing. Both of these studies were conducted shortly after Galagan's research, so the reasons for the different findings are not clear.

Since these studies were conducted, social and technological progress has dramatically changed people's way of living. For example, interior temperature control by air conditioning and central heating is widespread in the United States in homes, offices, and in public and private transportation. However, the implications of these changes on the relationship between fluid consumption and outdoor temperature among populations have not been studied lately. The aim of this analysis is to relate fluid consumption among US children to the local climate under modern conditions.

Methods

The NHANES III Survey. This study used data from the third National Health and Nutrition Examination Survey (NHANES III, 1988–94). The data were acquired from two series of public release CD-ROMs (15,16) released by the National Center for Health Statistics (NCHS).

A detailed description of design specifications and the sample design and weighting and estimation procedures for NHANES III can be found elsewhere (17). Briefly, the NHANES III sample represented the total civilian, noninstitutionalized population, aged 2 months and older, in the 50 states and the District of Columbia. In NHANES III 39,695 persons were selected over a six-year period; of those, 33,994 (86%) were interviewed in their homes. All interviewed persons were invited to the Mobile Examination Center (MEC) for selected physical examinations and a 24-hour dietary recall interview. In the dietary interview, respondents reported all foods and beverages consumed for the previous 24-hour time period (midnight to midnight). The dietary interviews were conducted in English and Spanish by trained bilingual dietary interviewers. For children under 12 years old, proxy respondents such as parents or guardians were allowed.

Study Population. The sample for our analyses included children aged 1–10 years who completed the 24-hour dietary interview (or proxy interview for the younger children) at the MEC during the NHANES III. Breast-fed children were excluded from this analysis because there was no way to measure the precise amount of breast milk many of these young children consume. Dietary interview data included information about the completeness of the survey as determined by the interviewer. As recommended by NCHS, only those with a final dietary recall status classified as complete were included in this analysis. As a result, among 8,613 children aged 1–10 years who completed the 24-hour diet recall survey, 688 (18%) were excluded due to incomplete data, leaving 7,925 eligible for this analysis.

Sociodemographic Information. Race and ethnicity classifications were non-Hispanic whites, non-Hispanic blacks (African Americans), Mexican Americans, and others. The "others" category includes all Hispanics, regardless of race, who were not Mexican American and also includes all non-Hispanics from racial groups other than white or African American. Socioeconomic status (SES) was categorized on the basis of the poverty income ratio (PIR), which is a ratio of reported annual family income to the federal poverty threshold. The categories of SES in this analysis were: low SES (0.000–1.300 PIR), middle SES (1.301–3.500 PIR), and high SES (3.501 and above PIR). Geographic regions were defined as Northeast, Midwest, South, and West as defined by the Bureau of the Census. Urbanicity was defined as central or fringe counties of metropolitan areas with a population of 1 million or more. All other areas were recorded as rural.

Fluid Consumption Data. There are two measurements of fluid consumption provided in the NHANES III data: (1) fluid intake from plain water drinking, and (2) fluid intake from food and beverages other than plain water drinking (15). The total amount of fluid intake for a child was calculated by adding these two measurements. Throughout this report, plain water intake was defined as fluid intake from tap water and spring water; total fluid intake was defined as sum of fluid intake from all sources including plain water, foods, and beverages. The amount of fluid from various sources was differentiated based on a separate Individual Food File in the NHANES III dataset (16). We identified major fluid sources as milk (and milk drinks), juice (fruit and vegetable juices and other noncarbonated drinks), carbonated drinks, and plain water. Fluid intake from sources other than these major sources were all grouped into other foods and beverages. The other foods and beverages includes bottled water, coffee, tea, baby food, soup, water-based beverages, and water used for dilution of food. All measures of the amount of fluid intake were converted to a metric scale, based on 1 fluid oz=29.59 ml. After initial analysis of fluid consumption, seven subjects with a total fluid intake over six standard deviations from the mean for each age were excluded from further analyses as outliers.

Data for Local Climate. NHANES III collected no information about weather. Climatic information, therefore, was acquired from other sources, including publications (18) and the US National Climatic Data Center on the Internet (19).

We were not able to ascertain climatic information for all of the NHANES III participants because detailed information of survey location, in terms of county and state, was released only for 35 counties with a population of more than 500,000 to prevent identification of respondents.

Also to protect respondents' confidentiality, the exact survey date was not included in the public release dataset. Only the month of the survey was available for each individual. Therefore, we used a 30-year average of the mean daily maximum temperature from 1961 to 1990 for the month during which the NHANES III data were collected for each survey location. Mean daily maximum temperature was chosen to describe a location's climate, because it is reportedly the most relevant to fluid intake (7,20).

Each mean daily maximum temperature was determined from the climate database. For some counties where more than one temperature measurement location was available, temperature measured at the airport or city hall was used as the county-level temperature.

Statistical Analysis. Data management included the merging of datasets and construction of variables. Preliminary analyses were carried out using Statistical Analysis System® Software (21). Because NHANES III is based on a complex, multistage cluster sample design, the Survey Data Analysis Software (SUDAAN, Release 7.5) was used to estimate variances adjusted for the design effect from sampling (22). All analyses incorporated sampling weights to adjust for unequal sampling probabilities and nonresponse bias (17).

Descriptive analysis included bivariable analyses of the amount of fluid intake by demographic factors such as age, sex, race or ethnicity, SES, geographic region, and urbanicity. Differences in fluid intake between levels of a variable were tested by the Bonferroni multiple comparison method.

Simple linear regression analyses were conducted to relate total fluid and plain water intake per kg body weight per day to the local temperature. Multiple linear regression analyses were also conducted to construct a model to explain variations in total fluid and plain water intake per kg body weight per day, controlling for confounding and interactions. In multiple regression analyses, age, sex, race or ethnicity, and SES were included, as well as the mean daily maximum temperature, because these variables were identified as significant covariates for the amount of fluid intake in the descriptive analysis.

TABLE 1
Selected Characteristics of Study Participants Aged 1–10 years (Mean or Percent±SE), NHANES III, 1988–94

Characteristics	Total Sample	Sample w/ Temperature	Sample w/o Temperature
Sample size	7,925	3,869	4,056
Estimated US population	35,601,358	15,037,523	20,563,835
Mean age (years)	5.5±0.1	5.6±0.1	5.5±0.1
Sex (%)			
Male	51.7±0.9	52.8±1.6	50.8±1.1
Female	48.3±0.9	47.2±1.6	49.2±1.1
Race/ethnicity (%)			
White*	65.0±1.6	52.5±3.0	74.1±2.4
African American*	15.6±1.2	17.9±1.9	13.9±1.8
Mexican American	9.3±0.9	13.3±2.0	6.4±1.4
Others	10.1±1.3	16.2±2.6	5.5±2.0
Socioeconomic status†			
Low	34.8±1.6	35.0±2.9	34.7±2.1
Middle	45.6±1.6	41.0±2.4	48.9±2.2
High	19.6±1.2	24.0±2.2	16.4±1.8
Region‡ (%)			
Northeast	17.3±1.2	28.2±4.5	9.4±3.1
Midwest	23.2±1.5	17.5±4.1	27.3±2.8
South	34.6±3.1	20.4±5.6	45.0±5.5
West	24.9±4.3	33.9±6.9	18.3±7.5
Urban/rural (%)			
Urban	47.7±5.4	81.8±7.7	22.8±7.3
Rural	52.3±5.4	18.2±7.7	77.2±7.3
Mean fluid intake (ml/kg/day) (selected)			
Total fluid	84.1±1.0	83.6±1.1	84.5±1.4
Plain water	26.8±0.8	27.3±1.0	26.4±1.1
Milk	17.6±0.3	17.7±0.6	17.7±0.4
Carbonated drinks	5.6±0.2	5.3±0.3	5.9±0.3
Juice	11.8±0.3	11.4±0.6	12.2±0.4

*Not of Hispanic origin.
†Based on ratio of household income to federal poverty threshold. Low: ≤1.300, medium: 1.301–3.500, high: ≥3.501.
‡Northeast=CT, ME, MA, NH, NJ, NY, PA, RI, VT; Midwest=IL, IN, IA, KS, MI, MN, MO, NB, ND, OH, SD, WI; South=AL, AR, DE, DC, FL, GA, KY, LA, MD, MS, NC, OK, SC, TN, TX, VA, WV; West=AK, AZ, CA, CO, HI, ID, MT, NV, NM, OR, UT, WA, WY.

Results

Of the 7,925 eligible children with complete dietary data, 3,869 (48.8%) for whom we could obtain temperature information were included in our analysis as the study group. Table 1 presents demographic characteristics and fluid intake of the total sample, the study group sample, and the sample without temperature data. Considering that the temperature data were available only for counties with a population of more than a half million, it was not surprising that the study group was mostly urban (81.8%), whereas only 47.7 percent of total sample was urban. For this reason, the Northeast and West regions, where there are more large cities, were somewhat overrepresented in the study group. Similarly, whites were underrepresented compared to other racial or ethnic groups. Fluid consumption showed similar results among these samples.

Table 2 presents the amount of total fluid and plain water intake among the 3,869 children in the study group. Total fluid intake (ml/day) increased as age increased while total fluid intake per body weight (ml/kg/day) decreased with age. Plain water intake (ml/day) also increased with age. However, plain water intake per body weight (ml/kg/day) did not show a consistent pattern by age. Boys showed significantly higher total fluid and plain water intake than girls. There was an inverse relationship between fluid intake (for both total fluid and plain water) and SES. Fluid intake

TABLE 2
Estimated Amount of Total Fluid and Plain Water Intake among Children* Aged 1–10 Years, NHANES III, 1988–94

		Total Fluid		Plain Water	
	n	(ml/day)±SE	(ml/kg/day)±SE	(ml/day)±SE	(ml/kg/day)±SE
Age (years)					
1	578	1,393.4±30.7	124.3±2.9	297.5±19.4	26.3±1.8
2	579	1,445.5±30.8	107.4±2.3	430.0±25.6	31.8±1.9
3	502	1,548.1±75.2	99.5±4.6	482.1±27.2	31.0±1.8
4	511	1,601.2±41.2	91.3±2.8	516.5±22.6	29.4±1.3
5	465	1,670.0±53.7	84.3±2.3	525.4±35.5	26.3±1.7
6	255	1,855.2±124.9	80.6±4.9	718.1±118.4	30.6±4.7
7	235	1,807.7±65.7	70.8±2.3	673.7±46.2	26.1±1.9
8	247	1,792.0±37.4	61.3±1.8	626.4±36.5	21.1±1.2
9	254	2,112.9±78.0	64.7±2.1	878.2±59.2	25.8±1.4
10	243	2,051.4±96.8	58.0±2.4	866.8±73.5	24.3±2.0
Sex					
Male	1,974	1,801.5±29.8	86.0±1.8	635.6±31.9	28.5±1.3
Female	1,895	1,664.1±24.3	80.9±1.5	579.2±25.6	25.9±1.0
Race/ethnicity					
White	736	1,653.1±25.6	79.0±1.8	552.4±34.2	24.4±1.3
African American	1,122	1,858.9±42.3	88.3±1.8	795.3±36.4	36.1±1.5
Mexican American	1,728	1,817.2±24.8	88.9±1.7	633.4±23.1	28.7±1.1
Other	283	1,812.9±47.0	89.6±4.2	565.2±39.4	25.6±1.7
Poverty income ratio					
Low	1,868	1,828.3±31.9	93.4±2.6	662.3±27.3	32.2±1.3
Medium	1,204	1,689.8±31.1	79.5±1.6	604.3±34.5	26.0±1.4
High	379	1,668.3±54.3	75.8±2.5	532.9±52.2	22.1±1.7
Region†					
Northeast	679	1,734.8±30.7	86.9±2.3	568.2±52.1	26.4±2.1
Midwest	699	1,734.4±45.3	83.7±1.5	639.7±53.8	28.9±1.8
South	869	1,739.4±31.2	83.2±2.2	612.9±24.1	27.6±1.3
West	1,622	737.4±24.5	81.1±1.7	624.4±44.2	27.0±1.9
Urban/rural†					
Urban	3,358	1,736.4±18.0	83.6±1.0	609.1±28.7	27.1±1.1
Rural	511	1,737.4±18.9	83.5±4.3	608.0±20.3	27.8±1.2
Total	3,869	1,736.5±15.2	83.6±1.1	608.9±23.7	27.3±1.0

*Children with temperature data.
†All variables except for Region and Urban/rural showed statistically significant differences for both total fluid and plain water intake by Bonferroni multiple comparison method.

varied among racial or ethnic groups. African Americans consumed more plain water than any other racial or ethnic group. Fluid intake did not differ significantly among geographical regions. However, because NHANES III is biased by region and season (e.g., examiners were not sent to the northern regions during winter), this relationship could not be evaluated directly (17).

Table 3 shows proportions of fluid intake from four major sources including plain water, milk, juice, and carbonated drinks by demographic variables. Plain water constituted 30.9 percent of total fluid intake. Proportions of total fluid intake made up of milk, juice, and carbonated drinks were 20.9 percent, 13.9 percent, and 7.4 percent, respectively. The remaining 26.9 percent of fluid consumption was from food and other beverages (data not shown). Proportions from plain water and carbonated drinks increased by age, whereas those from milk and juice decreased. While boys showed slightly higher milk consumption and girls showed slightly higher juice consumption, plain water consumption did not differ by sex. Among African American children, 38.3 percent of fluid intake was from plain water, compared to 29.2 percent for whites and 31.4 percent for Mexican Americans. Milk made up only 14.7 percent of fluid intake among African American children, while it made up 21.2 percent and 23.8 percent for whites and Mexican Americans, respectively. Children from lower SES strata showed a tendency of higher plain water consumption and lower milk, juice, and carbonated drink consumption than those from higher SES.

Results from simple regression analyses are presented in schematic plots for easy comparison to the result of Galagan et al. (7). Although a regression analysis in the 1950s showed a significant linear relationship (Figure 1), our analyses showed no significant linear relationship between fluid intake and mean daily maximum temperature for both plain water intake (Figure 2) and total fluid intake (Figure 3). In the 1950s, water intake among children aged 0–10 years varied by more than 50 percent from 22.0 ml/kg/day among those residing in areas with a mean daily maximum temperature of 60°F to 33.7 ml/kg/day among those in 90°F areas (Figure 1). With the same temperature increase in 1988–94, plain water intake among children (1–10 years old) increased only 11.6 percent (*P*=.17) from 25.7 ml/kg/day to 28.7 ml/kg/day (Figure 2), and total fluid intake increased only 4.8 percent (*P*=.37) from 82.1 ml/kg/day to 86.0 ml/kg/day (Figure 3).

Table 4 presents results from multiple regression analyses. Separate models were constructed for the outcome of fluid intake per kg body weight; one for total fluid, and the other for plain water only. Age and SES were identified as significant predictors in both models. Race/ethnicity was a significant predictor for plain water intake when controlling for other factors, but not for total fluid intake. Sex was a significant predictor for total fluid intake after controlling for other factors, but not for plain water intake. Mean daily maximum temperature was not significant with other factors in the model. We tested a model with interaction terms to identify interaction between temperature and race/ethnicity or SES. However, no interactions were significant, so all were dropped from the final model.

TABLE 3
Proportions of Fluid Consumption from Various Sources among Children* Aged 1–10 Years (Percent ± SE), NHANES III, 1988–94

	Plain Water	Milk	Juice	Carb. Drinks
Age (years)				
1	19.8±1.1	33.3±1.7	15.1±1.1	1.8±0.3
2	26.7±2.7	26.2±1.4	16.9±1.1	3.4±0.3
3	29.0±1.2	20.8±1.7	16.0±1.1	5.9±0.7
4	30.0±1.2	19.2±0.8	16.2±1.1	6.6±0.8
5	29.1±1.5	20.1±1.3	15.5±1.2	7.6±0.8
6	32.8±3.1	18.4±1.8	13.1±2.0	10.4±2.3
7	33.2±1.8	19.2±1.6	12.5±1.5	8.0±1.4
8	32.2±1.7	20.6±2.0	11.1±1.5	9.4±1.0
9	37.5±1.9	17.2±1.6	10.7±1.3	9.8±1.2
10	36.3±2.3	15.4±1.1	12.8±1.8	9.9±1.4
Sex				
Male	30.7±1.1	21.9±1.0	13.3±0.9	7.7±0.5
Female	31.1±1.2	19.8±0.7	14.6±0.9	7.0±0.6
Race/ethnicity				
White	29.2±1.4	21.2±0.8	14.0±1.1	8.7±0.6
African American	38.3±1.1	14.7±0.7	15.6±1.0	5.7±0.3
Mexican American	31.4±0.9	23.8±0.8	12.0±0.5	6.6±0.3
Other	27.3±1.5	24.4±1.5	13.5±1.5	5.4±0.8
Socioeconomic status				
Low	33.2±1.0	19.9±0.7	13.0±0.4	6.4±0.5
Medium	30.9±1.3	20.9±0.9	14.3±1.0	7.4±0.8
High	27.4±2.1	21.9±1.5	15.0±1.4	9.0±1.3
Region				
Northeast	27.9±1.8	21.0±0.7	15.8±1.7	6.8±0.6
Midwest	33.1±2.1	17.8±1.5	14.8±0.7	8.2±0.6
South	31.2±0.9	20.9±1.4	15.5±1.6	7.0±0.4
West	32.0±2.1	22.4±1.2	11.0±0.8	7.5±1.0
Urban/rural				
Urban	30.8±1.2	21.0±0.7	13.3±0.8	7.6±0.5
Rural	31.2±1.3	20.3±0.6	16.4±1.7	6.2±0.3
Total	30.9±1.0	20.9±0.6	13.9±0.8	7.4±0.4

*For whom temperature data were available.

Discussion

NHANES III adopted a 24-hour recall method for the dietary record, which has certain advantages in terms of speed and ease of administration. However, it does not necessarily provide reliable and valid estimation of an individual's diet or nutritional intake due to day-to-day variation. In a 24-hour recall, reports of extreme values, nonreporting, and underreporting were more common (23). Nevertheless, this method has been reported to provide a reliable estimate of dietary intake in a group, and thus a reliable comparison of group means (24,25). In the dietary recall at NHANES III, proxy respondents were allowed for all children until age 6 years and for some up to age 11 years. For children aged 1 to 2 years, the caregivers might be well aware of their children's fluid consumption. However, this would be less likely when children can obtain drinks by themselves, and even less likely for schoolchildren. Therefore, some underreporting by proxy respondents was probable for older children.

One important characteristic of NHANES III is that it was designed to avoid interviewing people in extremely hot or cold weather conditions. Therefore, the survey generally was conducted in the South during the fall, winter, and spring and in the North during the spring, summer, and fall (17). This design did not allow us to directly compare fluid consumption by season and geographical region. Instead, we linked the temperature data from other sources to each identifiable survey location and time in NHANES III. Although it seemed more desirable to use an individual temperature point for each location rather than season and region, it introduced several risks of potential bias. In the process of data linking, we lost more than half the sample. Our analysis was based only on the samples from large counties with a population of more than half a million. A systematic difference might exist between children from a large county versus a small county in terms of the temperature-fluid consumption relationship, although there is no evidence to support that. Our limitation of the sample to children from large counties or metropolitan areas may reduce the generalizability of the findings; however, it is these children who would be more likely to consume fluoridated water.

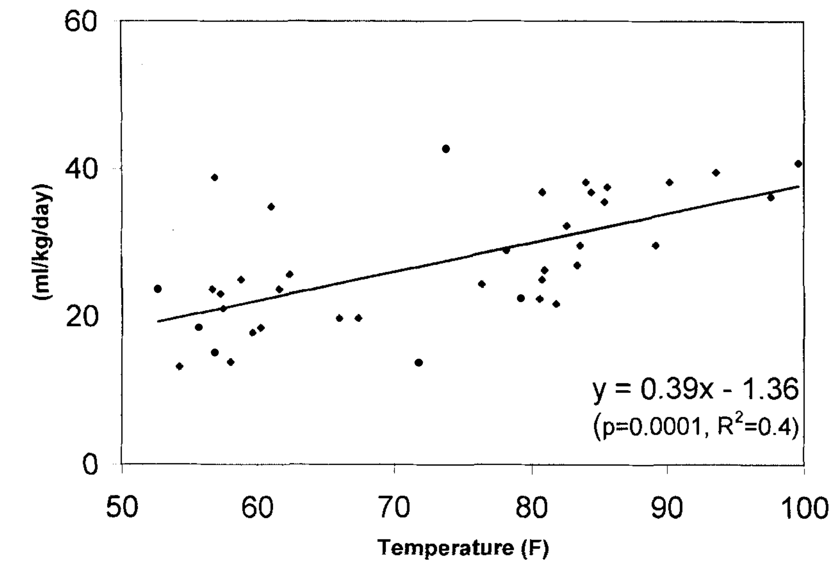
The mean maximum temperature points in our analysis ranged from 53.4°F to 89.3°F (Figures 2 and 3). Due to the biased design of NHANES III, more extreme temperatures were not included and the majority was distributed within the 65.0°F–85.0°F range. Therefore, the data in our analysis were more homogeneous than those in Galagan's study (7) and might have been biased toward null. However, we believe this range and distribution were sufficient to show differences in fluid intake if any existed.

While Galagan et al. (7) used actual daily maximum temperature of the survey date, we used the average of daily maximum temperatures during 1960–90 for the month for each county due to limited information availability in the NHANES III dataset. Using the 30-year average, rather than specific daily or monthly value of mean daily maximum temperature, could have introduced misclassification with the resulting regression parameter tending toward null. However, with the large sample size in this analysis, the statistical power was sufficient to reject the null hypothesis if a linear relationship did exist.

Another difference between Galagan's study and this one is the measurement of fluid intake. Galagan and colleagues measured water from drinking water, baby formula or reconstituted milk made with water, juices diluted with water, soups diluted with water, and other water-based beverages, while we used plain water intake (tap and spring water drinking only) and total fluid intake (sum of all fluid intake from diet). Because of these differences, direct comparisons of the actual amount of water intake are not appropriate. Nevertheless, these differences in methodology should not preclude the comparisons of the temperature–fluid consumption relationship of these two studies.

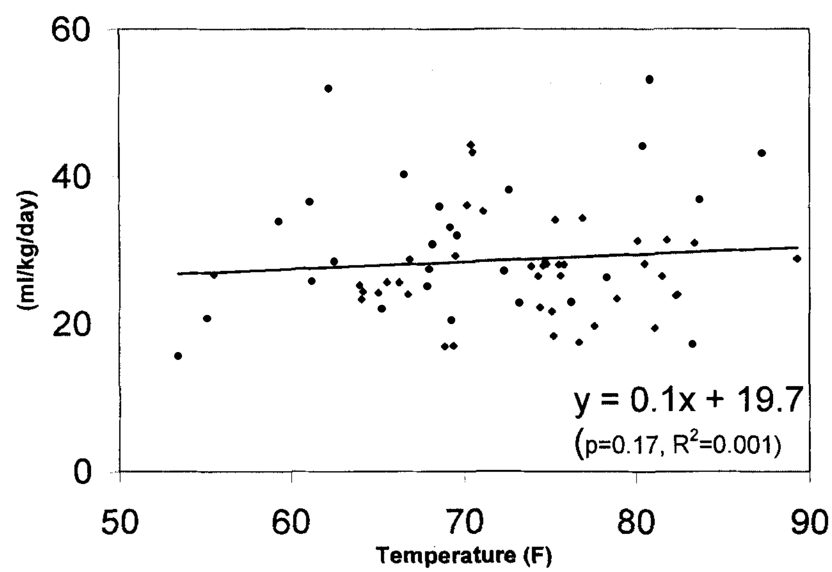
As shown by many studies (12,26), substantial interindividual variation in fluid consumption existed among children. Results of our analysis

FIGURE 1
Mean Water* Intake per Body Weight and Mean Daily Maximum Temperature† in 1950s (Data from Ref. 7)



*Water includes drinking water and water-based beverages.
†Galagan used actual daily mean temperature of the survey date.

FIGURE 2
Mean Plain Water* Intake per Body Weight and Mean Daily Maximum Temperature† (NHANES III, 1988-94)



*Plain water includes tap water and spring water only.
†30-year average (1960–90) of mean daily maximum temperature of the month in which the survey was conducted.

showed significant associations between fluid consumption and demographic factors such as age, sex, SES, and race or ethnicity. However, in the multiple regression model for total fluid intake, only about 26 percent of the variation in the total fluid intake (per kilogram body weight) could be explained by these predictor variables as well as by the mean daily maximum temperature. For the plain water intake (per kilogram body weight), only 5 percent of the variation could be explained by a multiple regression model with the same predictor variables. This finding indicates that most of the variation in fluid consumption was due to other factors. Level of physical activity could be important, but unfortunately, no information on physical activity was collected for children of this age group in NHANES III.

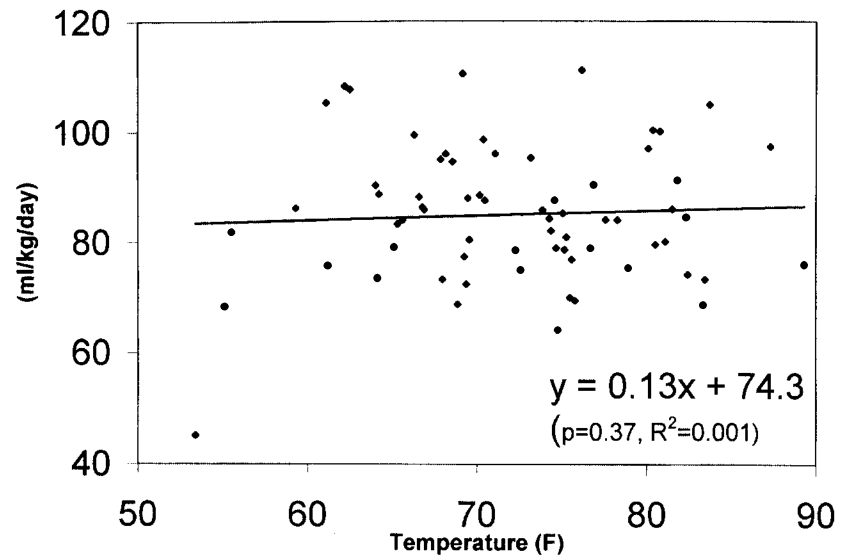
The effects of race or ethnicity and SES on fluid consumption were particularly noticeable. African American children consumed significantly more plain water and less milk than other racial or ethnic groups. White children showed the lowest total fluid intake as well as the lowest plain water intake. Children from the low SES group consumed more plain water and less milk than those from higher SES groups. These results might be due to differences in reporting food consumption by racial or ethnic groups (27). However, we cannot identify such potential biases in our analysis.

Two studies have found that African Americans had a higher prevalence of fluorosis than whites (28,29). However, these studies did not suggest a plausible scientific basis for those differences. Based on our results, it is possible that differences in fluid consumption might explain some of the differences between African Americans and whites in the occurrence of dental fluorosis.

When compared to the results from previous studies (7,12), the sources of fluid intake showed a clear trend of a decrease in plain water and milk consumption and an increase in carbonated drink consumption. We analyzed the consumption of carbonated drinks, because data from the *Beverage World* Web site (http://www.beverageworld.com) shows that each American consumed an average of 599 cans of soft drinks during 1998. Despite this enormous nationwide level of consumption, we did not find any significant change in the amount and proportion of carbonated drinks consumed in relation to mean temperature. Because carbonated drinks comprised only a small portion of fluid intake among young children, their influence might be of minor importance in this age group.

If there is no difference in fluid intake among children relative to local climate, as our results suggest, then children in colder climates who drink water with higher fluoride concentration than those in warmer climates may be ingesting more fluoride than children in warmer climates. How-

FIGURE 3
Mean Total Fluid Intake per Body Weight and Mean Daily Maximum Temperature* (NHANES III, 1988–94)



*30-year average (1960–90) of mean daily maximum temperature of the month in which the survey was conducted.

TABLE 4
Multiple Regression Models of Fluid Intake per Body Weight among Children Aged 1–10 Years, NHANES III, 1988–94) (n=3,250)

	Total Fluid Intake (ml/kg/day)			Plain Water Intake (ml/kg/day)		
Variable	β	SE (β)	*P*-value	β	SE (β)	*P*-value
Age	−6.66	0.35	<.01	−0.55	0.19	.01
Sex						
Male	0	0	—	0	0	—
Female	−4.56	1.86	.02	−2.61	1.45	.08
Race/ethnicity						
White	0	0	—	0	0	—
African American	4.28	2.82	.14	8.90	1.75	<.01
Mexican American	3.45	2.04	.10	1.35	1.59	.40
Other	3.09	3.18	.34	−2.18	2.13	.31
Socioeconomic status						
Low	0	0	—	0	0	—
Medium	−7.06	2.77	.01	−4.52	1.93	.02
High	−10.18	3.34	<.01	−7.65	2.33	<.01
Max. daily temp.	0.06	0.13	.66	0.03	0.07	.70
R^2		0.26			0.05	

ever, because dental fluorosis was not measured in NHANES III, this issue could not be directly studied in our analysis. While there have been several studies of fluoride intake based on detailed fluid intake among infants and young children (30,31), none of them have yet directly investigated fluorosis as an outcome. The 1986–87 National Survey of Oral Health of US Schoolchildren by the NIDR (32) remains the only source for the national-level status of dental fluorosis. Although that survey showed higher community-level fluorosis scores in northern areas, that finding might be ascribed primarily to widespread water fluoridation in those areas, and not necessarily to higher fluoride concentration (33). The relationship among fluid intake, fluoride concentration, and dental fluorosis cannot be explored fully until national data are collected for these variables within the same survey.

In conclusion, we could find no evidence that fluid consumption among US children is significantly related to mean temperature in modern conditions. This suggests that the temperature-related guidelines for fluoride concentration in drinking water, set by the US Public Health Service in 1962, may be due for reevaluation.

Acknowledgments

This study was a part of Dr. Woosung Sohn's dissertation at the University of Michigan, School of Public Health. The authors wish to acknowledge the contribution from the dissertation committee members: Drs. Steve Eklund, MaryFran Sowers, and Xihong Lin in the School of Public Health, and Dr. Amid Ismail in the School of Dentistry.

References

1. Burt BA, Eklund SE. Dentistry, dental practice, and the community. 5th ed. Philadelphia: W. B. Saunders, 1999.
2. Clark N, Corbin S. The evolution of standards for naturally occurring fluorides: an example of scientific due process. Public Health Rep 1983;98:53-6.
3. Dean HT, Jay P, Arnold FA, Elvove E. Domestic water and dental caries. II. A study of 2,832 white children, aged 12 to 14 years, of eight suburban Chicago communities, including Lactobacillus acidophilus studies of 1,761 children. Public Health Rep 1941;56:761-92.
4. Dean HT, Arnold FA, Elvove E. Domestic water and dental caries. V. Additional studies of the relation of fluoride domestic waters to dental caries experience in 4,425 white children aged 12-14 years of 13 cities in 4 states. Public Health Rep 1942;57:1155-79.
5. Arnold FA. Role of fluorides in preventive dentistry. J Am Dent Assoc 1943;30: 499-508.
6. Galagan DJ, Lamson GG. Climate and endemic dental fluorosis. Public Health Rep 1953;68:497-508.
7. Galagan DJ, Vermillion JR, Nevitt GA, Stadt ZM, Dart RE. Climate and fluid intake. Public Health Rep 1957;72:484-90.
8. Galagan DJ, Vermillion JR. Determining optimum fluoride concentrations. Public Health Rep 1957;72:491-3.
9. US Public Health Services. Public Health Service drinking water standards. Washington, DC: Government Printing Office, 1962; PHS pub no 956.
10. Centers for Disease Control and Prevention. Fluoridation census, 1992. Atlanta, GA: US Department of Health and Human Services, US Public Health Service, Centers for Disease Control, Division of Oral Health, 1993.
11. Crosby ND, Shepherd PA. Studies on patterns of fluid intake, water balance and fluoride retention. Med J Austral 1957;44:305-11.
12. Ershow AG, Cantor KP. Total water and tapwater intake in the United States: Population-based estimates of quantities and sources. Bethesda, MD: National Cancer Institute, 1989.
13. McPhail CWB, Zacherl W. Fluid intake and climatic temperature: relation to fluoridation. J Can Dent Assoc 1965;31:7-16.
14. Walker JS, Margolis FJ, Teate HL, Weil ML, Wilson HL. Water intake of normal children. Science 1963;140:890-1.
15. National Center for Health Statistics. Third National Health and Nutrition Examination Survey, 1988-1994, NHANES III (CD-ROM Series 11, no 1A). Hyattsville, MD: Centers for Disease Control and Prevention, 1997.
16. National Center for Health Statistics. Third National Health and Nutrition Examination Survey, 1988-1994, NHANES III Second Laboratory Data File (CD-ROM Series 11, no 2A). Hyattsville, MD: Centers for Disease Control and Prevention, 1998.
17. National Center for Health Statistics. Plan and operation of the Third National Health and Nutrition Examination Survey, 1988-94. Vital Health Statistics 1(32). Hyattsville, MD: National Center for Health Statistics, 1994; DHHS pub no PHS 94-1308.
18. Blair FE. The weather almanac. 6th ed. Detroit: Gale Research Inc., 1992.
19. National Climatic Data Center. http://www.ncdc.noaa.gov/. Date accessed: October 23, 1998.
20. Richards LF, Westmoreland WW, Tashiro M, McKay CH, Morrison JT. Determining optimum fluoride levels for community water supplies in relation to temperature. J Am Dent Assoc 1967;74: 389-97.
21. SAS Institute Inc. SAS for personal computers. Version 6.12. Cary, NC: SAS Institute Inc, 1989.
22. Shah BV, Barnwell BG, Bieler GS. SUDAAN user's manual. Release 7.5. Research Triangle Park, NC: Research Triangle Institute, 1997.
23. Yetley EA, Beloian AM, Lewis CJ. Dietary methodologies for food and nutrition monitoring. In: Breifel RB, Sempos CT, eds. Dietary methodology workshop for the third National Health and Nutrition Examination Survey. Hyattsville, MD: National Center for Health Statistics, 1992. Vital Health Stat 4(27):58-67; DHHS pub no (PHS) 92-1464.
24. Margetts BM, Nelson M. Design concepts in nutritional epidemiology. 2nd ed. New York: Oxford University Press Inc., 1997.
25. Persson LA, Carlgren G. Measuring children's diets: evaluation of dietary assessment techniques in infancy and childhood. Int J Epidemiol 1984;13:506-17.
26. McClure FJ. Ingestion of fluoride and dental caries—quantitative relations based on food and water requirements of children 1 to 12 years old. Am J Dis Child 1943;66:362-9.
27. Kristal AR, Feng Z, Coates RJ, Oberman A, George V. Associations of race/ethnicity, education, and dietary intervention with the validity and reliability of a food frequency questionnaire. Am J Epidemiol 1997;146:856-69.
28. Butler WJ, Segreto V, Collins E. Prevalence of dental mottling in school-aged lifetime residents of 16 Texas communities. Am J Public Health 1985;75:1408-12.
29. Kumar JV, Swango PA, Lininger LL, Leske GS, Green EL, Haley VB. Change in dental fluorosis and dental caries in Newburgh and Kingston, New York. Am J Public Health 1998;88:1866-70.
30. Levy SM, Maurice TJ, Jakobsen JR. Feeding patterns, water sources and fluoride exposures of infants and 1-year-olds. J Am Dent Assoc 1993;124:65-9.
31. Levy SM, Kohout FJ, Guha-Chowdhury N, Kiritsy MC, Heilman JR, Wefel JS. Infants' fluoride intake from drinking water alone, and from water added to formula, beverages, and food. J Dent Res 1995; 74:1399-407.
32. US Public Health Service, National Institute of Dental Research. Oral health of United States children. National Survey of Dental Caries in US Schoolchildren: 1986-87. National and regional findings. Washington, DC: Government Printing Office, 1989; NIH pub no 89-2247.
33. Heller KE. Risk factors for dental fluorosis prevalence and severity in US schoolchildren, 1986-1987 [dissertation]. Ann Arbor, MI: University of Michigan, 1996.