Mineral Status, Toxic Metal Exposure and Children's Behaviour

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Abstract

This study investigates the relationship between hair element status and problem behaviour in a sample of 237 children attending grades K through four in Victoria, British Columbia schools. Children were classified on the basis of behavioural status using the Walker Problem Behavior Identification Checklist. Logistic regression analyses were used in order to assess the degree of association between hair element status and behaviour. Two analyses were performed for each Walker scale, both of which used behavioural status as the response (dependent) variable. In the first analysis, dummy variables corresponding to hair element status were forced into the model in order to identify elements which were significantly associated with behavioural status as measured on each scale. In the second analysis, these same variables were forced into the model along with social and family factors. Comparison of the results from each analysis allowed for the identification of elements which were associated with behavioural outcomes before and after considering the effects of the other factors. Amongst all of the elements considered, calcium in particular appears to be of importance, with significant positive associations observed between 'low' hair levels of this macro-mineral and problem behaviour as measured by the Acting-Out, Withdrawal, Distractibility, and Total scales. With respect to specific behavioural problems, 'distractibility' may be the most affected by mineral status, with significant associations observed (both before and after consideration of the other factors) between problem behaviour of this type and 'low' calcium, 'high' manganese, and 'high' cadmium.

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Introduction

While studies undertaken internationally report a relatively broad range of estimates for the prevalence of childhood mental health problems,[1] research completed in Canada suggests that approximately one in five children and adolescents suffer from one or more psychological disorders which may significantly impair day-to-day functioning.[2,3] Highlighting the potential long-term importance of this problem, recent research demonstrates that behavioural differences in early childhood can predict psychiatric disorders in young adults. Based upon the results of a longitudinal study, Caspi et al.[4] suggest that children who are impulsive, restless, and distractible at age three are more likely to be suicidal, show characteristics of antisocial personality disorder, and engage in criminal behaviour at age 21. Those observed to be shy, fearful, or easily upset as children are more prone to depression and suicide attempts as young adults. Pakiz et al.[5] report the results of an 18 year follow-up study of 375 young adults: aggression and hostility, and disruptive behaviour at a young age are shown to be predictors of antisocial behaviour at age 21.

Thus, it is suggested that dysfunctional behaviour exists as a continuum throughout childhood and into young adulthood. Unresolved problem behaviours in childhood are likely to persist into later life, exacting high social costs such as antisocial and criminal behaviour, low educational attainment, and economic dependence.

Despite the obvious importance of this problem, the aetiology of childhood psychiatric disorder remains relatively poorly understood, with most research in this area focussing upon the relationships between mental health outcomes and parental characteristics, socio-economic status, and life stresses.[1] In recent decades, however, increasing interest has been shown in the potential influence of abnormal levels of toxic and essential elements on children's behavioural and intellectual development. In this paper, aspects of the 'orthomolecular' perspective on children's mental health are considered through an examination of the possible behavioural effects of a number of elements. In addition to reviewing the findings of existing literature in this area, results are reported from a study which examined associations between toxic and essential element status and behaviour in a sample of children living in Victoria, British Columbia.

Hair as an Indicator of Toxic and Nutritive Element Status

While body stores of a wide range of toxic and essential elements can be ascertained using a number of tissues, including blood, urine, teeth, and organ samples, scalp hair is increasingly considered a more desirable biopsy material for this purpose. As an excretory tissue, hair incorporates atoms of individual elements during its growth cycle and, after its formation, provides a permanent record of the levels of those elements in the body at the time of growth. While both blood and urine can be used to measure the concentration of particular elements in the body, they reflect only what was in the system at the time of, or in the hours preceding collection, and are therefore subject to a high degree of short-term variability. Concentrations of elements in hair, on the other hand, provide a measure of average exposure over the time period in which the hair was grown.[6]

Given the relative ease with which hair samples can be collected and stored, and their ability to provide a measure of long term exposure to particular elements, it is perhaps not surprising that hair elemental analysis has been increasingly employed in studies which examine the links between mineral status and human health. However, hair concentrations of some elements do not correlate with levels detected in other tissues. For the purposes of this discussion, elements were considered if: (1) abnormal levels of them may, in theory, influence behavioural functioning or cognitive development, and; (2) hair concentrations reflect environmental exposure, dietary intake, and/or tissue levels of the element (following Passwater and Cranton,[7] and Quig).[8] These elements include the toxic metals aluminum, arsenic, cadmium, lead, and mercury; and the essential minerals calcium, chromium, copper, magnesium, manganese, selenium, and zinc.

Element Status, Cognitive Functioning and Behaviour: Toxic Elements

Aluminum. Like a number of other toxic substances, aluminum has been used in the past for medicinal purposes.[9] Although the neurotoxicity of aluminum has been recognised for over 100 years,[10] the metal remains widely used in products which are consumed, such as pickles[9] and antacids; products in contact with food, such as aluminum foil or cookware;[7] and some which are in contact with the skin, such as antiperspirants.[11] Aluminum in drinking water may occur at varying levels naturally, but may be increased through the action of acid rain, or the deliberate introduction of the metal for the purposes of drinking water treatment.[12] For those with normal renal function, aluminum is usually easily removed from the body by the kidney,[7] provided that adequate systemic levels of magnesium, calcium, zinc, and phosphorus are available.[13]

While the most notable potential neurological effect of aluminum toxicity is Alzheimer's disease and other forms of dementia,[12] studies have reported elevated levels of aluminum in the hair of delinquent, psychotic and prepsychotic adolescent boys,[14] and in juvenile offenders[15] when compared to laboratory norms. As well, significant relationships between hair aluminum levels and diminished visual and motor performance,[16] and increasing scores on the Walker Problem Behavior Identification Checklist[17] have been reported for elementary school aged children.

Arsenic. Although an essential function for this element has been suggested,[7] arsenic has long been recognized as a poison with criminal potential. In spite of its toxicity, this element has been employed in attempts to cure diseases such as cancer and syphilis.[9] Usually occurring at low levels throughout the natural environment, arsenic can be found in the tissues of plants and animals, and in varying concentrations in both fresh and sea water. Human-mobilized sources of elemental arsenic and arsenical compounds include those resulting from glass and ceramic production, metal smelting,[18] and the production of insecticides, fungicides, and herbicides.[9]

Arsenic can be absorbed by the human body through the respiratory tract, the gastrointestinal tract, and the skin.[18] The neurotoxic effects of this metal may lead to confusion,[19] learning impairment, and agitation.[9] A significant direct relationship between hair arsenic concentrations and Total scale scores on the Walker Problem Behavior Identification Checklist has been reported in a study of elementary school children.[17]

Cadmium. Cadmium is a relatively rare element[20] which is considerably more toxic than lead.[21] Human exposure to cadmium can result from the consumption of contaminated food or water, and through inhalation of airborne cadmium from industrial sources, automobile exhaust, or cigarette smoke. Seafood may be an important source of ingested cadmium,[20] while the settling of airborne particles and the use of plastic pipes are major contributors to water contamination.[7]

This element, sometimes referred to as a 'super-toxin,' has been linked to a number of neurological effects. Elevated hair cadmium has been observed in children with learning disabilities[22] and dyslexia[23] when compared to 'normal' controls. As well, an inverse relationship between intelligence scores and hair cadmium levels has been reported for a sample of children and adolescents.[24] Other problems possibly linked to cadmium exposure include delinquency, schizophrenia, and high anxiety.[15]

Lead. The most widely known neurotoxin, lead has been recognized as a poison since ancient times,[25] and has been implicated in the fall of the Roman Empire.[21] Lead occurs naturally at low levels throughout the environment. Higher, more hazardous concentrations of lead, however, have resulted from the mobilization of lead and lead-based compounds through human activity. The most important source of airborne lead contamination in modern times has been through the emissions of automobiles fuelled by leaded gasoline, while localized high-level exposures have occurred as a result of lead smelting operations.[7]

Lead can also be absorbed via the gut through the consumption of food contaminated by the metal prior to or during processing. Plants, for example, can incorporate lead during growth or accumulate airborne lead particles on leaf surfaces, while lead-soldered cans may further contaminate preserved foods with the metal.[7] The ingestion of non-food substances such as contaminated soil and paint represents a significant additional risk of exposure for children.[26] Soil lead has been identified as an important source of exposure amongst children living near the lead-zinc smelter located in Trail, British Columbia, for example.[27,28]

The well established deleterious effects of this metal have made it one of the most widely studied of all elements, including a substantial body of literature concerned with the effects of lead exposure on the behavioural well-being and intellectual development of children. Significantly higher levels of lead have been detected in the blood and urine of hyperactive children[29] and 'neurotic' children[30] versus controls; while hair lead concentrations have been shown to correlate with attentional problems in school-aged children,[31,32] and with children's scores on the Walker Problem Behavior Identification Checklist.[33,34] Direct associations between lead exposure and children's scores on the Child Behavior Checklist have been observed in studies examining concentrations of the metal in blood,[35] and in bone.[36] As well, evidence for the connection between lead exposure and diminished cognitive functioning has been compiled in studies using hair,[14,24] blood,[37] and teeth.[38]

Mercury. Despite its neurotoxic effects, mercury has in the past been used, in various forms, for its perceived medicinal qualities[9] in the 'treatment' of skin diseases and syphilis.[25] Though mercury does exist in nature as the familiar liquid metal,[39] its highly toxic organic form, methylmercury, is of greater concern.[7] Sources of exposure to mercury include dental amalgam, paint, fungicides, seafood, and industrial air pollution.[7] The metal is absorbed through the inhalation of vapours, via the gastro-intestinal tract, or through contact with the skin.[39]

Notable for its connection with 'Mad Hatters,'[7] mercury exposure is associated with depression, emotional instability, irritability, memory impairment,[19] learning disabilities, and behavioural disorders.[40] Elevated hair mercury levels have been reported for emotionally disturbed children when compared to controls,[17,33] while a significant inverse relationship has been observed between hair mercury levels and intelligence scores in elementary school children.[41]

Essential Bulk Elements

Calcium. Calcium is the most abundant mineral in the human body and, though best known for its role in the development of healthy teeth and bones, is essential for proper functioning of the heart, and has a beneficial effect for the nerves, muscles, and skin.[7]

Calcium regulates the permeability of cell membranes to sodium, increasing the stress threshold of the cell, and consequently calming the nerves.[7] Calcium deficiency may result in agitation, cognitive impairment, delusions, depression, hyperactivity, irritability, and nervousness;[19] while a mood elevating effect has been suggested for dietary calcium supplementation.[42] Low hair calcium has been reported for autistic children versus sibling/neighbour controls.[43]

Excess calcium may depress muscular and nervous functions,[11] and lead to depression, irritability, memory impairment, and psychosis.[19] Significant direct correlations have been observed between hair calcium levels and preschool children's scores on the Walker Problem Behavior Identification Checklist's Total and Acting-Out scales.[34]

Magnesium. Magnesium is the fourth-most abundant mineral in the human body;[44] the majority of it is involved in the formation of bones and teeth. Like calcium, magnesium plays an important role in the activation and relaxation of nerves and muscles.[7]

Because of the beneficial 'calming' effect of magnesium, symptoms resulting from a deficiency in the mineral may include anxiety, depression, hyperactivity,[44] agitation, hallucinations, irritability, nervousness,[19] aggression, chronic stress,[45] learning disability, and memory impairment.[7] As well, a link between magnesium deficiency and suicidal behaviour has been suggested.[45] Significantly lower hair magnesium has been observed in dyslexic children compared to 'normal' controls.[23]

Magnesium intoxication, while rare, may cause depression of the central nervous system.[11] A significant direct correlation has been observed between hair magnesium levels and preschool children's Total scale scores on the Walker Problem Behavior Identification Checklist.[34] Elevated magnesium levels have been detected in the hair of autistic[46] children when compared to 'normal' controls; this finding is contradicted, however, by other research.[43,47]

Essential Trace Elements

Chromium. Chromium is an important micro-nutrient as a component of glucose tolerance factor.[48] Persons suffering from diabetes and those in a prediabetic condition have been shown to be deficient in body stores of chromium, and may suffer emotional instability resulting from changes in insulin and glucose levels.[49] Depressed levels of this element may also cause anxiety.[19]

While not generally associated with negative psychological effects, elevated levels of chromium have been detected in the hair of children with 'psychotic' and 'neurotic' behaviour[30] and in the hair of children with learning disabilities[50] when compared to controls. A significant direct relationship between hair chromium levels and parent and teacher ratings of preschool children's behaviour on the Walker Problem Behavior Identification Checklist (Total scale) has also been reported.[34]

Copper. Found in tissues throughout the human body, copper is vital in the formation of haemoglobin,[11] and is an essential constituent of a number of enzymes.[7] Although copper deficiency is relatively rare,[11,25] it can lead to a variety of maladies, including anaemia, skeletal defects, and degeneration of the nervous system. As well, deficiency in this nutritive element has been suggested as a possible cause of depression.[19]

Health effects are more frequently observed, however, in individuals with excess copper. Potential neurotoxic effects of this metal include depression, irritability, nervousness,[19] and learning and behavioural disorders in children.[51] Significant direct relationships between hair copper levels and scores on the Walker Problem Behavior Identification Checklist Total and Distract-ibilty scales have been observed for preschool children.[34] As well, hair copper levels in a sample of dyslexic children were reported to be significantly higher than for a non-dyslexic control group.[23]

Manganese. While most of the manganese contained in the human body is incorporated in the bones, liver, and kidney, the remainder is essential for enzymes involved in protein metabolism, energy production, and bone formation.[7] While low manganese levels have been observed in persons with schizophrenia,[15] elevated levels of manganese in the hair have been reported in violent versus non-violent criminals,[52] and in children with a learning disability versus 'normal' controls.[50] As well, significant direct relationships between hair manganese levels and preschool children's scores on the Total and Acting-Out scales of the Walker Problem Behavior Identification Checklist have been observed.[34] Other neurological effects of managanese intoxication may include hyperactivity,[45] hallucinations,[9] impaired judgement, poor memory, and Parkinsonian-Like Neurological Disorder.[19]

Selenium. Selenium is an important component of an antioxidant enzyme which acts to prevent the decay of cellular function,[7] and appears to offer protection from the effects of the toxic metals lead, mercury, and cadmium.[53] A geographical association between selenium deficiency and schizophrenia has been suggested,[54] while toxic levels of this micro-nutrient have been linked to irritability.[19] Significant direct correlations between hair selenium levels and teachers' responses to the Walker Problem Behavior Identification Checklist have been reported for school-aged children.[55]

Zinc. While the essential nature of zinc in human biological function has been established since the 1930s, the health-related effects of the metal have only more recently been understood. Zinc is important in enzymatic activity, and plays a role in both protein synthesis and carbohydrate metabolism. As well, this element may offer protection against the toxic effects of lead and cadmium.[7]

While zinc is itself toxic in large quantities, deficiency is generally considered of greater concern. Zinc status has been linked to intelligence and behaviour, with studies indicating that zinc supplementation may increase the IQ of some intellectually impaired individuals.[19] Other mental health-related symptoms of zinc deficiency include depression, irritability, memory impairment, paranoia,[19] and violent and aggressive behaviour.[7]

Materials and Methods

Data Collection. The research discussed in this paper was undertaken using data collected during the period October to December, 1997, as part of a larger study of children's mental health. Employing a cross-sectional design, the research targeted children attending grades K through 4 at 15 English-language public elementary schools located in the most highly urbanised portion of Greater Victoria, British Columbia (Figure 1, p.19); 14 of these schools agreed to participate in a follow-up study involving the collection of hair samples required for the present investigation. Implementation of the study was accomplished with the co-operation of the Greater Victoria School District, and the Principals and Teachers of the participating schools.

The main portion of the study involved the distribution of a two-part self-administered questionnaire sent home to parents/guardians from school. Parents were requested to complete both portions of the survey package and to return them in the addressed, postage-paid envelope provided.

The first part of the survey package, a 41 item questionnaire, was used to obtain information about factors which may influence the behavioural status of children, including the child's birth and medical history, family characteristics, social status, and housing factors. Of particular interest for the purposes of the present investigation were a number of social and family factors, measured as dichotomous variables, indicating whether the child:

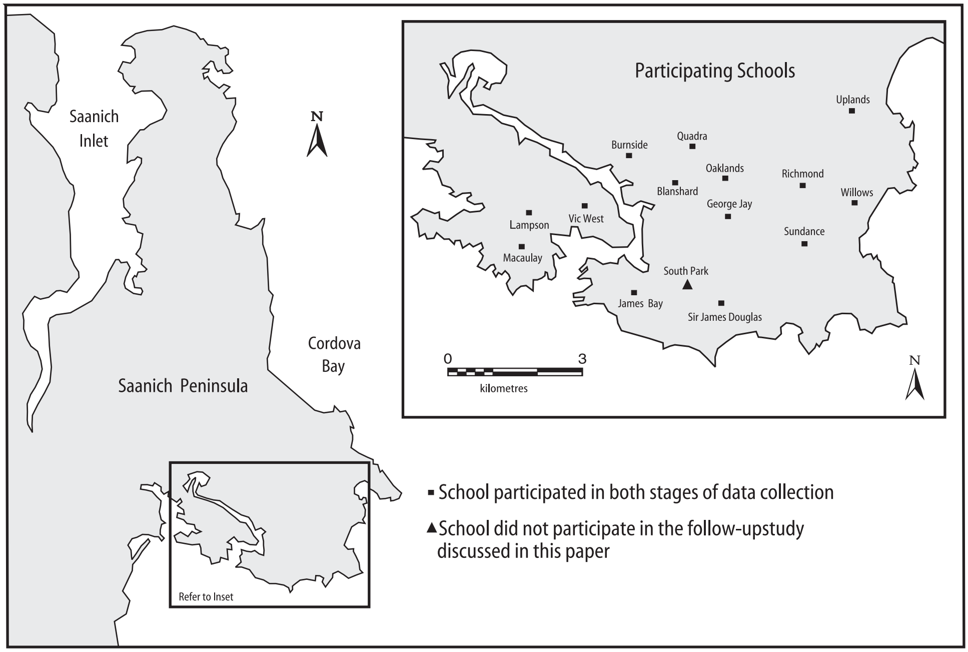
1) had a 'probable cause' for problem behaviour (learning disability, neurological disorder, physical disability)
2) had a biological parent who had ever been treated for a mental illness
3) lived in a single parent family
4) had been born to a mother under 20 years of age
5) lived in a family of low socio-economic status (annual income less than $20,000 and/or living in subsidised housing)
6) had experienced the death of a family member or pet in the preceding 6 months
7) had a family member move away from home in the preceding 6 months

The second part of the survey package consisted of the Walker Problem Behavior Identification Checklist,[56] a behavioural assessment tool which has been shown to be a reliable and effective means of differentiating between disturbed and non-disturbed behavioural patterns in children when completed by a teacher or a parent.[57] The checklist is comprised of 50 items describing negative behaviours, each with an associated "weight" (ranging from 1 to 4) which reflects its relative importance in "handicapping" a child's normal behavioural functioning. Respondents selected items which were characteristic of their child's behaviour in the preceding two month period.

Weighted scores were summed for each of the five Walker scales corresponding to:

1) Acting-Out (e.g. becomes hysterical, upset, or angry when things do not go his/her way; has temper tantrums; displays physical aggression toward objects or persons)
2) Withdrawal (e.g. has no friends; doesn't protest when others hurt, tease, or criticize him/her; does not initiate relationships with other children);
3) Distractibility (e.g. has difficulty concentrating for any length of time; is overactive, restless, and/or continually shifting body positions; does not complete tasks attempted);

Figure 1. Invited/Participating Schools in the Greater Victoria School District.



4) Disturbed Peer Relations (e.g. comments that no one understands him/her; refers to himself/herself as dumb, stupid or incapable; expresses concern about being lonely, unhappy)

5) Immaturity (e.g. reacts to stressful situations or changes in routine with general body aches, head or stomach aches, nausea; has nervous tics: muscle-twitching, eye-blinking, nail-biting, hand-wringing; weeps or cries without provocation).[56]

The total scale, a measure of overall behavioural functioning, was obtained by summing the scores calculated for each of the five scales. The checklist's sex and grade-range adjusted t-score distributions (a t-score of 60 or greater suggesting the need for further evaluation)[56] were used to dichotomize participating children into problem/non-problem behaviour groups for each of the Walker scales.

Volunteers for participation in the follow-up study involving the collection of hair samples were solicited through the inclusion of an informational insert/consent form in the main survey package. This stage in the data collection process allowed for the acquisition of hair specimens which were used to determine individual children's exposures to toxic metals, as well as body stores and/or dietary intake of nutritive trace and bulk elements.

Survey Response and Hair Sample Collection. Of the 2984 survey packages distributed to the 14 schools, 529 (17.7%) were returned complete and accepted for analysis. Permission for participation in the hair sampling stage was obtained from a total of 327 parents. Following receipt of parental consent, hair sample collection took place at the child's school during normal school hours. Of the 327 children for whom consent was received, 42 had hair which was too short to sample, 21 were absent or unavailable at school during the scheduled collection period, four withdrew consent, and two had transferred to a different school during the period between the receipt of parental consent and the collection of hair samples. As well, survey responses revealed that, of the remaining 258 children, 21 (8.1%) had one or more existing condition (learning disability, neurological disorder, or physical disability) which may represent a 'probable cause' for problem behaviour. These children were omitted from the sample for the purposes of this research; the remaining 237 children in the sample were accepted for further analysis.

Proximal hair samples of approximately 2.5 centimetres in length were collected, to a mass in excess of 250 milligrams, from approximately ten sites at the nape of the neck using clean stainless steel scissors. Samples were submitted for analysis to Doctor's Data, Inc., a licensed medical laboratory located in St. Charles, Illinois.

Determination of Hair Element Status. Upon receipt of the hair samples, technicians at Doctor's Data, Inc, cut the specimens into pieces approximately 0.3 centimetres in length and mixed them to allow for a representative sub-sampling of the hair. In order to remove contaminants, samples were washed (four times) in a nonionic detergent, rinsed in acetone, and in de-ionized water (three times). Hair specimens were again rinsed in acetone (twice) before drying in an oven at 75±5 degrees Celsius. The dry samples were digested in nitric acid and analysed for element content in an inductively coupled plasma - mass spectrometer (ICP-MS). To ensure valid element determinations, calibration verifications, a certified hair control, in house hair controls, spiked hair samples, and other appropriate control samples were tested.[58] Results of the hair analyses were reported in parts per million.

Theoretical normal ranges for each of the elements considered in this study have been established by Doctor's Data, Inc. using literature values, patient populations, and other laboratories' reference ranges; and subsequently validated by a physician-defined 'healthy' population.[59] These reference ranges, presented in Table 1 (p.22), were used to categorise the children on the basis of hair element status. Children were classified as 'high exposed' if, for the toxic and nutritive elements, the concentration of the element in their hair was greater than the upper limit of the 'normal' range (greater than one standard deviation above the mean concentration for the reference population). For the essential elements only, children were classified as 'low exposed' if the concentration of the element in their hair was less than the lower limit of the 'normal' range (greater than one standard deviation below the mean concentration for the reference population).

Assessing the Relationship Between Hair Element Status and Behaviour. Logistic regression analyses were used in order to assess the degree of association between hair element status and behaviour. Two analyses were performed for each Walker scale, both of which used behavioural status as the response (dependent) variable. In the first analysis, dummy variables corresponding to hair element status were forced into the model in order to identify elements which were significantly associated with behavioural status as measured on each scale. In the second analysis, these same variables were forced into the model along with the social and family factors. Comparison of the results from each analysis allowed for the identification of elements which were associated with behavioural outcomes before and after considering the effects of the other factors. The strength and direction of the associations between the response and explanatory variables are reported in terms of odds ratios.

Results

Prevalence of Problem Behaviour. The prevalence rates of problem behaviour within the study sample, as measured on each of the six Walker scales, are presented in Table 2 (p.22). With the exception of the Withdrawal and Distractibility scales (which had a prevalence of 5.1 and 13.9 percent respectively), rates of problem behaviour in the sample were relatively high, ranging from 28 to almost 37 percent.

Observed prevalence rates differed slightly by sex of participant, with boys having a higher rate of problem behaviour on all but the Immaturity scale. However, chi-square analyses of 2X2 contingency tables (sex by behavioural status) indicate that these differences are not statistically significant. Likewise, while the mean age of the children belonging to the 'problem behaviour' group is higher for all but the Distractibility scale, results of *t* tests indicate that the observed differences are not statistically significant.

While the rates of problem behaviour in the sample seem high, particularly in light of the rates of childhood psychiatric disorder reported in other studies, two factors make such comparisons problematic. First, the Walker Problem Behavior Identification Checklist is a screening tool designed to identify those children whose behavioural patterns suggest a need for further evaluation; it is not used to diagnose clinical psychiatric problems. Second, because it was necessary to seek a volunteer sample for this research, there may have been an 'interest' bias in the study, with parents/guardians of children with problem behaviour more likely to volunteer their participation in the research. Both of these considerations suggest that the rate of clinical psychiatric disorder would be lower in the population from which the sample was drawn than is implied by the results reported here.

Hair Element Status. Results for the classification of the children on the basis of hair element status are reported in Table 3 (p.23). In general, rates of 'high' exposure for the toxic elements were relatively low. Infrequent high-level exposures to the metals arsenic (3.4%) and mercury (2.1%) are particularly noteworthy. However, a relatively high rate of elevated aluminum exposure (26.2%) was observed.

'Abnormal' levels of the essential elements occurred much more frequently amongst the study participants. In particular, high rates of 'low' hair levels were observed for the bulk elements calcium (48.1%) and magnesium (78.9%), and for the trace element manganese (40.1%). 'High' hair concentrations were common in the sample for the elements copper (40.9%) and zinc (72.6%); while a large majority of children fell within the 'normal' range for the micro-nutrients chromium (98.3%) and selenium (80.5%).

While no information about dietary habits or potential sources of toxic exposure amongst the study participants is available, it is possible to speculate about explanations for the patterns of mineral status observed in the sample. The relative infrequency of 'high' exposure to the toxic metals, for example, is likely reflective of the nature of the study area. As an administrative centre and tourist destination, Victoria is not highly industrialized. As well, the limited industrial activity taking place in the region is largely removed from residential areas. Consequently, very few children would regularly be exposed to such pollutants. The 'high' exposures to lead observed in the sample may be the result of contact with paint and vinyl toys containing the metal, or through inhalation or ingestion of lead-contaminated household dust. With the exception of exposures to mercury, which may be attributable to dental amalgam (and cadmium, which may in part be due to second-hand cigarette smoke), most other exposures to the toxic elements are likely the result of dietary intake of the metals. Aluminum cans,[60] and additives used in the processing and refining of foods[61] are important dietary sources of aluminum, for example.

With respect to the minerals calcium, magnesium, and manganese, relatively high rates of 'low' exposure may reflect dietary inadequacy in the sample, in

Table 1. 'Normal' Reference Ranges.

Element	Males <6 Years of Age (ppm)	Males 6+ Years of Age (ppm)	Females <6 Years of Age (ppm)	Females 6+ Years of Age (ppm)
Toxic Elements				
Aluminum	≤8.00	≤8.00	≤9.00	≤9.00
Arsenic	≤0.15	≤0.15	≤0.15	≤0.15
Cadmium	≤0.25	≤0.25	≤0.25	≤0.25
Lead	≤0.70	≤0.70	≤0.70	≤0.70
Mercury	≤1.50	≤1.50	≤1.50	≤1.50
Bulk Elements				
Calcium	125 - 350	160 - 480	140 - 400	300 - 760
Magnesium	12 - 28	12 - 44	15 - 40	35 - 70
Trace Elements				
Chromium	0.35 - 0.80	0.35 - 0.80	0.35 - 0.80	0.35 - 0.80
Copper	8 - 15	9 - 20	11 - 20	12 - 33
Manganese	0.30 - 0.52	0.30 - 0.50	0.30 - 0.60	0.30 - 0.60
Selenium	0.95 - 1.70	0.95 - 1.70	0.95 - 1.70	0.95 - 1.70
Zinc	95 - 135	110 - 140	100 - 140	115 - 155

Table 2. Prevalence of Problem Behaviour.

Scale	Prevalence Rate (%)	Male Prevalence Rate (%)	Female Prevalence Rate (%)	Chi-Square	Prob.	Mean Age of Problem Behav. Group	Mean Age of Non-Problem Behav. Group	*t*	Prob.
Acting-Out	36.3	36.8	35.8	0.029	0.864	6.92	6.88	-0.193	0.847
Withdrawal	5.1	6.1	4.1	0.530	0.467	7.42	6.87	-1.284	0.200
Distractibility	13.9	14.9	13.0	0.179	0.672	6.79	6.91	0.455	0.649
Disturbed Peer Relations	34.2	37.7	30.9	1.225	0.268	7.07	6.80	-1.379	0.169
Immaturity	29.5	28.1	30.9	0.227	0.634	6.93	6.88	-0.234	0.815
Total	28.3	30.7	26.0	0.641	0.424	7.09	6.82	-1.304	0.193

terms of intake of the elements themselves, as well as consumption of foods which increase excretion or diminish absorption of them. Processed foods, for instance, are typically low in the bulk mineral magnesium and the trace element manganese.[7] 'Junk foods' high in the element phosphorus, such as soda pop and processed foods, and high protein and fat consumption, typical of North American diets, may lead to increased calcium excretion or interfere with calcium uptake. As well, physical inactivity, and emotional or physical stress can elevate the rate of calcium excretion.[61] While hard drinking water can be an important source of these elements,[62] water supplies in the study area are soft, and therefore low in mineral content.

Two of the trace elements, copper and zinc, were 'high' in a relatively large proportion of the sample. Domestic water supplies can be an important source of dietary intake of copper. Since the element is most readily released into soft water,[62] domestic plumbing may represent a significant source of copper exposure for the study sample. As well, false findings of 'high' copper may have resulted in some children as a result of exogenous contamination of hair due to swimming in pools treated with algaecides containing copper compounds.[8]

A majority of children in the current study were classified as being 'high' in hair zinc. Paradoxically, a high level of zinc in scalp hair may be indicative of low zinc in cells, and a functional zinc deficiency. Zinc can be readily displaced from the intracellular zinc binding protein (reservoir) by elevated levels of other metals such as cadmium, lead, copper and mercury, resulting in 'wasting' of zinc and, consequently, an increased accumulation of the element in hair.[8] Thus, it is more likely, particularly in the case of children for whom industrial exposures to zinc are most improbable, that high levels of zinc in the hair are indicative of a deficiency in the mineral. Such deficiencies are associated with low-meat diets, the consumption of refined foods, and high fat and sugar intake.[61]

Associations between Element Status and Behaviour. Since few of the children had hair concentrations of mercury, arsenic, and chromium which fell outside of the 'normal' range, these elements were excluded from further analysis. Similarly, because of their infrequent occurrence in the sample, 'high' magnesium and 'low' selenium were not considered. Results of the logistic regression analyses for the remaining variables are reported in Tables 4 through 9.

For the Acting-Out scale (Table 4, p.25), one hair element variable, 'low' calcium, was significantly associated with an increased likelihood of inclusion in the 'problem behaviour' group. The apparent

Table 3. Hair Element Status.

Element	Low Exposed		High Exposed	
Toxic Elements				
Aluminum	-		62	(26.2%)
Arsenic	-		8	(3.4%)
Cadmium	-		13	(5.5%)
Lead	-		24	(10.1%)
Mercury	-		5	(2.1%)
Bulk Elements				
Calcium	114	(48.1%)	18	(7.6%)
Magnesium	187	(78.9 %)	4	(1.7%)
Trace Elements				
Chromium	0	(0.0%)	4	(1.7%)
Copper	17	(7.2%)	97	(40.9%)
Manganese	95	(40.1%)	13	(5.5%)
Selenium	7	(3.0%)	39	(16.5%)
Zinc	16	(6.8%)	172	(72.6%)

importance of this factor persisted after allowing for the effects of the social and family characteristics, with only a slight decrease in the odds ratio reported in the second analysis. A single family factor was significantly related to behavioural status; those who recently had a family member leave home were more likely to exhibit problem behaviour characterised by 'acting-out.'

With respect to the Withdrawal scale (Table 5, p.26), 'low' calcium was associated with higher rates of problem behaviour in the study sample, while a 'protective' effect was suggested for 'low' magnesium. The statistical significance of these associations persisted, with only a slight decrease in the odds ratios, after including the effects of the social and family factors. As well, 'high' copper was negatively associated with problem behaviour on this scale, but only after the introduction of the social and family variables. One of the family characteristics, having a family member leave home recently, was a significant predictor of 'withdrawal' behaviour.

The Distractibility scale had three element status variables significantly associated with behavioural outcomes (Table 6, p.27). As with the previous scales, children in the 'low' calcium group appear to be at greater risk for problem behaviour on this scale. Unique to this behaviour type, however, are significant direct associations with 'high' manganese and 'high' cadmium. Inclusion of the social and family factors led to a slight increase in the odds ratios for 'low' calcium and 'high' manganese; while the odds ratio associated with 'high' cadmium, though still statistically significant, decreased by about one quarter. With respect to the social and family factors, children born to a mother under the age of 20 were significantly more likely to be included in the 'problem behaviour' group for this scale.

As shown in Table 7, (p.28), a single element status variable, 'high' zinc, had a significant direct association with problem behaviour on the Disturbed Peer Relations scale. This changed only slightly after consideration of the social and family factors in the second analysis. Family factors appear to be of particular importance for this behaviour type; children with a parent treated for a mental illness and those who had a family member recently leave home were more likely to exhibit problem behaviour of this type.

For the Immaturity scale (Table 8, p.29), a single element variable, 'high' lead, had a significant positive association with problem behaviour, but only after including the effects of the social and family factors; none of which were significantly related to behavioural outcomes on this scale.

Results for the Total scale (Table 9, p. 30) suggest that, as with a number of the previous scales, 'low' calcium was an important predictor of problem behaviour, with only a marginal decrease in the odds ratio associated with this variable resulting from the inclusion of the social and family factors. A significant 'protective' effect was suggested for the element status variable 'low' manganese, but only after allowing for the effects of the social and family of factors. Consistent with the findings for several of the other scales, having a family member recently leave home was significantly associated with behavioural status.

Discussion

A number of elements considered in this investigation were found to be significantly associated with the behavioural status of children in the sample, both before and after considering the effects of social and family status. While the use of cross-sectional data and the reliance upon a volunteer sample in this research preclude the advancement of causal statements, the findings here are suggestive of processes which merit further consideration.

Amongst all of the elements considered, calcium in particular appears to be of significance, with an increased likelihood of problem behaviour in children with 'low' calcium observed for the Acting-Out, Withdrawal, Distractibility, and Total scales. While the Walker scales in question measure markedly different behaviours, this finding is consistent with the diversity of neuropsychological effects attributed to calcium deficiency in research examined by Werbach.[19]

Interestingly, for the Withdrawal scale, while 'low' calcium was positively associated with problem behaviour, 'low' magnesium appeared to have a 'protective' effect. While it is unlikely that a deficiency in any essential element would have a beneficial influence on physical or psychological health, an explanation for this finding might be found in the biological interaction between calcium and magnesium. It has been suggested that, for some conditions, it is not the absolute amount of calcium or magnesium which is of concern, but rather the ratio of the two.[7] Given the relatively high rates of both depressed calcium and magnesium observed in the sample, it is possible that for this type of behaviour the ratio of the two elements, rather than the biological availability of each, is of primary importance.

An unexpected finding with respect to the Withdrawal scale was the significant negative association between 'high' copper and problem behaviour. High copper levels are typically associated with an increase in neuropsychological problems due to the toxic qualities of the metal; but a decrease was observed within the sample for problem behaviour of this type. However, as noted earlier, hair copper levels may be af-

Table 4. Logistic Regression Results–Acting-Out Scale.

Variable	Analysis 1 - Odds Ratio	Analysis 2 - Odds Ratio
Toxic Elements		
High Aluminum	1.41	1.50
High Cadmium	0.37	0.44
High Lead	0.99	1.00
Bulk Elements		
Low Calcium	2.49*	2.35*
High Calcium	0.86	0.76
Low Magnesium	0.34	0.34
Trace Elements		
Low Copper	0.99	0.95
High Copper	0.81	0.80
Low Manganese	0.81	0.74
High Manganese	0.65	0.61
High Selenium	0.98	1.01
Low Zinc	1.35	1.41
High Zinc	1.38	1.43
Social and Family Factors		
Parental Mental Illness	-	1.28
Recent Death in the Family	-	1.10
Someone Recently Left Home	-	2.68*
From a Single Parent Family	-	1.39
Low Socio-Economic Status	-	1.03
Born to a Teen-Aged Mother	-	0.64

* p.<0.05 ** p.<0.01

Table 5. Logistic Regression Results–Withdrawal Scale.

Variable	Analysis 1 - Odds Ratio	Analysis 2 - Odds Ratio
Toxic Elements		
High Aluminum	0.97	1.94
High Cadmium	1.51	1.62
High Lead	1.61	2.73
Bulk Elements		
Low Calcium	12.87*	11.92*
High Calcium	1.68	2.84
Low Magnesium	0.07*	0.06*
Trace Elements		
Low Copper	0.73	0.36
High Copper	0.10	0.02*
Low Manganese	0.58	0.62
High Manganese	3.71	10.70
High Selenium	1.38	1.76
Low Zinc	4.19	6.00
High Zinc	8.85	17.07
Social and Family Factors		
Parental Mental Illness	-	0.51
Recent Death in the Family	-	3.96
Someone Recently Left Home	-	6.00*
From a Single Parent Family	-	2.84
Low Socio-Economic Status	-	1.22
Born to a Teen-Aged Mother	-	3.68

* p.<0.05 ** p.<0.01

fected by copper compounds in swimming pool chemicals.[8] Accordingly, information concerning the swimming behaviour of the participating children was collected in the study. Examination of this information revealed that 95 (40.1%) of the children swam 'regularly' in the period preceding sample collection. Indeed, many parents/ guardians reported that their child typically swam more than once per week. Analysis of this data using a 2X2 contingency table indicated that regular swimming was significantly and directly associated with 'high' hair copper (phi=0.282; p<0.0001). Thus, for this sample, copper levels in the hair are unlikely to be reflective of actual systemic levels of the metal. In light of this, the negative association between hair copper and problem behaviour suggested by the analysis is, at best, suspect.

In general terms, the Distractibility scale measures behaviour which is characterised by heightened motor activity, underachievement, failure to conform to limits without intervention, and an inability to concentrate and focus on required tasks. In addition to 'low' calcium, variables indicating 'high' cadmium and 'high' manganese were significantly and positively associated with problem behaviour as measured on this scale. These findings are generally consistent with the reported links between cadmium exposure and learning disabilities;[22] and manganese neurotoxicity and hyperac-

Table 6. Logistic Regression Results–Distractibility Scale.

Variable	Analysis 1 - Odds Ratio	Analysis 2 - Odds Ratio
Toxic Elements		
High Aluminum	0.59	0.42
High Cadmium	10.04**	7.53*
High Lead	0.79	0.77
Bulk Elements		
Low Calcium	4.35*	4.91*
High Calcium	0.59	0.53
Low Magnesium	0.41	0.44
Trace Elements		
Low Copper	2.08	1.63
High Copper	0.69	0.81
Low Manganese	0.78	0.63
High Manganese	6.38*	6.77*
High Selenium	1.55	1.66
Low Zinc	4.20	3.56
High Zinc	2.47	2.74
Social and Family Factors		
Parental Mental Illness	-	2.06
Recent Death in the Family	-	1.51
Someone Recently Left Home	-	1.53
From a Single Parent Family	-	0.56
Low Socio-Economic Status	-	1.19
Born to a Teen-Aged Mother	-	7.54**

* p.<0.05 ** p.<0.01

tivity in children.[45] Likewise, the significant positive association between 'high' zinc (which, as suggested earlier, may be indicative of low systemic zinc levels) and problem behaviour for the Disturbed Peer Relations scale is consistent with some of the symptoms of deficiency reported for this trace metal, including depression and irritability.[19]

While the element status variable 'high' manganese had a direct relationship with behaviour characterised by 'distract-ibility,' those with 'low' manganese were less likely to receive a score in the 'problem behaviour' range for the Total scale after controlling for social and family characteristics. This finding is in partial agreement with the significant direct relationship between hair manganese levels and Total scale scores reported by Marlowe and Bliss.[34] It should be noted, however, that children with 'high' manganese were not, as would be suggested by such a relationship, significantly more likely to receive a score in the 'problem behaviour' range for this scale.

Although lead exposure has been linked to a number of neuropsychological effects, 'high' exposures to this toxic metal were significantly associated with problem behaviour described by the Immaturity scale alone, and only after controlling for the social and family factors. A number of the effects noted for lead toxicity are consistent with the behaviours of which this

Table 7. Logistic Regression Results–Disturbed Peer Relations Scale.

Variable	Analysis 1-Odds Ratio	Analysis 2-Odds Ratio
Toxic Elements		
High Aluminum	1.23	1.25
High Cadmium	1.11	1.06
High Lead	1.43	1.76
Bulk Elements		
Low Calcium	1.38	1.17
High Calcium	0.61	0.41
Low Magnesium	0.49	0.49
Trace Elements		
Low Copper	0.76	0.60
High Copper	0.68	0.72
Low Manganese	0.71	0.62
High Manganese	1.77	1.68
High Selenium	1.06	1.04
Low Zinc	1.01	0.83
High Zinc	2.55*	2.86*
Social and Family Factors		
Parental Mental Illness	-	2.20*
Recent Death in the Family	-	1.99
Someone Recently Left Home	-	4.08**
From a Single Parent Family	-	1.00
Low Socio-Economic Status	-	1.39
Born to a Teen-Aged Mother	-	1.23

* p.<0.05 ** p.<0.01

scale is comprised, including anxiety, irritability, fatigue, and restlessness.[19] While it is somewhat surprising that lead exposure was not more strongly associated with problem behaviour of all types, its relative weakness as a predictor of overall behavioural functioning may reflect the fact that the threshold level for 'high' lead used in this study is not necessarily indicative of lead poisoning.[8] Clearly, the importance of lead exposure as a risk to children's psychological and cognitive development is reinforced by its frequent appearance in the literature.

Conclusion

While health research in general has moved toward a more holistic approach in its attempts to explain the genesis of various ill-health conditions, the vast majority of research concerned with the aetiology of childhood psychiatric problems has focussed on the role of social and family factors in determining behavioural status. In spite of decades of such research, little has been accomplished to alleviate the individual and societal burdens of this problem.

The results of this research, combined with that described in the broader literature, suggest the need to give more serious consideration to what are often considered 'alternative' explanations for psychiatric disturbance. Indeed, while it is reasonable to assume that no single cause for childhood mental health problems will be found,

Table 8. Logistic Regression Results–Immaturity Scale.

Variable	Analysis 1 - Odds Ratio	Analysis 2 - Odds Ratio
Toxic Elements		
High Aluminum	0.60	0.58
High Cadmium	2.64	2.20
High Lead	2.53	2.76*
Bulk Elements		
Low Calcium	1.04	1.02
High Calcium	1.14	1.03
Low Magnesium	1.06	1.05
Trace Elements		
Low Copper	1.17	1.09
High Copper	0.94	1.01
Low Manganese	0.76	0.79
High Manganese	2.58	2.58
High Selenium	0.76	0.73
Low Zinc	0.53	0.47
High Zinc	1.35	1.29
Social and Family Factors		
Parental Mental Illness	-	1.18
Recent Death in the Family	-	1.40
Someone Recently Left Home	-	1.11
From a Single Parent Family	-	0.72
Low Socio-Economic Status	-	1.31
Born to a Teen-Aged Mother	-	1.28

* p.<0.05 ** p.<0.01

the relative ease with which trace, bulk, and toxic element status can be assessed suggests that, in attempting to identify the source of behavioural problems in a particular child (and hence a course of treatment), dietary deficiencies and exposures to environmental toxins should be given routine consideration. If no evidence for a dietary or environmental explanation is found, more 'traditional' approaches to treatment may be appropriate. In those cases where nutritional deficiencies or toxic effects are suggested, these 'standard' methods of intervention and remediation may prove ineffective.

Further research in this area is clearly necessary in order to clarify the relationship between element status and behaviour. In particular, consideration of the potential cumulative effects of social deprivation, dietary insufficiencies, and toxic exposures on children's mental health may prove valuable. Ultimately, however, research which determines whether the relationship between element status and childhood psychiatric disorder is one of causation, rather than association, will require randomized trials of mineral supplements and toxic metal exposure prevention programmes.

Acknowledgements

The authors wish to thank the Greater Victoria School District, the Principals and Teachers of the participating schools

Table 9. Logistic Regression Results–Total Scale.

Variable	Analysis 1 - Odds Ratio	Analysis 2 - Odds Ratio
Toxic Elements		
High Aluminum	0.99	0.96
High Cadmium	1.27	1.30
High Lead	1.61	1.81
Bulk Elements		
Low Calcium	3.12**	3.04**
High Calcium	0.76	0.64
Low Magnesium	0.53	0.58
Trace Elements		
Low Copper	1.23	1.07
High Copper	0.72	0.75
Low Manganese	0.51	0.43*
High Manganese	1.20	1.16
High Selenium	0.77	0.78
Low Zinc	1.01	0.93
High Zinc	1.79	1.95
Social and Family Factors		
Parental Mental Illness	-	1.41
Recent Death in the Family	-	1.48
Someone Recently Left Home	-	3.32**
From a Single Parent Family	-	1.51
Low Socio-Economic Status	-	1.45
Born to a Teen-Aged Mother	-	1.58

* p.<0.05 ** p.<0.01

and, most of all, the parents/guardians and children who agreed to take part in this study. Special thanks are also due to Dr. Harold Foster, Dr. Ge Lin, Dr. Mark Flaherty, Mr. Darrel Hickok, Ms. Jody Diana, Ms. Kimberly Bezaire, and the volunteers, too numerous to name, who helped with the substantial envelope stuffing required in the implementation of this research.

The first-named author gratefully acknowledges financial support for this research received from the British Columbia Health Research Foundation and the Sara Spencer Foundation.

This paper is dedicated to the memory of Dr. Frank C. Innes.

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