might be so (*24*). Examples of four fiber-cell pairs are shown in Fig. 2. In three of the four pairs both units were isolated and found to have similar field characteristics. The delays between the retinal fiber spike and the LGN cell spike for the two X-cells are about 1.2 msec (1.0 to 2.0) (21-day-old kitten) and 0.5 msec (0.5 to 0.8) (33-day-old kitten). The Y-cell pair of the 33-day-old kitten had an interspike delay of 2.0 msec (1.4 to 3.8), and the unclassified pair (21-day-old kitten) had a delay of 1.6 msec (0.5 to 2.8). This suggests the possibility that developmental events within the LGN may contribute to the observed latency difference between cells.

In adult cats the LGN cell responses are time-locked to the maintained activity of one to three retinal ganglion cells (*25*); however, this relationship has not been demonstrated in the kitten. It has been our finding that LGN cells of kittens younger than about 4 weeks of age have zero to very low (< 1 per second) maintained rates of firing, while retinal fibers have higher rates (*26*). It is likely that temporal and spatial summation are a requirement for driving immature LGN cells, in which case any single fiber-cell pair might not be related as in the adult cat. Certainly this should be investigated. Our finding, however, is that when the visual pathway is stimulated electrically, activating large numbers, if not all afferents to the LGN, cell pairs have different fiber-cell response intervals. And, in addition, the data we have indicate the possibility of longer intervals for immature Y-cells. The different fiber-cell response intervals, as well as the variability in intervals observed within a single pair of units, might be an indication that there is summation between synapses of different retinal afferents at single LGN cells in kittens. Loss of this convergent input, as well as synaptic maturation, might then account for synaptic delay changes. Furthermore, these processes may have different time courses for X- and Y-cells.

In addition to early OX latency maturation, we also find that some X-cells develop surround responses, surround inhibition, adult receptive field sizes, and mature responses to moving targets by 21 to 34 days and prior to nearly all Y-cells (*26*).

Our data show that before myelination of optic-nerve fibers, all LGN cells have long OX latencies and immature receptive field properties. After myelination onset it appears that some of the X-cells mature to their adult response character quickly. If some cells in the visual cortex receive primarily Y-cell input from the LGN (*9*), then some of those cells may mature more quickly than their counterparts receiving Y-cell input. This may account for the fact that some mature cells have been observed in young kitten visual cortex (*8*). Also, a protracted developmental period for Y-cells might help to account for some of their modifiability with visual deprivation (*27*).

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17. A Nova II minicomputer was used to present flashing and moving spots of various sizes and to collect spike data. Based on this data, we classified cells as sustained or transient and also noted their field sizes, presence of surround responses, strength of surround inhibition, and responses to different velocities of stimulus movement.
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20. The mean range of spike latencies for all cells of kittens 6 to 20 days of age was 6.5 msec (S.D. 3.8). At 21 to 27 days the mean range dropped to 1.5 msec (S.D. 0.5), and it was adultlike (0.5 msec, S.D. 0.2) at 35 to 41 days.
21. The means for all X-cells/Y-cells at 21 to 27 days and 28 to 34 days were 4.6 msec (S.D. 3.1)/5.1 msec (S.D. 2.6) and 3.4 msec (S.D. 1.2)/3.8 msec (S.D. 1.3), respectively.
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Hair Element Content in Learning Disabled Children

Abstract. *Hair samples from 31 learning disabled and 22 normal children were analyzed for content of 14 elements. Significant group differences were determined and a discriminant function was completed which separated the groups with 98 percent accuracy. Elevated lead and cadmium content in the learning disabled group is viewed as being of particular importance.*

The influence of heavy and trace elements on human physical functioning has been well studied (*1*). Much less is known about the effects of these elements on behavior. The finding reported here, of a significant relation between the content of these elements in the hair and learning disabilities, represents an initial step in assessing the behavioral effects of heavy and trace elements.

Definitions of learning disability often exclude the mentally retarded, the obviously neurologically impaired, and the emotionally disturbed. Occasionally, definitions are specific to difficulty in a single academic subject; in general, scholastic failure is crucial. The paradigmatic learning disabled (LD) child is therefore a child that does not fit one's list of exclusions but continues to have difficulties in school achievement. The suggested causes of learning disabilities tend to be as broad and variable as present definitions, and range from minimal brain damage to lags in educational maturation (2).

The 31 LD children of this study were selected from a sample of 1030 regular third- and fourth-grade students for whom the Pupil Rating Scale (3) had been completed. This teacher-completed scale covers five areas: auditory comprehension, spoken language, orientation, behavior, and motor skills. The 226 children who obtained scores below 67 on this scale were then administered the Peabody Picture Vocabulary Test, from which an intelligence score was computed, and the Metropolitan Achievement subtests of reading, spelling, mathematics computation, and mathematic problem solving. Those children who obtained normal or higher than normal scores on the Peabody test but failed one or more subtests on the Metropolitan Achievement battery, and for whom parental consent could be obtained, constituted the LD group.

Many reports (4) which focus on nutritional deficiencies and exposure to toxic substances in LD children led us to collect samples of head hair. The hair was collected from the children according to the procedure of the Trace Element Laboratory, Case Western Reserve University, and then sent to that laboratory for analysis by means of atomic absorption spectroscopy. This method, which is quick and inexpensive and is relatively unobtrusive for the subject, is used for investigating the level of heavy elements and is a promising technique for assessing trace elements (5).

The data obtained indicated that the subjects deviated from provisional norms on many of the elements. This raised questions concerning the applicability of these norms. An additional group was therefore selected for hair analysis. Twenty-two children from the original sample of 1030 who scored above 68 on the Pupil Rating Scale, and therefore designated as normal controls, were chosen at random from the same school, class, and sex as 22 of the experimental children, thus approximating control over socioeconomic, geographical, and sex variables.

Table 1. Mean element scores [expressed as mean parts per million (ppm)] for the two groups (LD children and controls) and analysis of variance (d.f. = 1, 47) for each element across groups (N.S., not significant).

Element	LD (ppm)	Control (ppm)	F ratio	Level of significance
Calcium	397	344	1.75	N.S.
Magnesium	35	37	0.28	N.S.
Potassium	1359	1240	0.21	N.S.
Sodium	1637	919	5.10	$P < .02$
Cadmium	1.72	1.08	84.52	$P < .001$
Cobalt	0.16	0.23	35.00	$P < .001$
Copper	12	17	0.72	N.S.
Iron	23	22	0.82	N.S.
Lead	23	4	28.32	$P < .001$
Manganese	0.83	0.58	15.21	$P < .001$
Zinc	139	140	0.10	N.S.
Chromium	0.25	0.09	8.49	$P < .01$
Lithium	0.22	0.40	7.29	$P < .01$
Mercury	14	15	0.52	N.S.

In order to determine more accurately the socioeconomic status of each child in both the experimental and control groups, the occupation of the parent earning the major part of the family's income was used to assign a socioeconomic index (6). The mean socioeconomic index for the LD group was 39.5; for the control group, it was 40.3. The two groups proved to be similarly well-matched for age (LD = 137.0 months mean age; control = 137.5 months), sex (31.8 percent of the control group was female; 25.8 percent of the LD group was female), and language (9.1 percent of control group was non-English speaking; 6.5 percent of LD group was non-English speaking).

Samples of hair from the children in the control group were collected in the same way as before and were sent unlabeled to the same laboratory for analysis (Table 1).

An analysis of variance of the 14 elements yielded seven significant differences between the two groups (Table 1) and a significant main effect for sex on only three elements: calcium (F = 11.95; d.f. = 1, 47; $P < .01$), magnesium (F = 7.68; d.f. = 1, 47; $P < .01$), and zinc (F = 5.19; d.f. = 1, 47; $P < .05$). None of these elements were later used in a discriminant function between groups. There were no significant group by sex interactions for any metal.

To test the possibility that other, organismic variables might better account for the variation in trace metal content than did the group variable, we entered each child's socioeconomic index, language, age, sex, as well as group into a regression equation for each metal. Sex and group proved useful predictors of the same trace metals described above. Neither age nor language contributed significantly to any regression equation. Socioeconomic status contributed significantly only in the prediction of cobalt (F = 4.14; d.f. = 1, 44; $P < .05$). This was owing to a very small, positive correlation (r = .25, $P < .05$) between socioeconomic index and cobalt level. We are inclined to believe that this is due to chance.

A discriminant function analysis revealed that by using cadmium, cobalt, manganese, chromium, and lithium, all subjects could be classified as LD or normal with 98 percent accuracy, a result that was quite unexpected. Although some of the predictive factors may represent nutritional peculiarities, numerous inexplicable differences remain. It is important, however, that the higher lead and cadmium content in the LD group relates to a specific literature (7–10). It will be noted that the discriminant function does not include lead, because the predictive function of this element is served by cobalt and cadmium. There is a strong, negative correlation (r = −.67, $P < .001$) between the lead and cobalt levels, and a positive correlation between the lead and cadmium levels (r = +.53, $P < .001$).

The role of lead toxicity on behavior is well documented (7). Although the LD subjects showed considerably lower amounts than those regarded as toxic, increasing evidence (8) suggests that exposure to low concentrations of lead also has deleterious effects on behavior. Childhood hyperactivity is one syndrome gaining considerable attention in this regard, although methodological questions concerning a lack of control for the socioeconomic variable have been raised (9). In this regard, the results of our study represent a control for the socioeconomic variable. Cadmium toxicity is also receiving increased attention (*10*), although studies of its effect on behavioral disturbances are lacking.

The definition of LD used in the present study, although typical, is overly general, having been selected originally for reasons unrelated to hair element study. Consequently, statements as to what specific behaviors account for the reported relation between groups and metals cannot be made. Also, the possible importance of the time difference (2½ months) in collecting hair from LD group and from the control group is unknown. Nevertheless, the high levels of significance reported here, the presence of geographical and socioeconomic controls, the consistency with a growing literature on the subject, and the general failure of educative techniques with many LD children suggests that element patterns may prove not only a fruitful diagnostic procedure, but may also provide answers pertaining to etiology and treatment.

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Entropy Estimates of Garnets and Other Silicates

As a way of estimating third law entropies of silicates, Saxena (*1*) has presented equations in which there is a linear relationship between the molar entropy at 298.15°K and the molar volume. He has used these equations to estimate the entropy of the garnets pyrope ($Mg_3Al_2Si_3O_{12}$) and almandine ($Fe_3Al_2Si_3O_{12}$). The equation applied to pyrope was obtained from the data for the orthosilicates of Be, Mg, Ca, and Zn, and the equation for almandine was based on the entropy of $FeSiO_3$ and $MnSiO_3$. The procedures used by Saxena are open to criticism on two counts: (i) the linear relationship between entropy and volume completely ignores the well-known role of mass, and (ii) for compounds containing transition metal ions, significant magnetic contributions to entropy are neglected.

In essence, Saxena (*1*) provides expressions for estimating the entropy of lattice vibrations. It has long been known (*2*) that "lattice" entropy can be estimated satisfactorily in terms of atomic mass. Of course, volume will also be a factor. Indeed, Cantor (*3*) has shown, from the Debye theory of specific heats, that lattice entropy S is related both to molar mass M and to molar volume V by the equation

$$S = A + \frac{3}{2} nR \ln MV^{2/3} \quad (1)$$

where A is nearly constant for closely related compounds, n is the number of gram-atoms in a mole of the crystal, and R is the gas constant. Values of A for the orthosilicate series of the formula $M_2^{II}SiO_4$ are given in Table 1. These values were obtained from the experimental entropies, at 298.15°K, critically compiled by Robie and Waldbaum (*4*). At 298.15°K, Ca-olivine is more stable than larnite (β-Ca_2SiO_4), and it is Ca-olivine that is correlated by Eq. 1. Saxena (*1*) specifically excludes Ca-olivine from his correlation for orthosilicates, presumably because his estimated entropy was too high by 9.15 gibbs/mole.

Table 1. Values of A for orthosilicates of the formula $M_2^{II}SiO_4$.

Silicate	Formula	A (gibbs/mole)
Phenacite	Be_2SiO_4	−133.01
Forsterite	Mg_2SiO_4	−133.02
Ca-olivine	γ-Ca_2SiO_4	−135.36
Willemite	Zn_2SiO_4	−136.47
Average		−134.47

A more directly applicable form of Eq. 1 is the expression

$$S_y = S_x + \frac{3}{2} nR \ln [M_y V_y^{2/3}/(M_x V_x^{2/3})] \quad (2)$$

where y refers to a compound whose entropy is to be estimated and x signifies a reference compound, that is, one chemically and structurally similar to y whose entropy is known. For instance, to estimate the entropy at 298.15°K of pyrope ($Mg_3Al_2Si_3O_{12}$), we use grossularite ($Ca_3Al_2Si_3O_{12}$) as the reference compound. Substituting in Eq. 2 the experimental data tabulated in (*1*), we have pyrope entropy = 1.5(20)1.987 ln $[403.15(113.27)^{2/3}/(450.454(125.3)^{2/3})]$ = 57.7 = 47.07 gibbs/mole.

The estimation of entropy at 298.15°K for crystalline silicates containing transition metal ions requires an additional term to account for the disorder of magnetic moments. For compounds of the first transition series, Ulbrich and Waldbaum (*5*) have shown that magnetic entropy S_m can be approximated from the spin quantum number S by the equation

$$S_m = R \ln (2S + 1) \quad (3)$$

For example, in rhodonite ($MnSiO_3$), S for divalent manganese is 5/2 and, from Eq. 3, S_m = 3.561 gibbs/g-atom. The lattice entropy at 298.15°K, estimated from enstatite ($MgSiO_3$) according to Eq. 2, is 21.26 gibbs/mole. The sum, 3.561 + 21.26 = 24.82 gibbs/mole, agrees quite closely with the experimental entropy of 24.5 ± 0.5 gibbs/mole given in (*4*). We can estimate (Table 2) the entropies of the orthosilicates tephroite (Mn_2SiO_4) and fayalite (Fe_2SiO_4) from Eq. 3 by calculating lattice entropy from Eq. 1, using the average A (−134.47 gibbs/mole) ob-

Table 2. Calculation of the entropies of tephroite and fayalite.

Formula	Lattice entropy (Eq. 1)	Magnetic entropy (Eq. 3)	Estimated entropy	Experimental entropy (*4*)
Mn_2SiO_4	30.30	7.12	37.42	39.0 ± 1.0
Fe_2SiO_4	29.83	6.40	36.23	35.45 ± 0.4