Low Level Aluminum Exposure and Childhood Motor Performance

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Abstract

The study investigated the relationship between children's hair aluminum concentrations and children's motor performance. Hair aluminum concentrations of 31 children drawn from a general school population were correlated with their performance on the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP). Increasing hair aluminum values correlated significantly with decreased scores on three subtests and the gross motor composite, fine motor composite, and battery composite of the BOTMP. A continuing reexamination of aluminum exposure in the young is needed in order to determine the margin of safely regarding potentially toxic levels of aluminum.

Keywords

aluminum exposure; aluminum toxicity; hair aluminum concentrations; childhood motor performance; Bruininks-Oseretsky Test of Motor Proficiency

The behavioral effects of aluminum have not been extensively studied. Although subtle behavioral changes are noted in certain species soon after aluminum infusion, with increasing time the behavioral changes become more overt as severe neuropathological signs appear. Most authors describe a progression of symptoms: the first to appear is reduced motor activity and an increased irritability to external stimuli. Progressive weakness and incoordination ensue, and this is followed in the terminal stages by seizures and convulsions (Crapper, 1973; Selkoe, Liem, Yen and Shelanski, 1979; Crapper & Dalton, 1973).

In humans there appears to be considerable evidence to suggest that elevated aluminum may be the precipitating neuropathological event in dialysis dementia (Altrey, Legendre & Kaehny, 1976), while aluminum may be a secondary event in Alzheimer's disease (Petit, 1982). Dialysis dementia, a neurological syndrome observed in some patients undergoing renal dialysis (whose aluminum accumulation is due to the intake of oral aluminum-containing phosphate binders and exposure to low water aluminum concentrations) is characterized by confusion, personality changes, sometimes severe psychoses, and delirium. With progression of the disease, a loss of muscle coordination, marked motor abnormalities, and the onset of seizures occur, the clinical course terminating in convulsions and death. Aluminum is also known to be implicated in a range of other neurological diseases characterized by marked motoric abnormalities, including atypical motor neurone disease, Downs Syndrome and Guam disease (Cross, 1990).

Although aluminum is not generally considered to represent an environmental hazard, levels of aluminum routinely encountered in the environment have recently been associated with fine motor deficits (Marlowe, Stellern, Errera & Moon, 1985), learning disabilities (Capel, Pinnock, Dorrell, Williams & Grant, 1981; Marlowe, Cossarit, Errera & Welch, 1984), and behavioral disorders in children (Moon & Marlowe, 1986). The purpose of this study was to examine children's motor performance in relationship to aluminum values. It was hypothesized that as children's aluminum concentrations increased, their performance on a test of motor proficiency would decrease.

In this study aluminum concentrations were determined via hair samples and atomic absorption spectroscopy. Although blood values are the most widely used indicator of aluminum status, blood aluminum levels, similar to blood levels of other metals, can only serve as an indicator of circulating aluminum levels and not total body store (Bowdler, 1979; Altrey, 1980). As a result, there is increased interest in the use of hair as a diagnostic tool for the

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assessment of trace metal status. Trace elements are accumulated in hair at concentrations that are generally at least ten times higher than those present in blood, and hair samples provide a continuous record of exposure to metal pollutants (Maugh, 1978; Laker, 1982; Passwater & Cranton, 1938). Yokel (1982) has found that hair aluminum is a reasonable biopsy technique for establishing excessive systemic aluminum exposure. Bryukhanov (1972) reported that the content of aluminum in the hair varied with the intensity of occupational contact with aluminum, and Parkhurt and Pate (1978) noted elevated hair aluminum concentrations in patients on dialysis with encephalopathy syndrome.

Method

Subjects

The 31 subjects in this study were randomly drawn from grades one through six at the University Laboratory School of the University of Wyoming, Laramie. The mean age of the subjects was 9.80 with a range from six to 12. Twenty-four subjects were male, and all subjects were Caucasian. Subject and parental consent was required for participation in the study.

Classification of Aluminum 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 the child's neck, as close to the scalp as possible, by the senior researcher, using stainless steel scissors. The hair samples were then submitted to Doctor's Data, Inc., a state and Center for Disease Control licensed laboratory in West Chicago, where they were analyzed with atomic absorption spectropro-tometer, the graphite furnace, and the induction coupled argon plasma torch to determine the children's hair aluminum levels.

Precise quantometer standards are used by Doctor's Data, Inc., to assure reliability of results and to meet reproducibility requirements. These include:

(1) Upon receipt the hair sample is washed thoroughly with deionized water, a nonionic detergent, and an organic solvent to remove topical contaminants.

(2) A control sample is run from the initial steps through the entire procedure to assure reproducibility of methods.

(3) At least one of every ten tests is a standard. Working standards are made to as sure proper values.

(4) The in house spiked pool is completely remade and analyzed daily as every 50th specimen as part of the quality control procedure.

(5) Temperature and humidity are controlled to assure reliability and consistency of the testing instrument.

Bruininks-Oseretsky Test of Motor Proficiency

The Bruininks-Oseretsky Test of Motor Proficiency (BOTMP) (Bruininks, 1978) was developed to provide educators and researchers with useful information to assist them in assessing motor skills of individual students, in developing and evaluating motor training programs, and in assessing serious motor dysfunctions and developmental handicaps in children.

Each of the eight subtests in the BOTMP is designed to assess an important aspect of motor development. Four of the subtests measure gross motor skills, three measure fine motor skills, and one measures both gross and fine motor skills. The four gross motor subtests are (1) running speed and agility, (2) balance, (3) bilateral coordination, and (4) strength. The combined gross and fine motor subtest is upper limb coordination, while the three fine motor subtests are (1) response speed, (2) visual motor control, and (3) upper limb speed and dexterity. The gross motor composite summarizes performance on the four gross motor subtests, the fine motor composite summarizes performance on the three fine motor subtests, and the battery composite summarizes performance on all 47 items contained in the eight subtests and serves as an index of general motor proficiency.

Norms and standardization for scoring are based on 765 nonhandicapped children in ten age groups ranging from ages four and one-half to 14 and one-half. Interpretation of the child's performance is based on converting raw scores to standard scores and comparing these to the scores of the age appropriate standardization group. Age adjusted subtest standard scores have a mean of 15 with a standard deviation of five. The mean normalized standard score for the three composites is 50 with a standard deviation of 10.

Bruininks (1978) reported the test has statistically acceptable test-retest reliability and inter-rater reliability. Fine (1979) reviewed the BOTMP and reported the test has good content and construct validity, is easily administered, and is very useful in research situations.

Administration of the BOTMP

The BOTMP was administered by two graduate students in special education at the University of Wyoming. The examiners were thoroughly familiar with all aspects of the test administration and were carefully supervised by the researcher so that test administration procedures would be carried out exactly as required. At the beginning of the testing period and at the end studies were conducted to investigate the inter-rater reliability of scores on the eight items in subtest seven: visual motor control. The scoring of these items requires more judgment than do items in the other subtests. Median correlations between all of the item raw scores assigned by the pair of independent raters were 1.00 in study one and 1.00 in study two. The examiners were blind to the children's aluminum levels.

The testing was conducted in a stage area free from noise or other distractions. Because of insufficient space, subtest one: running speed and agility was conducted in a gymnasium. All subjects were familiar with the physical surroundings.

Results

The means and standard deviations for the 31 subjects' eight subtest and three composite scores on the BOMPT are shown in Table 1. The eight subtest means and the three composite means were all within one standard deviation from the established normative means. The group's mean battery composite score was 51.09 compared to a normative battery composite score mean of 50.00.

The group's mean hair aluminum concentration was 9.16 parts per million (ppm) with a standard deviation of 3.43. The group's mean for hair aluminum was well below the normally tolerated limit of 30 ppm established by

Table 1
Means, Standard Deviations, and Zero-order Correlations of Aluminum with Motor Skills

Variables	M	SD	r
Aluminum	9.16	3.43	
Running Speed and Agility	18.77	6.25	-.50**
Balance	14.70	4.96	-.03
Bilateral Coordination	15.09	4.13	-.18
Strength	16.00	6.28	-.29
Upper Limb Coordination	14.80	7.95	-.47**
Response Speed	14.93	4.96	-.13
Visual Motor Control	16.32	5.02	-.41*
Upper Limb Speed and Dexterity	12.35	3.71	.15
Gross Motor Composite	53.38	9.81	-.39*
Fine Motor Composite	48.87	9.22	-.37*
Battery Composite	51.09	9.71	-.51**

* $p < .05$
** $p < .01$
Note: n = 31

the laboratory (Doctor's Data, Inc., 1982).

To examine the extent to which hair-aluminum was linearly related to gross motor and fine motor skills, simple Pearson correlations were computed. The results are also depicted in Table 1. There were significant negative relationships between hair aluminum concentrations and the subtests measuring running speed and agility ($r = -.50$, $p < .01$), upper limb coordination ($r = -.47$, $p < .01$), visual motor control ($r = -.41$, $p < .05$), and between the gross motor composite ($r = -.39$, $p < .05$), the fine motor composite ($r = -.37$, $p < .05$), and the battery composite ($r = -.51$, $p < .01$). Hair aluminum values approached negative significance with the strength subtest ($r = -.29$, $p < .10$); the remaining subtests were not significantly related to hair aluminum values. Simple Pearson correlations were also computed between age, sex (female = 0, male = 1), and hair aluminum values; neither age ($r = .11$) nor sex ($r = .17$) were significantly related to hair aluminum values.

Discussion

While not establishing an etiological relationship, the data of this study show an association between increased aluminum levels and decreased gross and fine motor performance. This study's findings support two previous studies of aluminum concentrations and psychomotor performance of children and adults.

Marlowe, Stellern, Errera, and Moon (1985) examined hair aluminum and other hair metal concentrations in relationship to children's performance ($N = 69$) on the Bender Visual-Motor Gestalt Test, a paper and pencil visual-motor integration test. Increases in hair aluminum and the combination of hair aluminum-hair lead were significantly associated with decreased visual motor performance. Hair aluminum levels accounted for almost 9% of the variance, and the interaction of lead with aluminum accounted for an additional 8% of the outcome variance. Disruption of visual-motor performance such as Gestalt distortion is considered an early clinical sign of brain damage both in children and adults. The licensed psychologist administrator of the Bender noted, however, that some children's Bender errors appeared to be caused by distractibility or an attention deficit. The degree of impairment on the Bender was not interpreted in terms of brain damage; rather, it was interpreted in terms of perceptual inaccuracy based on an attention deficit. In this light it should be noted that increased hair aluminum levels have been linked to attention deficits and increased distractibility in children (Marlowe, Moon & Errera, 1985; Marlowe, Jacobs, Moon & Errera, 1984; Moon and Marlowe, 1986).

Altman, Hamon, Blair, Chanesha, Cunningham & Marsh (1989) examined the psychomotor performance of 27 long term dialysis patients with apparently normal cerebral function, who had only mildly raised serum aluminum levels. Compared to a control group, the patients' response times on a computerized symbol digit coding test were significantly longer, and abnormalities were also detected in five other computerized tests of psychomotor function. The investigators also found that mild aluminum accumulation inhibits erythrocyte dihydropterdine reductase (DHPR) activity, and the inhibition is reduced by desferoxamine, an aluminum chelator. DPHR is an important neurotransmitter enzyme, and inhibition of brain DPHR is associated with impairment of psychmotor function. Patients receiving desferoxamine demonstrated improved DHPR erythrocyte activity and psychomotor function.

Aluminum as a health hazard and its effect on psychomotor functioning is highlighted in the July 1988 accidental contamination with aluminum sulfate solution of the public water supply to the town of Camelford in southwest England (Cross, 1990). The solution, used in the purification of drinking water, was accidentally discharged into the water tanks, which supplied some 20,000 residents and tourists. Although to date public health authorities have obstructed an epidemiological survey of Camelford's residents, many people suffered persistent medical problems after the incident, some of which are still so severe that the victims are no longer able to lead a normal life. Symptoms appearing after the contamination included mouth ulcers, upper gastric complaints, severe lethargy, motor coordination difficulties, persistent bone pain, memory problems, and impaired concentration and judgment. It was subsequently found that 21 of 31 post-incident referrals showed significantly increased blood aluminum levels up to one year later (Taylor, 1990).

Given the above studies, there appears to be an emerging relationship between increasing aluminum concentrations and decrements in children and adults' behavioral performance. These data suggest that aluminum toxicity may not be a threshold or "all or none" phenomenon, but, rather, reflects a continuum of deleterious effects. In this study low aluminum levels achieved negative significance with motor performance in a population of children with normal motor development. The subjects' mean hair aluminum of 9.16 ppm was well below the laboratory's established normally tolerated limit of 30 ppm, and the subjects' mean BOTMP composite was 51.09 compared to a normative mean of 50.00. The values for human hair aluminum in the present study are in general agreement with those found in previous studies of children in general populations or control groups, e.g. 9.53 (Marlowe, Stellern, Errera & Moon, 1985), 9.41 (Marlowe, Moon & Errera, 1985), 10.13 (Marlowe, Jacobs, Moon & Errera, 1984).

Conclusion

Humans are naturally exposed to high amounts of aluminum in the natural environment. Aluminum is the third most common element in the earth's crust. Aluminum also occurs in varying amounts in fresh water, depending on geochemistry, and in large amounts in sea water, and in the air as dust particles. In addition to naturally occurring aluminum, we are exposed to additional aluminum in the form of food additives, antacids, cosmetics, beverage containers, drinking water (because of the use of aluminum sulphate during purification procedures), plants, and animals.

We now have a firmly clear picture of the sequence of events involved in aluminum encephalopathy in the experimental animal (Petit, 1983). Aluminum appears to enter the brain and bind to chromatin and possibly other cellular structures. It causes an increase in the production of protein, and neurofibrillary tangles subsequently appear in the cytoplasm. Shortly after the appearance of tangles, subtle behavioral changes are noted. These are followed by electrophysiological, neurochemical, and anatomical changes that become progressively worse.

Unfortunately, we have a greater understanding of the effect of aluminum in nonhuman animals than we do in humans. The neurotoxin has dramatic effects in certain species, with little or no effect on others. What we do not know is the effect it has on the human species, e.g., there is uncertainty as to whether it induces neurofibrillary tangles in human neurons. Animal research to date suggests that an encephalopathy is seen only in those species that develop tangles, such that if humans do undergo an aluminum encephalopathy, but do not develop tangles as suggested, this will be the first species reported to do so.

The biological significance of these findings is not clear, especially given the moderately low levels of aluminum reported here. The significance is compromised by the lack of basic information of the variability of aluminum levels in the hair and its correspondence with variability in the rest of the body's organs and tissues. This is an area in which basic research needs to be done before precise meaningful applications on an individualized basis will be possible. Aluminum is ubiquitous in our environment, the field of aluminum neurobehavioral toxicology is in its infancy, and future studies are needed examining other biopsy materials to better understand aluminum's potential role in psychomotor functioning.

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