Lead and Mercury Levels in Emotionally Disturbed Children

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Abstract

The present study investigated possible relationships of metal levels to emotional disturbance in children. Hair metal concentrations of lead, arsenic, mercury, cadmium, and aluminum in emotionally disturbed children (N = 37) were compared to those hair metal levels in a control group (N = 107). Each child was also rated on the Walker Problem Behavior Identification Checklist (WPBIC). The group of disturbed children had significantly higher hair lead and hair mercury levels. Discriminant function analysis revealed that by using lead, mercury, arsenic, and aluminum, subjects could be correctly classified as disturbed or controls with 77.8 percent accuracy. Analyses revealed significant positive correlations between lead and the WPBIC scales measuring acting-out, withdrawal, distractibility, disturbed peer relations, and immaturity, and significant positive correlations between mercury and acting out, disturbed peer relations, and immaturity. It is concluded a continuing reexamination of metal poisoning concentrations is needed because levels of metal previously thought harmless may be associated with emotional disturbances in children.

Children exposed to toxic amounts of lead and other metal pollutants are subject to severe behavioral disorders resulting from damage to the central nervous system (Byers and Lord, 1943; Pfeiffer, 1977). It remains to be determined whether sub-toxic metal levels are an etiologic agent in behavioral disorders. Sub-toxic lead levels previously thought harmless are now being associated with hyperactivity, impulsiveness, and short attention span (David, Clark and Voeller, 1972; David, Hoffman, and Sverd, 1976; Wiener, 1970), negative ratings by teachers on classroom behavior (Needleman, Gunnoe, Levi-ton, Reed, Peresie, Mahler and Barret, 1979; Marlowe and Errera, 1982), school failure due to behavioral and learning problems (de

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la Burde and Choate, 1975), and mental disorders (Albert, Shore, Sayers, Strehlow, Kneip, Pasternack, Friedhoff, Covan, and Ciminio, 1974). Although only marginally examined, previous investigations have also linked subtoxic cadmium, mercury, and aluminum levels to measures of non-adaptive classroom behavior (Marlowe, Errera, Ballowe and Jacobs, 1983; Phil and Parkes, 1977).

This study had three major purposes. The first purpose was to investigate the relationship between metal levels and emotional disturbance in children without demonstrable cause for their emotional deficit. The second purpose was to determine which metals, if any, separated the disturbed children from a nondisturbed control group. In addition, from the subset of metals that significantly discriminated between the two groups, a determination of the relative importance of each metal to the discrimination between the groups was to be made. The third purpose was to explore relationships between metal levels and teachers' ratings of the children on a behavior problem checklist.

METHODS

Subjects

The 144 subjects in this study were randomly drawn from five elementary schools and a residential school for emotionally disturbed children in three rural counties situated in the southeastern region of Wyoming. In the six schools 37 emotionally disturbed children were randomly selected. All emotionally disturbed children were receiving special education services. Their diagnosis of emotional disturbance was based on an overall evaluation from a series of consultations by school psychologists, classroom teachers, and other appropriate specialists where indicated.

Presence or Absence of Probable Cause

All of the emotionally disturbed children's school records were reviewed to determine whether there was a known or highly probable medical reason for emotional disturbance, e.g., brain injury, metal poisoning. Any children with "probable cause" were to be removed from the study, but none of the children's records contained a probable cause. The 37 children with unremarkable medical histories for emotional disturbance were assigned to the experimental group.

The control subjects (N = 107) were randomly drawn from the general school population at the five elementary schools. Interviews with their teachers indicated none of the children were receiving special education or related services for emotional disturbance.

Two of the experimental and one control subject had histories of "pica", the behavioral habit of ingesting inedible materials such as clay, paper, plaster, and paint. Pica has been shown to substantially contribute to increased metal levels and/or metal poisoning.

Table 1 shows the relevant demographic data for the two resulting groups of subjects. There were no significant differences between the groups in age or ethnic group distributions. The groups did differ significantly in sex and social class.

TABLE 1 Demographic Characteristics of Two Groups of Children

	N	Sex M/F	Age (yr.) Mean ± S.D.		Range	Ethnic (Caucasian	Group Other	Socio-economic Status Mean + S.D.	
Emotionally disturbed group	37	30/7*	9.50	3.24	6-18	32	5	2.89	1.12*
Control group	107	64/43	8.67	3.21	6-12	92	15	2.04	0.94

Children in each group came from social classes 1, 2, 3, 4, and 5 as defined by Hollingshed and Redlich (1958).

*p < .01

Classification of Metal Levels

After obtaining parental permission children were asked to submit a small sample of hair (about 400 mg) for trace mineral analysis. Hair samples were collected from the nape of each child's neck, as close to the scalp as possible, by the senior researcher using stainless steel scissors. The hair samples were submitted to a state-licensed clinical laboratory where they were analyzed with three instruments — the atomic absorption spectroprotometer, the graphite furnace, and the induction - coupled plasma torch — to determine five toxic metal levels. The five toxic metal levels tested for were lead, arsenic, cadmium, mercury, and aluminum.

Precise laboratory techniques were used to assure reliability of results and to meet reproducibility requirements. These techniques included:

1. A blind sample was run from the initial steps through the entire procedure to assure reproducibility of methods.
2. At least one of every ten tests was a standard. Working standards were made to assure proper values.
3. The in-house pool was completely remade and analyzed monthly to eliminate the possibility of precipitating elements and to assure reproducibility.
4. Temperature and humidity were controlled to assure reliability and consistency of the testing instruments.
5. The hair samples were weighted to the thousandths of a gram (.00lg is equal to approximately 4 hairs, 1 inch [.0254m] long); and only Volumetric Flasks, the most accurate available, were used for diluting the ashed sample.
6. Lot number control sheets for all reagents were used to assure uniformity. Records are kept and available for inspection.
7. All glassware was acid washed in-house before use and between each use, including acid pre-washed disposable test tubes.
8. The water used was virtually mineral free, rated at 18+ MegOHM.

Reports summarizing the findings of the hair analysis for each subject were received from the laboratory subsequent to analysis. Each report listed both the observed metal levels and the suggested upper limit for each metal level, and plotted the levels in relation to their upper limits.

Hair: A Useful Diagnostic Tool

Every part of the human body contains at least a few atoms of every stable element in the period table. Although a large number of these elements are found in detectable amounts in human tissue, blood, and urine, hair in particular contains a higher concentration of many of these elements. Trace elements are accumulated in hair at concentrations that are generally higher than those present in blood serum, and provide a continuous record of nutrient mineral status and exposure to heavy metal pollutants and may serve as a probe of physiologic functions (Gordus, 1973; Maugh, 1978). Scalp hair has several characteristics of an ideal tissue for epidemologic study in that it is painlessly removed, normally discarded, easily collected, and its contents can be analyzed relatively easily (Hammer, Finklea, Hendricks, Shy and Horton, 1971).

The best results have been obtained with heavy metal pollutants such as lead and arsenic. Numerous investigations world wide have shown that concentrations of lead and other heavy metals in the hair provide an accurate and relatively permanent record of exposure, and there is a strong correlation between concentrations in hair and concentrations in internal organs (Kyle and Pease, 1966; Schroeder and Nason, 1969).

Walker Problem Behavior Identification Checklist

The Walker Problem Behavior Identification Checklist (WPBIC) is a screening device designed for elementary teachers in selecting children with behavior problems who may need referral for further psychological evaluation, referral, and treatment. The WPBIC consists of 50 observable operational statements of classroom behavior that might limit a child's adjustment in school. Differential score weights are assigned to each statement based on their influence in handicapping a child's adjustment. Factoring the 50 items, 14 items related to acting-out (aggressive and disruptive behavior), 5 items relate to withdrawal (socially avoidant and passive behaviors), 11 items relate to distract-ibility (poor attentiveness and restlessness), 10 items relate to disturbed peer relations, and 10 items relate to immaturity.

Standardized on 534 elementary age children,

TABLE 2

Distributions of Metal Concentrations in Two Groups

Metal	Statistics	Emotionally Disturbed	N=37	Control N=107	
Lead	Mean ± S.D. Nonelevated < 15 ppm. Elevated	10.78 31 6***	5.76***	7.02 107 0	2.76
Arsenic	Mean ± S.D. Nonelevated < 7 ppm. Elevated	2.74 37 0	1.50	3.12 107 0	1.35
Mercury	Mean ± S.D. Nonelevated < 2.5 ppm. Elevated	1.30 34 3*	0.96**	0.95 107 0	0.47
Cadmium	Mean + S.D. Nonelevated < 1.0 ppm. Elevated	0.75 31 6	0.51	0.65 95 12	0.37
Aluminum	Mean ± S.D. Nonelevated < 30 ppm. Elevated	12.62 36 1	16.07	10.13 106 1	

*p < .05
**p < .01
***p < .001
Note: All upper limits established by Doctor's Data, Inc. (1982)

the mean raw total score was 7.76 with a standard deviation of 10.53. One standard deviation above the mean separates disturbed behavior from nondisturbed behavior and Walker (1970) reported the split half reliability of the scale at .98 and the difference between the means of disturbed and nondisturbed children on the scale significant beyond the .001 level.

In this study, classroom teachers were instructed how to fill out the scale by the senior researcher. All teacher ratings were based on observations of the child's classroom behavior for the past two months prior to hair collection.

Results

The two groups of children were compared for hair-metal concentrations. As shown in Table 2 the mean lead and mercury concentrations for the disturbed group were considerably above that of the control group. The emotionally disturbed group had a mean hair lead of 10.78 parts per million (ppm.) and a mean hair mercury of 1.30 ppm., while the control group had a mean hair lead of 7.02 and a mean hair mercury of 0.95 ppm. The data were then analyzed with the t test for two independent samples design of SPSS (Nie, Hull, Jenkins, Steinbrenner and Bent, 1975) yielding a statistically significant t values for lead ($t = -5.24, 142$, $p < .001$) and mercury ($t = -2.85, 142$, $p < .01$), indicating the variation between the two means was unlikely to have occurred by chance. Analyses of the other metals failed to show significant differences in the group means.

The distribution of metal concentrations in the two groups is also shown in Table 2. No children secured hair metal levels associated with metal poisoning. Six of the disturbed children had elevated hair lead concentrations, while none of the control children

TABLE 3
Comparison of WPBIC Scores Among Two Groups - Means and SD

Scale	**Emotionally Disturbed Group**	**Control Group**	**T Value**	**Raw Score Denoting Disturbed Behavior**
Total Scale	30.00 ± 13.06*	8.40 + 8.04	-11.73	21
Acting Out	11.75 ± 6.59*	2.81 ± 3.92	-9.88	8
Withdrawal	2.54 ± 3.10*	0.47 ± 1.16	-5.81	5
Distractibility	6.83 ± 2.33*	3.34 ± 2.98	-5.45	6
Disturbed Peer Relations	5.16 ± 4.33*	1.10 ± 1.87	-7.82	3
Immaturity	3.75 ± 2.93*	0.76 ± 1.55	-11.73	3

*p < .001

had elevated hair-lead concentrations (p < .001).

A discriminant analysis was then performed using a program from SPSS (Nie et al., 1975). The stepwise method was employed to ascertain the relative contributions of the metals to the separation of the groups. Table 3 shows the results of the analysis. Of those metals the combination of lead, mercury, arsenic, and aluminum in order of entry into the discriminant function significantly separated the disturbed and normal children (F4, 139 = 12.96, p < .001). Of those metals lead, mercury, and arsenic contributed uniquely over and above the previously entered metals to the discrimination between groups (F = 27.43,19.38, and 16.87, respectively). Finally, the standardized canonical discriminant function coefficients revealed that lead is the most important (1.00) followed by mercury (.56), arsenic (-.48) and aluminum (-.20).

On the basis of the discriminant function 77.8 percent of the 144 subjects were correctly classified as disturbed or nondisturbed controls. These percentages are optimistic, however, since the function was applied to the data that produced it. A cross validation of the discriminant function is expected to result in somewhat smaller percentages.

The two groups of children were next compared for behavioral scores on the WPBIC. The disturbed group scored significantly higher than the controls on all subscales and the total scale of the WPBIC.

Mean WPBIC total scale raw scores were 30.00 for the disturbed group and 8.40 for the controls (p < .001). A total scale raw score of 21 or more is considered to denote disturbed behavior; thus, the emotionally disturbed group secured a mean within the disturbed behavior range.

The results of the WPBIC were then analyzed relative to the 144 children's metal levels. Table 4 represents a zero-order correlation matrix between metals, WPBIC measures, and social class, sex, and age. In order to control for the influence of other metals in examining individual metal-WPBIC relationships, the partial correlation procedure of SPSS (Nie et al., 1975) was employed. Controlling for other metals, lead levels correlated significantly and positively with acting-out (.35, p < .01), withdrawal (.24 p < .01), ' distractibility (.44, p. < .01), disturbed peer relations (.26, p < .01), immaturity (.38, p < .01) and total scale score (.42, p < .01), while mercury levels achieved positive significance with acting out (.22, p < .01), disturbed peer relations (.27, p < .01), immaturity (.15, p < .05), and total scale score (.22, p < .01).

Aluminum levels also achieved positive significance with distractibility (.14, p < .05) after partialling out the influence of the four other toxins. All other metal-WPBIC measure relationships were nonsignificant.

The above reported significant relationships between lead, mercury, and aluminum levels and WPBIC measures were then examined, while controlling for the influence of social class, sex, and age with the partial correlation procedure. Lead, mercury, and aluminum levels remained significantly correlated

TABLE 4

Correlation Matrix:

WPBIC Scales, Age, Sex, Social Class, and Metals (N = 144)

	Lead	Ars	Hg	Cd	Al	S1	S2	S3	S4	S5	TS	Age	Sex	Social Class
Lead		.24*	.00	.46*	.38*	.39*	.21*	.51*	.32*	.42*	.47*	.03	.23*	.15*
Ars	.24*		-.00	.30*	.23*	.10	-.08	.22*	.00	.03	.07	.18*	.23*	-.11
Hg	.00	.00		.05	.27*	.21*	.04	.00	.28*	.14*	.20*	.11	-.19*	-.08
Cd	.46*	.30*	.05		.18*	.21	.00	.32*	.25*	.15*	.26*	.19*	.12	-.00
Al	.38*	.23*	.27*	.18*		.20*	-.02	.31*	.22*	.18*	.24*	-.10	.03	.09
s,	.39*	.10	.21*	.21*	.20*		.37*	.59*	.57*	.53*	.88*	.21*	.27*	.27*
s_2	.21*	-.08	.04	.00	-.02	.37*		.28*	.46*	.57*	.59*	-.02*	.16*	.22*
S_3.51*		.22*	.00	.32*	.31*	.59*	.28*		.50*	.46*	.74*	.15*	.25*	.25*
s_4	.32*	.00	.28*	.25*	.22*	.57*	.46*	.50*		.55*	.80*	.12	.11	.16*
s_s	.42*	.03	.14*	.15*	.18*	.53*	.57*	.46*	.55*		.75*	.20*	.09	.29*
TS	.47*	.07	.20*	.26*	.24*	.88*	.59*	.74*	.80*	.75*	.20*		.24*	.30*
Age	.03	.18*	.11	.19*	-.10	.21*	-.02	.15*	.12*	.20*	.20*		.01	-.06
Sex	.23*	.23*	-.19*	.12	.03	.27*	.16*	.25*	.11	.09	.24*	.01		.03
Social Class	.15*	-.11	-.08	-.00	.09	.27*	.22*	.25*	.16*	.29*	.30*	-.06	.03	

*p<.05

Note: Si = TS = Total Acting out; S2ⁱ Score. =Withdrawal; S3=1 Distractibility; S4=Disturbed Peer Relations; S5 = Immaturity;

with their respective WPBIC measures below the .01 level of confidence.

DISCUSSION

The data of this study do not establish a causative relationship but show an association between lead and mercury concentrations and behavioral deficits in children. Disturbed children had significantly higher lead and mercury levels, and correlational data indicated that increases in lead and mercury were associated with significantly higher scores on various WPBIC measures. The R^2 value between lead concentrations and total scale score was 0.2276, thus indicating approximately 22 percent of the variance of the total scale scores of the 144 subjects may perhaps be accounted for by their lead levels. Cogently, the dose-response relationship reported here is in agreement with a previous study (Marlowe and Errera, 1982), which reported an R^2 value of 0.2554 between lead concentrations and WPBIC total scale score (N = 55).

Discriminant function analysis revealed that by using lead, mercury, arsenic, and aluminum, subjects could be correctly classified as disturbed or controls with 77.8 percent accuracy. Stepwise discriminant analysis revealed that lead accounted for 17 percent of the variance between the two groups, mercury accounted for an additional five percent, arsenic another five percent, and aluminum one percent. Each metal contributed significantly over and above previously entered metals to the separation of the groups with lead being the most important.

Although arsenic and aluminum as predictive factors may represent nutritional peculiarities (e.g., controls had higher arsenic levels), the significantly higher lead and mercury content relates to a specific literature. The role of lead toxicity in behavioral development is well established. Although the disturbed children showed considerably lower amounts of lead than those regarded as toxic, increasing evidence suggests that exposure to low concentrations of lead also had deleterious effects on behavior. While not controlling for other environmental toxins, Needleman et al. (1979) offered evidence that lead exerts its neurotoxic effects over a continuum. Part of their study examined the relationship between teachers' ratings of children on an informal 11-item classroom behavior scale and the children's dentine lead levels (N = 2,146). The relationship of negative reports increased in a dose related fashion for all 11 items. Despite the occasional appearance in the literature of a negative study, the data on low level lead toxicity have been sufficiently convincing that the United States Environmental Protection Agency (1978) concluded that "surprisingly low levels of blood lead can at times be associated with the most extreme effects of lead poisoning, including severe irreversible brain damage," and further that "evidence tends to confirm that some type of neural damage does exist in asymptomatic children and not necessarily only at very high levels of blood lead."

Low level mercury toxicity remains relatively virginal to investigation, although recent studies have linked low mercury levels to childhood learning problems (Capel, Pinnock, Dorrell, Williams and Grant, 1981; Marlowe, Folio, Hall and Errera, 1982). The R^2 value between mercury concentrations and total scale score was 0.0439, and a previous study (Marlowe et al., 1983) reported a R^2 value of 0.0444 between mercury concentrations and WPBIC total scale score ($N = 47$).

The finding of both increased lead and mercury levels in the disturbed group is especially disturbing since these potentially lethal metals may have a negative combining effect which increases the total toxicity of the child's system. Importantly, recent findings (Marlowe, Errera, Moon, Ballowe and Jacobs, in press) indicate lead-mercury combinations have a significantly more negative relationship to the WPBIC scale than do individual lead or mercury levels.

The behavioral disorders described in clinical and experimental metal poisoning are extremely variable and complex. The data of this study also demonstrate behavioral variability and inconsistency, inasmuch as WPBIC scales measuring such oppositional behaviors as acting-out and withdrawal both correlated positively and significantly with lead dose. It may be one should consider the nature of metal induced changes as a randomization of behavioral responses or as a generalized hyperreactivity. This hyperreactivity would be situation-dependent and highly responsive to sensory stimuli, which might account for the variability reported in this and other behavioral studies.

The data of this study indicate the continuing need to reexamine metal poisoning concentrations, because concentrations of metal previously thought harmless may now have to be considered metal poisoning and viewed as an etiological factor in intellectual/ behavioral dysfunctions. Lead is the only metal that has even been marginally examined for low level effects.

A number of limitations of the study must be considered. First, results of the comparisons between the two groups need careful interpretation since observed differences in lead and mercury levels could have derived from variation between the groups in sex and social class. In defense of the comparative data, it should, however, be noted that after partialling out the contributions of sex and social class, significant correlations remained between lead and mercury levels and WPBIC measures. A second limitation is the possibility that characteristics not identified differentiated the children, e.g., perinatal, genetic variables.

Confidence in the associations reported here between WPBIC measures and lead and mercury levels depends on the validity of hair as a marker of exposure. The classification of lead and mercury to hair metal levels has been validated in a number of other studies. Hair lead levels are elevated in children with increased lead burdens (Pueschel, Kopito and Schwachman, 1972) and chronic lead poisoning (Kopito, Byers and Schwachman, 1967). Hair lead levels also vary in relation to the concentration of lead in housedust (Creason, Hinners, Baum-garner and Pinkerton, 1975) and in relation to location proximity to a major lead processor (Roberts, Hutchinson and Paciga, 1974) and to lead based pesticides and fertilizers (Hutchinson, Czuba and Cunningham, Note 1). Likewise, hair mercury levels are elevated in individuals with increased mercury burdens and chronic mercury poisoning (National Research Council, 1978) and vary in relation to the consumption of mercury containing fish and occupational exposure to mercury (Hartung and Dinman, 1972).

The biological and developmental significance of our findings is not clear. While warranting replication, the increased WPBIC scores may be functional evidence of low-level lead and mercury induced neuronal damage. Recent neurochemical studies of low level lead exposure confirm that lead at low levels is a potent neurotoxin (Silbergeld and Hruska, 1980), and its effects are demonstrable in neuronal systems using acetylcholine, catecholamines, and GABA as transmitters. These studies caution against assuming the existence of a "safe" level of lead exposure and raise concerns the neuron may be irreversibly damaged by any exposure to lead.

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