EPA-600/1-78-037c
July 1978

HUMAN SCALP HAIR: AN ENVIRONMENTAL EXPOSURE INDEX FOR TRACE ELEMENTS

III. Seventeen Trace Elements in Birmingham, Alabama and Charlotte, North Carolina (1972)

by

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FOREWORD

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The Health Effects Research Laboratory, Research Triangle Park, conducts a coordinated environmental health research program in toxicology, epidemiology, and clinical studies using human volunteer subjects. These studies address problems in air pollution, non-ionizing radiation, environmental carcinogenesis and the toxicology of pesticides as well as other chemical pollutants. The Laboratory participates in the development and revision of air quality criteria documents on pollutants for which national ambient air quality standards exist or are proposed, provides the data for registration of new pesticides or proposed suspension of those already in use, conducts research on hazardous and toxic materials, and is primarily responsible for providing the health basis for non-ionizing radiation standards. Direct support to the regulatory function of the Agency is provided in the form of expert testimony and preparation of affidavits as well as expert advice to the Administrator to assure the adequacy of health care and surveillance of persons having suffered imminent and substantial endangerment of their health.

These data are provided for those researchers interested in developing a reliable and easily collected index of environmental exposure to certain trace elements, and as well, the data shed light on the influences of personal covariates on the trace element content of hair. These data are timely with regard to the current concerns regarding low-level environmental exposure to trace elements and their uptake by exposed populations.

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ABSTRACT

Seventeen trace elements - arsenic (As), barium (Ba), boron (B), cadmium (Cd), chromium (Cr), copper (Cu), Iron (Fe), lead (Pb), lithium (Li), manganese (Mn), mercury (Hg), nickel (Ni), selenium (Se), silver (Ag), tin (Sn), vanadium (V), and Zinc (Zn) - were measured in human scalp hair in two southeastern United States communities - Birmingham, Alabama and Charlotte, North Carolina. Of the seven for which dustfall trace element measurements were available (lead, nickel, cadmium, copper, zinc, chromium, and manganese) lead showed a significant positive relationship with male and female children's scalp hair levels, while copper was significantly related to female children's and male adults' scalp hair concentrations, and cadmium levels were significantly related to scalp hair levels in male adults. These results support conclusions of previous studies concerning lead. Relationships involving copper and cadmium were not indicated in previous studies, while the results for the other 4 trace elements are in agreement with previous 2 studies. Only 4 out of 60 tests of significance were significant when housedust was used as an environmental exposure index for 15 trace elements. This result is about what one would expect by chance if no differences actually existed. Therefore it appears that housedust is not an effective index of exposure when scalp hair levels are used as indicators of body burdens of trace elements. Several personal covariates were assessed for influences on scalp hair trace element levels for male and female children and adults. These covariates are evaluated as potential confounding factors in future use of hair as an environmental index.

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SECTION 1

INTRODUCTION

This study is the third in a series of collections of scalp hair from CHESS[1] communities across the United States (1,2). These and other studies have shown that human scalp hair can reflect increased environmental exposure to many trace elements (3-8). The earlier studies have also demonstrated that scalp hair is an excellent test object for population sampling, is painlessly removed, is normally discarded, and is easily collected and conveniently stored.

The purpose of this study is to replicate and extend findings in the two earlier CHESS studies of relationships between environmental exposure and trace element content of hair. Relationships indicated in the prior two studies between values for some trace elements in scalp hair and personal covariates such as age, sex, smoking habits, socioeconomic level, and personal grooming and hygiene are also re-examined here.

A better knowledge of the effects of these personal covariates on trace element content of scalp hair will permit a more accurate assessment of the quantitative relationships between this tissue and environmental exposure.

Dustfall has been used as an index of environmental exposure to trace substances (9,10). More intimate indices to trace substance exposure - such as household dust, soil and water from CHESS participant homes - have already been considered (11,12). Dustfall and housedust are again examined as to their common reflection of environmental exposure to trace elements.

[1]CHESS stands for Community Health and Environmental Surveillance System.

The following 17 trace elements are dealt with in this report: arsenic (As), barium (Ba), boron (B), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), lithium (Li), manganese (Mn), mercury (Hg), nickel (Ni), selenium (Se), silver (Ag), tin (Sn), vanadium (V), and zinc (Zn). All 17 trace elements were measured in the housedust samples, while only 7 (Cd, Cr, Cu, Pb, Mn, Ni, Zn) were measured in dustfall. Eighteen elements were measured in scalp hair, but so many of the values for Cobalt (Co) were below minimum detectable (70%) that this element could be given only cursory attention.

The specific hypotheses to be tested are:

1. There are significant relationships between concentrations of trace elements in dustfall and in housedust.

2. Environmental exposure, as measured by the above two media, is significantly related to the concentrations of selected trace elements in scalp hair.

3. There are significant variations in the concentrations of trace elements in scalp hair that can be attributed to personal covariates such as race, sex, age, hair length, hair grooming habits, hair cosmetic treatments, smoking habits, and socioeconomic status.

In addition to the above specific hypothesis, the distributional characteristics of each scalp hair trace element, including baseline levels, ranges, and distribution skewness, are also examined.

SECTION 2

METHODS

Environmental Monitoring

Two southeastern United States CHESS communities were selected for community-wide sampling of scalp hair - Charlotte, North Carolina and Birmingham, Alabama. Within each of these communities, three areas of study were selected such that a general environmental pollution gradient was believed to exist across them. Atmospheric studies including dustfall measurements were made at CHESS air monitoring sites within each of the areas in conjunction with other ongoing CHESS studies (13). The locations of these sites were such that the population of each area of interest was within 2.5 kilometers (km) of its monitoring site.

Data on dustfall was obtained monthly over 30 months (February 1970 through July 1972) in Charlotte and 33 months (January 1970 through September 1972) in Birmingham at the central site or sites within each area. Standard procedures of collection were followed (14). Housedust samples were obtained from 44 households in one area of Birmingham and 106 total households in three areas of Charlotte by collecting the contents of vacuum cleaner dust bags from selected houses.

Scalp Hair and Covariate Information

In the spring of 1972, letters describing the proposed trace element study were sent to all families actively participating in a CHESS Acute Respiratory Disease Study (ARD) in the two communities. These letters included for each family member a return-addressed postpaid envelope, with the individual member identification label affixed to the back, and instructions for collecting the hair sample. Almost all hair samples were obtained in June and July of 1972.

In the instructions it was stressed that the hair should be from the next normal haircut or trim, and that as much hair as possible should be collected. It was also stressed that there was no special need to wash or shampoo the hair before the haircut or trim, because it would be washed in the laboratory before analysis. Polyethylene bags for hair samples were sent with the letters and had an identification label on the back, with each person's first name, family name, and a space for the date of the haircut. In addition, information as to frequency of haircut, place of haircut, use and type of hair coloring preparation (dye, tint, or shampoo), natural hair color, frequency of shampoo, and hair length was obtained during a regular ARD study telephone interview. All of this information was then combined with the CHESS ARD background information questionnaire obtained at the start of the ARD study to make a complete covariate information file on each contributing family member.

Chemical Analysis

Dustfall samples were acid extracted and the metals determined by atomic absorption spectrophotometry (14). Housedust samples were sieved through a 0.5-mm screen for 5 minutes at 260 oscillations per minute on a mechanical shaker and extracted with nitric acid (6 mol/liter) at 50° C in a muffle furnace. Hair specimens were washed with a detergent solution, rinsed, and dried according to the procedure of Harrison *et al.* (15). The sample was prepared for analysis by combustion in oxygen for some elements and by dry ashing for others, as indicated in Table 1. The dry ashing procedure consisted of wetting the hair with quartzdistilled sulfuric acid and heating at 550° C in a muffle furnace. To prevent any losses when volatile elements were to be analyzed, weighed portions of the washed and dried hair were prepared by the Schöniger flask technique (16).

Table 1 also shows the analytical methods used for each element. Standard laboratory quality-control procedures were used. In addition, recoveries of all 17 elements added to a housedust sample and to a hair sample were evaluated by using additions that were either twice the detection limit or twice the endogenous level, whichever was larger. Recovery rates exceeded 85% in all cases and were greater than 95% in most cases.

Statistical Analysis

Before statistical analysis of the data for hair, the values were edited for outliers, values so far removed from the main body of readings as to warrant their removal from the population for statistical analysis purposes.

A statistical procedure was developed for this process, so that the editing was completely objective. In this procedure the inherent population variability, as measured by the standard deviation of the logarithms of the values, was estimated from the central section of the sample. Limits were then set at three standard deviations from the mean of the logs. Histograms of the data were carefully examined to ensure the effectiveness of this procedure, and to verify that a large number of seemingly valid observations were not being eliminated. The percent rejected ranged from 0.6% for Cd to 8.7% for Se. Logarithms of the concentration values were used to normalize the data and to make significance tests valid. Standard statistical techniques of correlation and multiple linear regression were then used to discover the effects and interrelationships of all of the measured variables.

SECTION 3

RESULTS

Study Population Characteristics

Contact was made with 1,683 families totaling 8,731 individual members for participation in this study through the existing CHESS sampling network, and 313 families with a total of 651 members were selected at random from the sub-population of families who responded to the hair study letter and contributed hair. Family members who gave no hair, who gave an insufficient quantity of hair, or who gave no covariate information were excluded. The resultant population consisted of 635 individual subjects with fairly complete information. The distribution of subjects by age, sex, and city of residence is shown in Table 2. The study population is seen to consist of two distinct age groups. This is a result of the method of contact in the ARD study, wherein only families having children in elementary schools were selected. This population division presents no difficulty, however, since subsequent analyses are made on children and adult populations separately.

The distributions of parents with respect to smoking habits (Table 3) reveals that a slight shift in smoking patterns occurred in moving from the original population to the sub-population of families donating hair samples. There appears to be more non- and ex-smokers and fewer smokers in the final population. The smoking patterns varied significantly between the two cities, with Charlotte having more smokers and ex-smokers than Birmingham. Charlotte was found to have more families with a high school or greater educational attainment by the head of household. The education level varied greatly across areas within each city as well.

Reported hair color by sex for children (15 years of age and less) and adults (over 15 years of age) showed significant differences in hair color distribution between adult males and females, but not between male and female children (Table 4). The adult males showed a higher percentage of black hair, while adult females had a higher percentage of subjects with brown and red hair. These differences might be explained by looking at hair preparation usage in adults (Table 5). There are many more females reported as using a dye, tint, or hair coloring shampoo than there are males. There were no children reported as using a hair coloring preparation. As expected, males were found to have more frequent haircuts than females in both the children and adult groups.

A significant difference in shampoo frequency between males and females was found only in the adults (Table 6). Males and females displayed different patterns of hair length for both children and adults (Table 7). The females had much greater frequency of shoulder length hair and longer. This was especially true of the children.

No relationship was found between hair length and frequency of shampoo in adults, but a significant interaction between these variables was found in both the male and female children (Table 8). For both sexes, there was a significant shift towards reduced frequency of shampooing as hair length increased.

<u>Scalp Hair Trace Element Characteristics</u>

The trace elements in this study all have a log-normal type of distribution typical of trace elements in hair (17,18). Analytical hair values obtained are shown in Table 9. They generally agree with published values.

The inter-relationships of scalp hair trace metal levels were examined separately for children (15 years of age or less) and adults (over 15 years of age), since children are in a rapidly developing stage of growth in contrast to adults, who have reached a leveling off in growth and development. In addition, the use of hair coloring preparations by adults could possibly affect trace element levels. Some adults also are likely to have been exposed to some work-related sources of trace elements, and hence may display a good degree more variability from person to person in scalp hair trace element burden.

It was found that children have significantly higher mean scalp hair levels than adults for Pb, Cd, Fe, Cr, Ag, V and Mn while Ba, B, Ni, and Sn were significantly higher in the adults (Table 10).

Pairwise correlation coefficients were computed separately for the adult and children groupings using the logs of scalp hair trace elements. There were 77 significant correlations for adults and 101 for the children out of the 120 correlation coefficients (Table 11). (Arsenic was not included in the correlation matrix because of the large number of censored values.) Selenium was the only element to show consistently significant negative correlations to the other elements. This result for Se is in close agreement with the New York and New Jersey studies (1,2).

Pollution Media Trace Element Characteristics

Arithmetic means of dustfall trace element concentrations for Pb, Cd, Cu, Zn, Cr, Ni and Mn by community, and arithmetic and geometric means for 15 trace elements in housedust from a total of 150 homes selected from three areas of Charlotte and one of Birmingham are given in Tables 12 and 13, respectively.

Of the 7 elements measured in dustfall, all except Cu and Ni showed significant differences in trace element levels among the six areas. Of the 15 elements examined in housedust (Pb, Cd, Cu, Zn, Li, Se, Fe, Ba, B, Cr, Ni, Ag, V, Sn, and Mn), all except Li, Se, Ba, V, and Sn showed significant differences in trace element levels between the four areas in which they were measured.

Tables 12 and 13 demonstrate the gradients across areas as well as the similarities and differences in trace element patterns in these two media. Cadmium, Cr, and Ni generally have much lower concentrations than Cu, Pb, Mn, and Zn in both dustfall and housedust in all areas where measurements are available. This is in exact agreement with the two earlier CHESS hair studies.

In order to assess more precisely the inter-relationships of housedust and dustfall, correlations of the respective trace elements across these two media were computed. Logs of the concentrations were used in this computation to normalize the data and make significance tests valid. Of the seven elements measured in both media, three showed significant positive correlations - Zn, Cu, and Mn. This is in contrast to the New York study, where all 7 elements were found to be significantly correlated.

Hair Trace Element Concentrations in Relation to Hair-Related Covariates

The possible influences of hair color, hair length, frequency of haircut, and frequency of shampoo were assessed separately for children ($<$ 16 years old) and adults ($\geq$ 16 years old). In the adult groups, "hair preparation usage" is included as one hair color category for analysis purposes. The covariates usually have quite different distributional patterns between sexes. A separate analysis of each covariate was carried out for each sex-age group category in order to avoid the confounding of covariate effects with sex differences. The results of the linear model analysis of each covariate are presented in one table for each sex-age group in order to allow camparisons of significant factors for each trace element (Tables 14-15).

For the children, shampoo frequency and hair color are significant repeatedly for both males and females. Haircut frequency and hair length are also significant many times in both sexes, with haircut frequency predominating in males and hair length predominating in females. This may be a result of the males having much less variability in hair length, while the females have much less variability in frequency of haircut. Hence, some common factor, such as "age" of hair sampled, is probably being reflected in different ways in each of these groups. In subsequent analyses, therefore, shampoo frequency and hair color will be included as covariates for both sexes in children, with haircut frequency also included for males and hair length for females.

There were fewer significant hair covariates in the adult groups, but the pattern was maintained in each sex with regard to haircut frequency and hair length. Shampoo frequency was only significant for adult males in Pb and Mn, while hair color was significant for several elements in each sex. Hence, in subsequent analyses, hair color will be included as a covariate in both adult groups, with haircut frequency included for males and hair length for females.

Hair Trace Element Concentrations in Relation to Environmental Exposure and Personal Covariates

For each age group, a linear multiple regression analysis is used to examine the relation of environmental exposure (as measured by dustfall or housedust trace element content) to hair trace element content for the seven elements measured in dustfall and for all the elements measured in housedust. The linear models for each age group include age, sex, socioeconomic level (as measured by education of head of household), hair length (in females), haircut frequency (in males), shampoo frequency (in children only), and smoking patterns (in adults only) as covariates, along with environmental trace element levels. The logs of both the scalp hair and environmental trace element levels are used in the analyses to make the scalp hair values more closely fit a normal distribution and to help insure the fit of a linear model to the data. The results of the statistical tests when monthly average trace element dustfall rates are used are given in Tables 16 and 17.

Dustfall trace elements are significantly related to hair levels of Pb in children of both sexes and to hair levels of Cu for female children. In the adults, Cd and Cu levels show significant relationships to dustfall levels in male adults, while hair trace element levels in females show no significant relationships to dustfall levels. All of these significant relationships indicated increasing levels of scalp hair trace elements with increasing dustfall trace element levels. The Pb results for children are in exact agreement with the two earlier scalp hair studies. Relationships of adult scalp hair trace element levels to dustfall levels were found to be consistent with the previous studies, in that no relationships have been found that are significant in more than one of the three studies carried out.

In examining the results of the analyses of housedust, one is led to conclude that this index of environmental exposure to trace elements is nonproductive when scalp hair is considered as a measure of body burden. Although four housedust trace elements show a significant relationship (Cu and Ag in male children, Ba in female children and male adults) to scalp hair levels, it is quite possible that even these relationships are spurious. Since 60 different tests of significance were carried out (15 trace elements x 4 groups), one would expect about three significant results by chance alone (60 x 0.05 = 3.).

In examining the age factor and its relationship to scalp hair trace element levels, one again finds only four significant results, a result quite close to what one would expect by chance alone. Since in the previous studies significant trends were indicated for a number of trace elements, with these positive trends being concentrated in females, the results of the present study are in conflict with earlier results. There are of course several possible explanations for this discrepancy - lower levels of exposure, smaller age gradients, or even spurious results in earlier studies. Only with future studies will we discover the true nature of these relationships.

SECTION 4

SUMMARY AND DISCUSSION

Earlier studies in this series of reports have indicated that hair trace element content can reflect exposure trends within a metropolitan area when there are substantial environmental gradients between communities (1,2). This report supports those study findings of significant effects on Pb concentrations in children's scalp hair, using dustfall trace element concentrations as an environmental index. Two other trace elements (Cd in adult males and Cu in adult males and child females) showed significant relationships where none had been indicated in previous studies. The other four trace elements (Cr, Mn, Ni and Zn) showed no significant relationships, a result in agreement with the previous studies.

The use of housedust as an index of environmental exposure to trace elements was found to be ineffective in this study, when evaluated on the criteria of its relationship to scalp hair trace element levels. Only four trace elements (Cu and Ag in male children, Ba in female children, and Ba in male adults) showed a significant relationship, whereas by chance alone one would expect three significant findings in this number of tests of significance.

Several hair related covariates were found to influence trace element concentrations in scalp hair. The important covariates in children were hair color and shampoo frequency, with haircut frequency also important in male children and hair length important in female children. For the adults, hair color was significant only occasionally, while haircut frequency was again important in male adults and hair length was important in female adults. Shampoo frequency was not found to be relevant in determining the scalp hair trace element levels in adults. Discussions of the relationship of all these covariates to scalp hair trace element levels may be found in the earlier reports from this series (1,2). The results of this study support those well-defined conclusions.

Age was not found to be as strong a factor in this study as it was in the earlier reports. However, a number of trace elements levels were found to increase with age, most notably Cd and Zn in both male and female children.

Smoking in adults and socioeconomic level in adults and children were not found to be strongly or consistently related to any scalp hair trace element concentrations.

The hair trace element intercorrelations show agreement with the two earlier reports. As in the two previous reports, hair Se (a nonmetal) showed a negative correlation with certain hair elements. The significant correlations in hair between Cd, Cu, and Pb have been found by other investigators (18-20) as well as in the two earlier studies.

The use of special shampoo containing Se increases hair Se content significantly (18). This may account for the high proportion of Se outliers (8.7%) found in this study as well as in the two earlier reports (1,2).

The relationship between trace element content of hair and (a) content in other tissues and (b) metabolic status are separate and complex issues, which should not be confused with the exposure relationships that are demonstrated here. Some evidence indicates that trace element content of hair can reflect whole body content (21-24) or content in specific tissues (5,21,23,25-31). When values for hair do not reflect values for tissues, hair may reflect the metabolic or health status (21,26,30-32) while the blood and other tissue values may not (11,21,30,32-38).

This report, when considered in the light of two others in this series (1,2), should provide a good picture of true and consistent relationships between scalp hair trace elements on the one hand and indices of exposure and personal determinants of concentrations on the other. A careful review of these three studies should be undertaken before any final and conclusive statements are made as to the utility of dustfall as a measure of exposure to particular trace elements. However, it appears fairly certain that housedust will not prove to be an adequate measure of exposure to trace elements in our environment. Of course, this conclusion is based on the assumption that scalp hair trace element levels are a reflection of body burden, an assumption that in itself may prove to be untenable for certain trace elements. Hopefully, future studies will clarify these intricate relationships further.

TABLE 1. SAMPLE PREPARATION AND ANALYTICAL METHODS+

Metals	Preparation	Analysis*
Cd,Pb	Oxygen combustion	AA aspiration
Cu,Mn,Zn,Fe	Oxygen combustion	AA aspiration
As,Hg,Se	Oxygen combustion	AA on vapor
Li	Oxygen combustion	Flame Photometry
Ag	Oxygen combustion	ES
Ba,B,Cr	Dry ashing	ES
Ni,V,Sn	Dry ashing	ES

* AA = atomic absorption
ES = emission spectroscopy

\+ Manganese in hair was evaluated from ES data when detection from AA was found to be inadequate.

TABLE 2. NUMBER OF PARTICIPANTS BY AGE, SEX, AND CITY OF RESIDENCE*

	Charlotte		Birmingham	
	Males	Females	Males	Females
1-5	20	16	6	2
6-10	98	55	28	13
11-15	45	24	17	8
16-20	9	8	2	3
21-25	0	2	0	1
26-30	4	12	3	5
31-35	25	48	4	9
36-40	15	23	12	9
41-45	28	22	7	9
46-50	9	6	4	1
51+	6	7	4	3
Totals	259	223	87	63

* Age was not reported for 19 subjects in Charlotte and 2 subjects in Birmingham.

TABLE 3. DEMOGRAPHIC CHARACTERISTICS OF ADULTS

Smoking Patterns of Parents (%)

	Original Population	Families Giving Hair	Parents Giving Hair
Never	37.9	40.2	40.2
ExSmoker	16.2	20.9	20.7
Current Smoker	45.9	38.9	39.1

Smoking Patterns of Parents Giving Hair by City of Residence (%)

	Charlotte	Birmingham
Never	34.4	53.7
ExSmoker	21.7	14.9
Current Smoker	39.9	31.4

Education of Head of Household by Area of Residence (%)

		<HS	HS	>HS
Charlotte	Area 1	0 (0.0)	8 (7.0)	107 (93.0)
	Area 2	43 (46.7)	31 (33.7)	18 (19.6)
	Area 3	6 (46.2)	6 (46.2)	1 (7.7)
Birmingham	Area 1	0 (0.0)	11 (28.2)	28 (7.18)
	Area 2	7 (21.9)	17 (53.1)	8 (25.0)
	Area 3	8 (80.0)	2 (20.0)	0 (0.0)
	Total	64 (21.3)	75 (24.9)	162 (53.8)

TABLE 4. HAIR COLOR BY AGE CATEGORY AND SEX

	Children			Adults*		
	Male	Female	Overall	Male	Female	Overall
Brown	108	58	166	77	121	198
Blond	68	46	114	14	16	30
Red	6	3	9	0	7	7
Black	30	10	40	25	12	37
Grey & White	1	1	2	16	12	28
Total	213	118	331	132	168	300

* Significant difference in hair color patterns between males and females in adults but not in children.

TABLE 5. HAIR PREPARATION USAGE IN ADULTS BY SEX*

	Male	Female	Overall
Yes	1	49	50
No or Unanswered	131	119	250

* There were no children reported as using a hair coloring preparation.

TABLE 6. FREQUENCY OF HAIRCUT AND HAIR SHAMPOO BY AGE CATEGORY AND SEX

Frequency of Haircut*

	Children			Adults		
	Male	Female	Overall	Male	Female	Overall
Every 2 weeks or less	42	2	44	67	1	68
Once a month	116	10	126	59	37	96
Every 3 months	49	16	65	5	72	77
Every 6 months or longer	6	90	96	1	58	59

* Significant differences between males and females for both adults and children.

Frequency of Hair Shampoo+

	Children			Adults		
	Male	Female	Overall	Male	Female	Overall
Every 1-2 days	101	41	142	86	40	126
Once a week	103	70	173	43	120	163
Less than once a week	9	7	16	3	8	11

+ Significant differences between male and female hair shampoo frequency in adults but not in children.

TABLE 7. LENGTH OF HAIR BY AGE CATEGORY AND SEX*

	Children			Adults		
	Male	Female	Overall	Male	Female	Overall
Short	105	9	114	100	72	172
Medium	101	19	120	30	49	79
Shoulder	6	19	25	1	22	23
Longer	1	71	72	0	25	25
Total	213	118	331	131	168	299

* Significant differences by sex for both adults and children.

TABLE 8. LENGTH OF HAIR BY FREQUENCY OF SHAMPOO FOR CHILDREN*

		Males		
	Frequency:	1-2 days	Weekly	Less than once a week
Length:	Short	62	40	3
	Medium	36	59	6
	Shoulder	3	3	0
	Longer	0	1	0
		Females		
	Short	2	5	2
	Medium	8	10	1
	Shoulder	8	8	3
	Longer	23	47	1

* Significant interaction for both male and female children, but no differences found in adult patterns.

TABLE 9. TRACE ELEMENT LEVELS IN HUMAN SCALP HAIR FOR ALL RESPONDENTS*

	No. of Obs.	Arith. Mean	Geo. Mean	Min.	Max.	± 1 geo. std. dev. Lower	Upper
Arsenic+	628	.10	.04	.003	3.14	.01	.18
Barium	600	2.91	1.63	.06	19.00	.55	4.81
Boron	601	.94	.57	.02	13.00	.20	1.58
Cadmium	631	1.21	.84	.08	9.24	.37	1.92
Chromium	597	1.71	1.06	.07	18.00	.41	2.71
Copper	616	17.01	10.82	1.00	162.00	4.13	28.30
Iron	622	47.90	36.56	4.40	310.00	17.96	74.42
Lead	628	12.47	8.91	1.23	87.80	4.07	19.48
Lithium	629	.07	.05	.005	.36	.02	.11
Manganese	600	1.16	.87	.13	7.00	.41	1.82
Mercury+	621	.47	.26	.03	7.51	.10	.73
Nickel	605	1.72	1.03	.08	16.00	.39	2.72
Selenium	576	.57	.45	.05	3.01	.23	.88
Silver	602	.28	.13	.003	3.20	.04	.48
Tin	603	1.66	1.02	.10	13.00	.40	2.60
Vanadium	604	.36	.24	.013	2.90	.09	.62
Zinc	617	113.48	93.13	10.90	505.00	46.62	186.02

* All concentrations are in μg/g of hair.

+ About 16% of the As and 6% of the Hg values were below detectable limits. In those cases, the minimum detectable value for that sample was used in the above calculations.

TABLE 10. TRACE ELEMENT LEVELS IN HUMAN SCALP HAIR IN CHILDREN* AND ADULTS*

Children	No. of Obs.	Arith. Mean	Geo. Mean	Min.	Max.	± 1 geo.std. dev. Lower	Upper
Arsenic	323	0.12	0.05	0.003	1.25	0.01	0.22
Barium⁻	311	2.42	1.42	0.06	19.00	0.51	3.97
Boron⁻	310	0.82	0.51	0.04	7.70	0.19	1.36
Cadmium+	326	1.50	1.11	0.10	9.24	0.52	2.37
Chromium+	304	1.78	1.14	0.09	18.00	0.46	2.81
Copper	314	18.25	11.35	1.00	162.00	4.24	30.36
Iron+	322	52.58	40.65	4.40	276.00	20.16	81.96
Lead+	325	13.94	10.21	1.33	87.80	4.77	21.88
Lithium	322	0.07	0.05	0.01	0.36	0.02	0.12
Manganese+	310	1.29	0.96	0.13	7.00	0.45	2.04
Mercury	322	0.46	0.27	0.03	5.44	0.10	0.71
Nickel-	311	1.53	0.92	0.08	16.00	0.36	2.37
Selenium-	298	0.59	0.45	0.05	3.01	0.22	0.93
Silver+	308	0.37	0.20	0.003	3.20	0.06	0.64
Tin	311	1.22	0.84	0.11	12.00	0.38	1.89
Vanadium+	310	0.38	0.28	0.02	2.20	0.12	0.63
Zinc	316	110.84	90.25	10.90	357.00	44.69	182.27
Adults							
Arsenic	288	0.09	0.03	0.003	3.140	0.01	0.14
Barium	273	3.41	1.86	0.18	19.00	0.61	5.69
Boron	275	1.09	0.96	0.02	15.00	0.36	2.57
Cadmium	289	0.87	0.61	0.08	8.35	0.28	1.34
Chromium	277	1.62	0.96	0.07	15.00	0.36	2.57
Copper	285	16.02	10.47	1.00	113.00	4.10	26.78
Iron	283	41.57	31.77	5.04	310.00	15.89	63.52
Lead	286	10.52	7.50	1.23	78.20	3.49	16.13
Lithium	291	0.07	0.05	0.01	0.36	0.02	0.11
Manganese	275	1.00	0.77	0.15	6.90	0.38	1.56
Mercury	282	0.47	0.25	0.03	7.51	0.09	0.74
Nickel	278	1.88	1.12	0.16	15.00	0.41	3.06
Selenium	263	0.55	0.46	0.10	2.92	0.25	0.83
Silver	279	0.18	0.09	0.004	2.10	0.02	0.29
Tin	276	2.15	1.25	0.10	13.00	0.45	3.50
Vanadium	278	0.34	0.20	0.01	2.90	0.07	0.57
Zinc	285	117.73	97.78	10.90	505.00	49.85	191.77

* Children defined as ages 0 through 15, adults as age greater than 15. All measurements are in μg/g.

\+ Geometric mean for children significantly higher than for adults (α=0.05).

\- Geometric mean for children significantly lower than for adults (α=0.05).

TABLE 11. A SIGNIFICANCE TABLE FOR HAIR ELEMENT/ELEMENT CORRELATIONS*

	Pb	Cd	Cu	Zn	Hg	Li	Se	Fe	Ba	B	Cr	Ni	Ag	V	Sn	Mn
Pb		+	+	+	+	+	+	+	+		+	+	+	+	+	+
Cd	+		+	+	+	+		+	+		+	+	+	+	+	+
Cu	+	+		+	+	+		+	+		+	+	+	+	+	+
Zn	+	+	+		+	+		+	+		+	+		+	+	+
Hg		+	+	+		+		+	+	+	+	+	+	+	+	+
Li	+	+	+	+	+	+		+	+		+	+	+	+	+	+
Se						+			-		-				-	
Fe	+	+				+			+	+	+	+	+	+	+	+
Ba							-	+		+	+	+	+	+	+	+
B								+	+		+	+		+	+	+
Cr	+	+	+	+		+	-	+	+	+		+	+	+	+	+
Ni			+		+	+	-	+	+	+	+		+	+	+	+
Ag	+	+				+		+			+	+		+	+	+
V	+	+				+		+	+	+	+	+	+		+	+
Sn	+	+				+		+	+	+	+	+	+	+		+
Mn	+	+	+	+		+		+	+	+	+	+	+	+	+	

* A + indicates a significant positive relationship while a - indicates a significant negative relationship at $\alpha=0.05$.

TABLE 12. MEAN DUSTFALL TRACE ELEMENT LEVELS BY COMMUNITY AREA*

	Charlotte			Birmingham		
	Area 1	Area 2	Area 3	Area 1	Area 2	Area 3
Cd+	0.055	0.079	0.141	0.073	0.110	0.182
Cr+	0.103	0.146	0.135	0.492	0.311	0.371
Cu	1.552	1.987	2.273	2.286	4.049	3.718
Pb+	2.475	5.847	4.196	3.732	5.747	9.453
Mn+	0.586	1.904	1.009	12.263	6.820	6.924
Ni	0.066	0.209	0.150	0.308	0.314	0.346
Zn+	4.998	7.480	5.367	27.476	24.118	31.710

* Concentrations in $mg/m^2/month$

+ Significant differences between areas at $\alpha = 0.05$.

TABLE 13. ARITHMETIC AND GEOMETRIC MEAN HOUSEDUST TRACE ELEMENT LEVELS BY COMMUNITY AREA*

	(a) Arithmetic Means					(b) Geometric Means			
	Charlotte			Birmingham		Charlotte			Birmingham
	Area 1	Area 2	Area 3	Area 1		Area 1	Area 2	Area 3	Area 1
Ba	220.736	184.129	186.091	200.432	Ba	196.763	169.864	151.866	179.289
B	68.491	28.806	34.636	67.250	B+	40.895	14.835	21.179	42.991
Cd	23.541	26.352	16.325	19.372	Cd+	20.308	21.715	12.256	18.653
Cr	69.811	54.387	54.182	107.364	Cr+	51.419	38.168	39.449	87.008
Cu	213.785	227.323	109.400	240.597	Cu+	167.001	165.836	83.513	197.947
Fe	15918.958	13008.667	15201.857	43935.897	Fe+	13147.672	12173.296	13279.808	36026.138
Pb	488.104	337.267	290.000	585.641	Pb+	359.603	309.823	249.136	414.884
Li	4.386	4.479	4.459	5.044	Li	4.047	4.043	3.728	4.721
Mn	240.542	280.800	539.786	651.308	Mn+	223.855	255.699	480.103	614.003
Ni	70.698	45.871	221.682	84.023	Ni+	46.993	31.031	42.606	62.615
Se	0.285	0.316	0.212	0.261	Se	0.249	0.239	0.134	0.238
Ag	1.425	0.426	0.605	1.157	Ag+	0.394	0.180	0.245	0.296
Sn	163.189	8.774	19.409	18.364	Sn	9.641	4.740	8.314	8.855
V	56.170	37.548	35.045	39.591	V	39.173	31.281	30.569	34.022
Zn	1637.667	1069.633	1282.500	1943.154	Zn+	1376.088	957.188	962.949	1702.750

* Concentrations in μg/g housedust.

+ Area differences significant at $\alpha = 0.05$.

TABLE 14. TESTS OF SIGNIFICANCE OF THE EFFECT OF HAIR-RELATED FACTORS ON CHILDREN'S SCALP HAIR TRACE ELEMENT LEVELS*

	Males				Females			
	Shampoo Frequency	Haircut Frequency	Hair Length	Hair Color	Shampoo Frequency	Haircut Frequency	Hair Length	Hair Color
B	-	-	-	-	.04	-	-	-
Ba	-	-	.01	-	.003	.03	.04	-
Cd	.002	-	-	.003	-	.02	.02	-
Cr	-	.04	-	-	-	.003	-	-
Cu	-	.05	-	-	.04	-	.04	-
Fe	-	.01	-	.01	-	-	-	.006
Li	.03	.0001	.02	-	-	-	-	.03
Hg	-	-	-	-	-	-	.04	-
Pb	.004	.05	-	.0001	-	-	-	-
Mn	.01	.01	-	.0001	.02	.01	.002	-
Ni	-	.01	-	-	-	.001	.003	-
Se	.02	.04	-	.05	-	-	-	-
Ag	-	-	-	.0002	-	-	.02	.002
Sn	-	-	-	-	.05	-	.003	-
V	-	-	-	.003	-	.01	.005	-
Zn	.04	.03	-	-	-	-	-	.05

* Values given are the probability of the observed difference in sample mean levels between factor categories assuming no difference in the original population. Only values of .05 or less are listed.

TABLE 15. TESTS OF SIGNIFICANCE OF THE EFFECT OF HAIR-RELATED FACTORS ON ADULT'S SCALP HAIR TRACE ELEMENT LEVELS*

	Males				Females			
	Shampoo Frequency	Haircut Frequency	Hair Length	Hair Color	Shampoo Frequency	Haircut Frequency	Hair Length	Hair Color
B	-	-	-	.03	-	-	-	-
Ba	-	.02	-	-	-	-	-	.01
Cd	-	-	-	-	-	-	.002	-
Cr	-	-	-	-	-	-	-	-
Cu	-	-	-	-	-	-	-	-
Fe	-	-	-	-	-	-	-	.002
Li	-	-	-	-	-	-	-	-
Hg	-	-	-	.05	-	.05	.005	-
Pb	.02	-	-	-	-	.02	.006	-
Mn	.05	.007	-	-	-	-	.02	-
Ni	-	.008	-	.001	-	-	.01	-
Se	-	.03	.004	.03	-	-	-	-
Ag	-	-	-	-	-	-	.007	-
Sn	-	-	-	-	-	-	.001	.001
V	-	-	-	-	-	.04	.01	-
Zn	-	-	.01	-	-	-	-	-

* Values given are the probability of the observed difference in sample mean levels between factor categories assuming no difference in the original population. Only values of .05 or less are listed.

TABLE 16. TESTS OF SIGNIFICANCE OF THE EFFECT OF SELECTED FACTORS ON SCALP HAIR TRACE ELEMENT LEVELS, USING DUSTFALL AS A MEASURE OF ENVIRONMENTAL EXPOSURE

(a) Children

	Males						Females					
	Dustfall	Age	Education	Hair Color	Shampoo Frequency	Haircut Frequency	Dustfall	Age	Education	Hair Color	Shampoo Frequency	Hair Length
Cd	-	.05	-	-	.03	-	-	.02	-	-	-	.009
Cr	-	.004	-	-	-	-	-	-	-	-	-	-
Cu	-	-	.01	-	-	-	.02	-	-	-	-	-
Pb	.02	-	-	.005	.008	-	.04	.04	-	-	-	-
Mn	-	-	-	<.001	-	-	-	-	.03	-	-	.003
Ni	-	-	-	-	-	-	-	-	-	.03	-	-
Zn	-	.03	.02	-	-	-	-	.01	.05	-	-	-

(b) Adults

	Males						Females					
	Dustfall	Age	Smoking	Education	Hair Color	Haircut Frequency	Dustfall	Age	Smoking	Education	Hair Color	Hair Length
Cd	.02	-	-	-	-	-	-	-	-	-	-	.008
Cr	-	-	.04	-	.02	-	-	-	-	-	-	-
Cu	.001	-	-	-	-	-	-	-	-	-	-	-
Pb	-	-	-	-	-	-	-	-	-	-	-	.02
Mn	-	-	-	-	-	.05	-	-	-	-	-	.04
Ni	-	-	-	-	-	-	-	-	-	-	-	-
Zn	-	.01	-	-	-	-	-	-	-	-	-	.05

TABLE 17. TESTS OF SIGNIFICANCE OF THE EFFECTS OF SELECTED FACTORS ON SCALP HAIR TRACE ELEMENT LEVELS, USING HOUSEDUST AS A MEASURE OF ENVIRONMENTAL EXPOSURE

(a) Children

			Males				Females		
	Housedust	Age	Education	Shampoo Frequency	Haircut Frequency	Housedust	Age	Education	Hair Length
Ba	-	.001	-	-	-	.04	-	.05	-
B	-	-	-	-	-	-	-	.005	-
Cd	-	.04	.04	-	-	-	-	-	-
Cr	-	-	-	.03	-	-	.05	-	-
Cu	.03	-	-	.02	-	-	-	.05	.05
Fe	-	-	-	-	.03	-	-	-	.05
Pb	-	-	-	-	.05	-	-	-	-
Li	-	-	-	-	-	-	-	-	-
Mn	-	-	.05	-	-	-	-	-	-
Ni	-	-	-	-	-	-	-	-	-
Se	-	-	-	-	-	-	-	-	-
Ag	.004	-	-	-	.05	-	-	.002	-
Sn	-	-	-	-	-	-	-	-	-
V	-	-	-	-	.02	-	-	-	-
Zn	-	-	-	-	-	-	-	.02	-

TABLE 17. (CONTINUED)

	(b) Adults											
	Males						Females					
	Housedust	Age	Smoking	Education	Hair Color	Haircut Frequency	Housedust	Age	Smoking	Education	Hair Color	Hair Length
Ba	<.001	-	-	-	-	-	-	-	-	-	-	.04
B	-	-	-	-	-	-	-	-	-	-	-	-
Cd	-	-	-	-	-	-	-	-	-	-	-	.01
Cr	-	-	-	-	-	-	-	-	-	-	-	-
Cu	-	-	-	-	-	-	-	-	-	-	-	.001
Fe	-	-	-	-	-	-	-	-	-	-	.02	.002
Pb	-	-	-	-	-	-	-	-	-	-	-	-
Li	-	-	-	-	-	-	-	-	-	-	-	-
Mn	-	-	-	-	-	-	-	-	-	-	-	-
Ni	-	-	-	-	.02	-	-	-	-	-	.03	-
Se	-	-	-	-	-	-	-	-	-	-	-	-
Ag	-	.01	-	-	-	-	-	-	-	-	-	-
Sn	-	-	-	-	-	-	-	-	-	-	-	.009
V	-	-	-	-	-	-	-	-	-	-	-	-
Zn	-	-	-	-	-	-	-	-	-	-	-	-

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TECHNICAL REPORT DATA

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1. REPORT NO. EPA-600/1-78-037c	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE HUMAN SCALP HAIR: AN ENVIRONMENTAL EXPOSURE INDEX FOR TRACE ELEMENTS. III. Seventeen Trace Elements in Birmingham, Alabama and Charlotte, North Carolina (1972)		5. REPORT DATE July 1978 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) John P. Creason, Thomas A. Hinners and Joseph E. Bumgarner		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Health Effects Research Laboratory and Environmental Monitoring and Support Laboratory Office of Research and Development Research Triangle Park, N.C. 27711		10. PROGRAM ELEMENT NO. 1AA601 11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Health Effects Research Laboratory RTP,NC Office of Research and Development U.S. Environmental Protection Agency Research Triangle Park, N.C. 27711		13. TYPE OF REPORT AND PERIOD COVERED 14. SPONSORING AGENCY CODE EPA 600/11

15. SUPPLEMENTARY NOTES

16. ABSTRACT

Seventeen trace elements - arsenic (As), barium (Ba), boron, (B), cadmium, (Cd), chromium (Cr), copper (Cu), Iron (Fe), lead (Pb), lithium (Li), manganese (Mn), mercury (Hg), nickle (Ni), selenium (Se), silver (Ag), tin (Sn), vanadium (V), and Zinc (Zn) - were measured in human scalp hair in two southeastern United States communities - Birmingham, Alabama and Charlotte, North Carolina. Of the seven for which dustfall trace element measurements were available (lead, nickle, cadmium, copper, zinc, chromium and manganese) lead showed a significant positive relationship with male and female children's scalp hair levels, while copper was significantly related to female childrens' and male adults' scalp hair concentrations, and cadmium levels were significantly related to scalp hair levels in male adults. Only four out of sixty tests of significance were significant when housedust was used as an environmental exposure index for fifteen trace elements. This result is about what one would expect by chance if no differences actually existed. Therefore it appears that housedust is not an effective index of exposure if in fact scalp hair levels are indicators of body burdens of trace elements. Several personal covariates were assessed for influences on scalp hair trace element levels for male and female children and adults. These covariates are evaluated as potential confounding factors in future use of hair as an environmental index.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
trace elements hair indexes (ratios) environmental surveys	Charlotte North Carlina Birmingham Alabama	06 T, F

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS *(This Report)* UNCLASSIFIED	21. NO. OF PAGES 44
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (9-73)