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THE SUMMER DISEASE

SOME FIELD EVIDENCE ON SEASONALITY IN CHILDHOOD LEAD POISONING

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Abstract—Blood leads of 32 well children measured before and after the summer show a significant elevation indicating that circulating lead is seasonally mobilized from the body burden. In a larger sample of 243 well children, white, black and chicano, of mean age 36 ± 16 months, tested for blood leads, analysis reveals a close correlation between month of birth and lead level; spring-born and summer-born children constitute low and high blood-lead groups, respectively. Seasonal variations of placental transfer of lead to the foetus is implicated; as are other factors. Density of skin pigments affecting biosynthesis of vitamin D apparently causes seasonality variations among the three ethnic groups. The seasonality factor accounts for 16% of explained variance of blood-leads of black children, 12% for chicano, and 4% for white children. Public health screening programs should ideally be conducted in summer to identify the maximum number of children at risk. Where year-round readings are taken, proportional adjustments should be made in the order of 30–50% to allow for summer elevations. Physicians should be particularly alerted to summer elevations in black children.

Childhood lead poisoning is largely a summer manifestation. The etiology of elevated levels of blood lead in the summer is complexly derived from increased outdoor ingestion and inhalation, increased absorption through elevated vitamin D levels, and increased mobilization of the body burden of lead. A synthesizing model of these and other seasonality relationships is presented earlier in this journal and need not be recapitulated here [1].

Particularly lacking, it seems, are seasonal field measurements of pediatric blood lead that may identify quantitatively the parameters of the seasonal effect. Also lacking is a consideration of the phenomenon's implications for public health services.

In 1972, with the support of state and county health departments, the author organized a community-wide, door-to-door sampling of well-babies in the City of Lansing, Michigan. Blood was collected and measured for lead content. Personal information was obtained from the mothers, and environmental data were also gathered. The first goal of the survey was to ascertain the prevalence of elevated blood leads among children in the city, and to report these findings to the health authorities. The second, more difficult, goal was to identify associations, possibly causal in nature, between elevated lead levels and behavioral and environmental factors. This report focuses solely upon a portion of the second goal, namely, the phenomenon of seasonality. It offers the following new contributions based upon field survey: (1) measurement of pediatric blood lead levels in a group of children followed through a summer; (2) analysis of pediatric blood leads by birth date and by season of birth; (3) evidence suggesting the possible importance of placental transfer of lead during a summer gestation; (4) evidence implicating density of skin pigments as a factor in seasonal variation of circulating lead; and (5) a statistical association between solar radiation income and circulating lead levels in children by month of birth.

BLOOD LEAD LEVELS THROUGH A SUMMER

A sample of 32 children in Lansing were measured for levels of lead in the blood over the summer of 1972. The sample was derived from a larger study group on the basis of the willingness of mothers to cooperate, and on the basis of availability at the time of the survey. The children were not identified through clinic or hospital attendance, but were selected at random in geographically scattered houses in the city. They were not known to be suffering from lead intoxication. Their mothers regarded them as normal, well babies. Residences were free-standing; their quality varied but severe blight was absent. The environmental circumstances of the children surveyed appeared to be generally representative of the non-suburban areas of the city.

Blood samples were collected by finger-prick and analyzed by atomic absorption spectrometry (see Acknowledgements). The mean age of the children, at first measurement, was 37 months; 66% were female, 56% were white, 31% were chicano, 13% black. Each child was measured twice for blood lead over an interval of 3–4 months. The survey periods ranged from May 4th to June 6th, and from August 24th to October 13th, thus approximately bracketing the summer of 1972.

At the beginning of the summer, the mean lead reading was 31.7 μg/100 gWB, and by the end it had risen by 22.5% to 38.8 μg; 71.9% of the children showed elevated levels. Individual increases ranged up to roughly 100%. Before the summer, only 6% of the children had "exposed" lead levels, i.e. more than 40 μg, whereas, at the end of the summer, 38% were

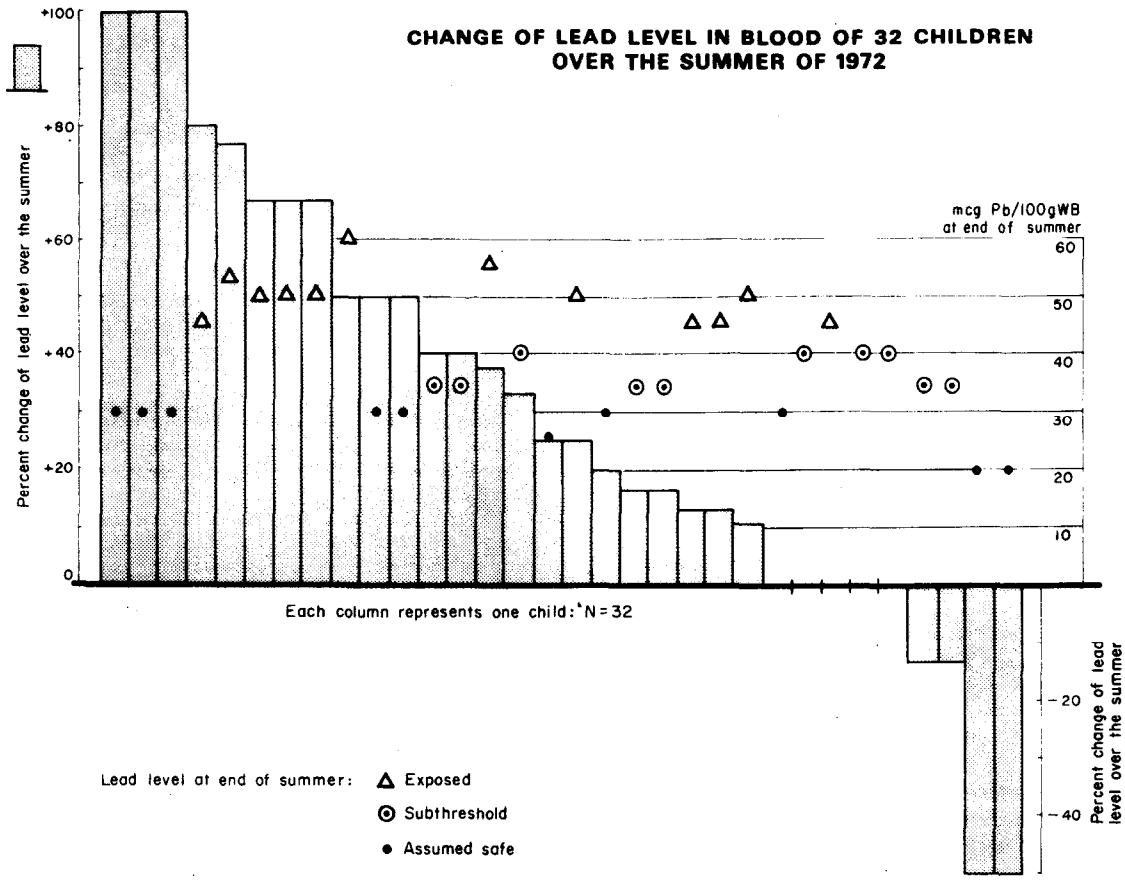

Fig. 1. By summer's end, over a period of 3–4 months, the mean lead level had risen by 22.5%, and 38% of the children were found to have "exposed" blood levels of $\geq 41\ \mu g$. Source: author's survey.

exposed, and 31% were subthreshold, i.e. 31–40 μg. The proportional change in blood lead for each child, together with the end-of-summer reading, is indicated by histogram (Fig. 1). The sample is small, but the significance of these findings seems to be that, even in an apparently normal, low-risk, pediatric population, summer sunshine will elevate blood lead by an average of 22.5% in 3 or 4 months and, in some instances, precipitate clinical or near-clinical conditions.

Gross, cross-sectional survey data of approx 30,000 children under 6 yr of age in Chicago suggest seasonal variation of even greater magnitude over the year. Children measured in June had an average blood lead level some 48% higher than those measured in December; conversely, the latter group was 32% below the former [2]. In the same survey, older children in a control group, 10–14 yr of age, also showed a considerable seasonal variation of +35% or −26%.

The implications of the longitudinal findings in Lansing, and of the cross-sectional findings in Chicago, for public health services, are obvious. Mass screening campaigns should take place in the summer months so as to be more certain of identifying all children at risk. Where screening campaigns are necessarily conducted in winter, or where individual testing is done on a year-round basis, a proportional adjustment of readings is indicated to allow for summer elevations.

BLOOD LEAD LEVELS BY DATE OF BIRTH

The Lansing sample population, of which the summer group discussed above was a subset, was derived in 1972 from a community-wide, door-to-door survey in the City of Lansing. Measurement techniques, including finger-prick, capillary tube specimens, and atomic absorption spectrometry, were identical with those of the summer survey described above. All measurements were made in the winter and early spring, i.e. before the onset of summer. Among other information, birthdates of the surveyed children were collected, and these are analyzed below, in relation to blood lead levels.

The sample covered 243 children. Their mean age was 36 ± 16 months; 44% were white, 33% black, and 22% chicano. There is an apparent bias towards spring births (40%), with the other seasons being approximately uniform (19–21%).

An important finding of the survey was the fact that black children had higher levels of blood lead

Table 1. Lead in blood of Lansing children, surveyed in 1972, by season of birth, 1967–71

PART 1. MEAN LEAD LEVELS

	Summer			Fall			Winter			Spring			Year		
Months	6–8			9–11			12–2			3–5			1–12		
*	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
White	18	37	±11	19	32	±13	18	36	±14	51	32	±13	106	34	±11
Black	24	58	±25	16	47	±12	20	47	±16	21	44	±13	81	50	±18
Chicano	8	41	±19	17	36	±14	6	36	±12	22	35	±11	53	37	±13
Total	50	48	±22	52	38	±14	46	42	±15	95	35	±15	243	40	±16

* (a) No. of children; (b) mean μgPb/100 gWB; (c) standard deviation.

PART 2. PERCENT COMPARISONS WITH ANNUAL MEAN

	Summer	Fall	Winter	Spring	Year
White	108.8	94.1	105.9	94.1	100.0
Black	116.0	94.0	94.0	88.0	100.0
Chicano	110.8	97.3	97.3	94.6	100.0
Total	120.0	95.0	105.0	87.5	100.0

PART 3. PERCENT HIGH–LOW COMPARISONS

	Summer	Fall	Winter	Spring
White	115.6	100.0	112.5	100.0
Black	131.8	106.8	106.8	100.0
Chicano	117.1	102.9	102.9	100.0
Total	137.1	108.6	120.0	100.0

Source: Author's survey. $N = 243$ includes 3 "other" children.

than the other groups: an average of 50 μg/100 gWB, compared with 34 μg for whites, and 37 μg for chicanos (Table 1.1). The present study does not attempt to examine the circumstances that result in such absolute differences; it focuses only upon related seasonality aspects.

If the surveyed children are grouped by quarter of birth, it is seen that summer-born children have the highest lead levels (a mean of 48 μg), and that spring-born children have the lowest levels (a mean of 35 μg); with winter-born children exhibiting a secondary peak (Table 1.1, Fig. 2). In fact, summer-born children had circulating lead levels that were 37% higher than those of spring-born children (Table 1.3). Remarkably, these birth-related differences obtain, on average, 3 yr after birth. The total group pattern by season of birth is replicated in each subset of white, black and chicano children. Blacks have the highest summer-born values (mean of 58 μg) and also the greatest seasonal increase (Table 1.1 and 1.3, Fig. 2).

When the children are further ranked by month of birth, rather than by season, it is at once apparent that their mean lead levels are non-randomly distributed (Table 2, Fig. 3). May-born children have the lowest levels, and July-born the highest, with February-born providing a secondary peak. Mean blood lead levels of July-born and February-born children are 59% and 38% higher, respectively, than that of May-born children. The monthly trend for black children closely parallels that for white children, although it is much higher. With a small population sample ($N = 243$) divided by month of birth, and by ethnic group, the data are inevitably much diluted, but the startling conclusion that one draws from these findings is that the accident of season of gestation and birth can have an influence upon the level of lead in the blood of a young child some three or more years later.

Comparison of lead levels of 1-year-old children with 3-year-olds, by month of birth, very clearly shows the seasonality aspect of lead increments (Fig. 4). Again, they are non-random. Major increments occur in June-, July- and August-born children; while minor, winter increments are observable for January-born and February-born children.

During the seven months of May–November the distribution of mean lead levels, by month of birth, is closely consonant with environmental temperatures and solar radiation in what is apparently a cycle of circulating lead (Fig. 5). The correlation coefficient between lead level and radiation income of the preceding month is surprisingly significant considering the small number of observations: $N = 7$, $R = 0.906$, $P = 0.005$. This finding strongly implicates the seasonal biosynthesis of vitamin D, related to date of birth, as a factor in levels of blood lead in childhood. The phenomenon seems to be related to findings described elsewhere for the City of Cleveland where reported monthly hospital admissions for pediatric plumbism over a seven-year period show a very strong association with solar radiation income of the preceding month ($R = 0.905$, $P < 0.0005$) [3].

In searching for an explanation of the non-random relationships between pediatric blood levels and season of birth, we may refer to the model of hypothesized seasonal relationships previously mentioned [4]. Children born in summer will inevitably be subject to greater exposure of summertime environmental conditions. These might include more inhalation of aerosol lead, increased outdoor geophagical risk and, importantly, higher absorption rates of lead due to elevated vitamin D levels. Increased absorption will

augment storage rates which, in turn, will result in a greater body burden. The importance of summer exposure time will proportionately diminish with the increasing age of a child; that is, the age effect will eventually over-ride the season-of-birth effect. Nonetheless, as the Lansing survey shows, season of birth is still important in a population that is 3 yr of age, ±16 months.

The foregoing arguments, however, offer only a partial explanation. Undoubtedly *in utero* transfer of maternal lead stores is also a key factor. Variations of newborn lead levels will reflect the volume of maternal lead stores and the degree to which these have been mobilized during gestation. In this respect, gestation in summer months will produce the highest level of circulating lead, the greatest risk of transfer to the foetus, and hence the largest neonatal inheritance of lead. It should be noted, however, that, in the absence of actual measurements, it is not possible to distinguish between the relative proportions of foetally and post-natally acquired lead in a child.

The secondary peak for winter-born children (B in Fig. 5) is unrelated to the annual radiation curve. We know, however, that increments of blood lead accrue in this group between the ages of one and three in those born in January and February (Fig. 4). Obviously some influence is at work, and one can suggest that it is behavioral and developmental in origin rather than environmental. A child born in January–February will be six months and actively crawling by mid-summer. Increased tactile exploration, ingestion, inhalation and absorption, coinciding with summer radiation, may be sufficient to produce a small secondary risk group, beyond the level for fall- and spring-born children. By comparison, the spring-born child will not be so actively crawling, if at all, during his or her first summer. Fall-born children have mean lead levels that are intermediate between spring and winter levels (Table 1).

Lead levels in a pediatric population vary with environmental exposure and ingestion. The hazard is multicausal and multidimensional. Seasonality phenomena contribute only part of the total variation. An attempt to ascertain the extent of this contribution is presented in Table 3. Taking the group as a whole, and comparing the four seasons of birth, we find that those born in summer show a positive correlation with lead levels ($R = 0.265$, $P < 0.0005$), while those born in spring show a negative correlation ($R = -0.219$, $P = 0.001$). The multiple correlation coefficient between season of birth and lead level for all subjects is $R = 0.301$, which is significant at $P < 0.0005$ and accounts for 9% of the variance in the group.

A supplemental attempt to measure the summer influence can be made by comparing summer exposure time with lead levels (Table 3). In this calculation, the number of June, July and August days, from day of birth to day of testing, is used as the independent variable. Summer exposure, thus defined, is of course partly a function of age of the child since, the older a child is, the larger its aggregate exposure [5]. It is also partly a function of season of birth. The relationship between lead levels and summer days proved to be weaker ($R = 0.182$) than the association with season of birth, but it is still significant ($P = 0.005$). When season of birth and summer exposure are combined into a so-called "seasonality factor", the association with lead levels in the sample population in a multiple correlation is stronger: $R = 0.345$, $P = <0.0005$. Allowing for reservations

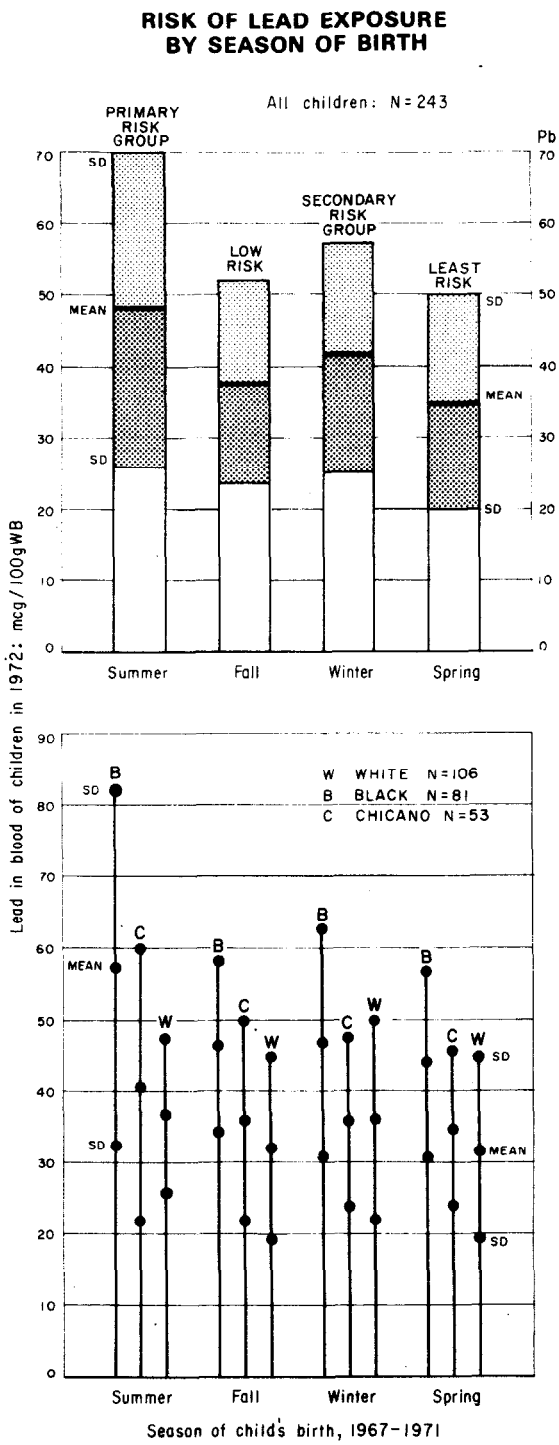

Fig. 2. Children born in summer and in spring had the highest and the lowest blood-lead levels, respectively; the mean differences being +37% and −27%. These differences also exist among ethnic groups. See Table 1. Source: author's survey.

Table 2. Mean lead levels surveyed in 1972, arranged by month of birth 1966–1971, for white, black and chicano children compared; Lansing, Mich.

Month of birth of child 1966–1971	LEAD IN BLOOD OF CHILDREN, SURVEYED IN 1972											
	White μg/100 gWB			Black μg/100 gWB			Chicano μg/100 gWB			Total μg/100 gWB		
	No.	Mean	±S.D.	No.	Mean	±S.D.	No.	Mean	±S.D.	No.	Mean	±S.D.
Jan.	6	35	9	7	42	14				14	39	13
Feb.	7	42	14	10	51	18	3	28	8	20	44	19
Mar.	10	31	10	10	45	13	6	36	11	26	38	12
Apr.	12	38	12	3	56	19	4	42	10	19	42	13
May	29	30	13	8	37	10	12	31	14	50	32	13
June	10	37	7	8	61	24	5	41	17	23	46	21
July	5	43	6	9	56	24	2	50	15	16	51	20
Aug.	3	31	9	7	57	28	1	30		11	48	25
Sep.	3	30	8	6	47	11	6	42	15	15	42	12
Oct.	8	33	15	7	45	15	6	37	7	21	38	14
Nov.	8	32	11	3	51	12	5	28	14	16	34	16
Dec.	5	31	9	3	45	4	3	45	4	12	40	14
Total	106	34	11	81	50	18	53	37	13	243	40	16

Source: Author's survey; $N = 243$ includes 3 "other" children.

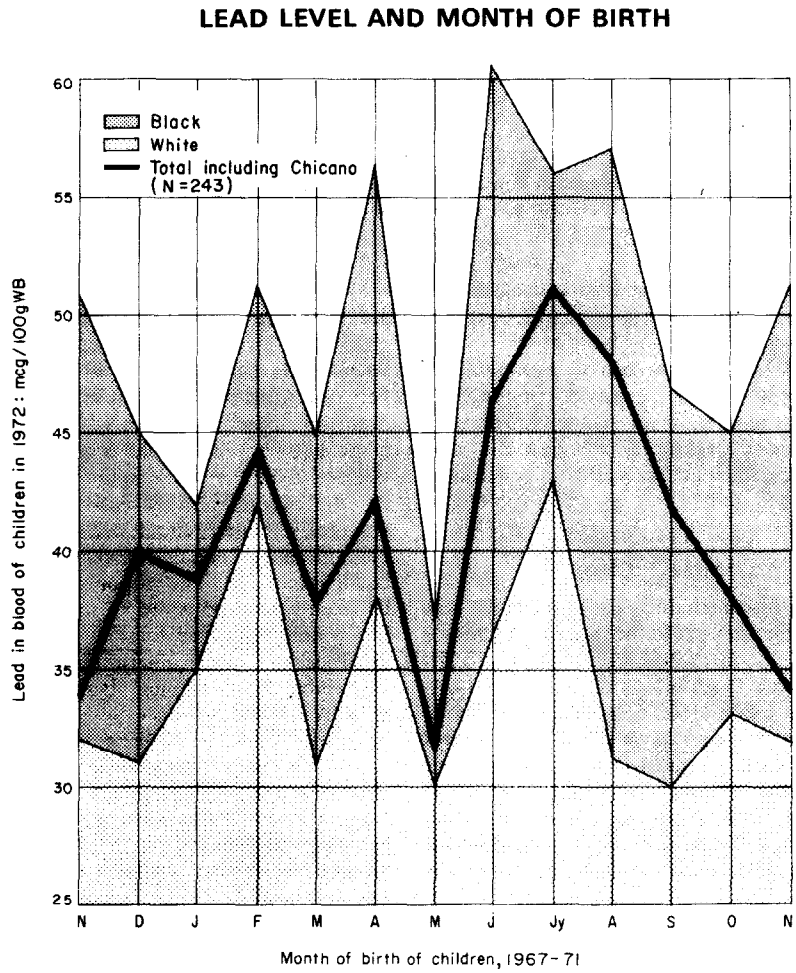

Fig. 3. The distributional patterns for white children and black are basically parallel, but the latter's blood-leads are much higher. Two sub-patterns are visible: one for summer-born children (May–November) and one for winter-born (November–May). See Table 2. Source: author's survey.

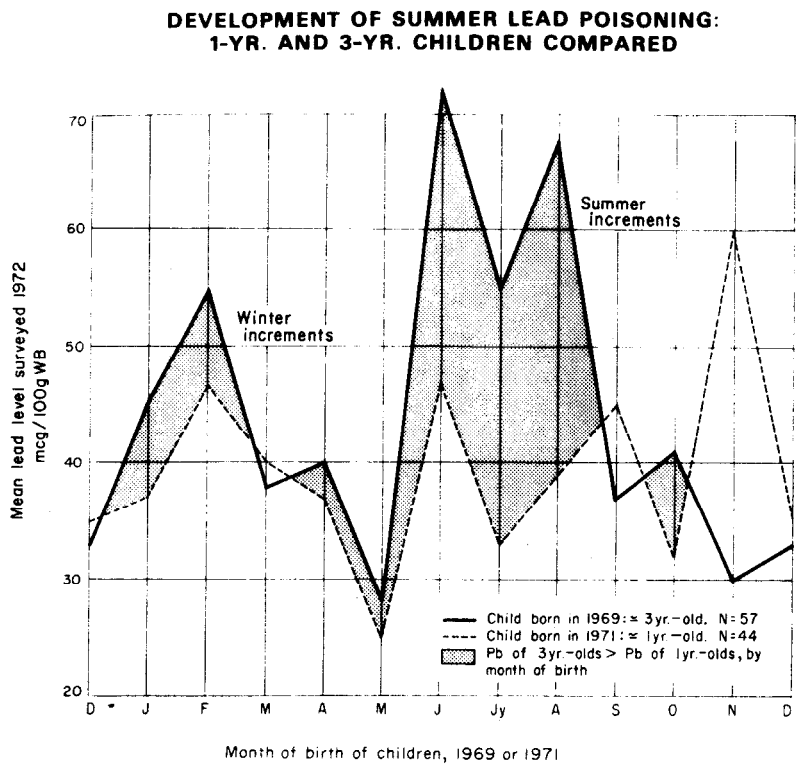

Fig. 4. It is apparent that summer accounts for the major increments of lead to the body burden, but that a secondary risk obtains in winter. The latter relates to child development, and the former to the solar environment. Source: author's survey.

related to sample size, and to problems of measuring the independent variables, one may conclude that seasonality phenomena account for about 12% of the variance of blood leads in the pediatric population. Other findings in the author's survey, unpublished and not reported here, indicate that environmental exposure, ingestion differences and various behavioral factors account for most of the remaining variance.

DENSITY OF SKIN PIGMENTS AND THE SEASONALITY EFFECT

One highly intriguing finding of the Lansing case study is that there appear to be major differences among ethnic groups in the degree of seasonal variation of blood leads. These ethnic differences are evident in Figs. 2 and 3 and in Tables 1–3. It can be seen that white children born in summer or winter are at risk to increased levels of blood lead, as opposed to those whites born in spring or fall. Days of summer exposures are insignificant for whites, and the total seasonality factor accounts for only 4% of the variance of blood leads. In the chicano group, summer exposure time is important (7.3% of the variance), and summer carries a slightly higher risk than it does for whites. The level of explained variance for seasonality is 3 times larger than it is for whites: 11.7% compared with 4.0% (Table 3). For blacks, season of birth, notably summer and spring, is important, as is the period of summer exposure. Seasonality gives an explained variance of 15.5% which is nearly 4 times greater than the white level. White children are therefore at least risk to seasonality of lead absorption and/or mobilization of lead stores, whereas blacks are at greatest risk, with chicanos in between. A black child born in summer is at the maximum apparent risk which is Level 6 in Fig. 6, and a spring-born white child is at minimum risk which is Level 2 in the same figure. This ordering of risk by ethnic group, and by season of birth in the model assumes, of course, equal levels of environmental lead contamination, equal exposure, equal ingestion and equal inhalation. The important absolute differences between black and white, as indicated by the parallel but widely separated lines in Fig. 3, may be due to differences of foetal inheritance. This would be true if in fact, black women, because of disadvantaged backgrounds, have generally higher body burdens of lead to be mobilized during a pregnancy.

For whites, chicanos and blacks, the levels of explained variance due to seasonality are, respectively, 4%, 12% and 16%. This is a gradation that seemingly represents density of skin pigments. It is known that the depigmented skin of northern Europeans absorbs more ultraviolet radiation than does the darker skin of southern Mediterranean peoples; and that the skin of the latter in turn screens out less ultraviolet radiation than does equatorial African skin. These are differences that result from evolutionary adaptations of prehistoric man to the solar environment, whereby skin cancer selects against fair skin in the tropics, and rickets, osteomalacia and

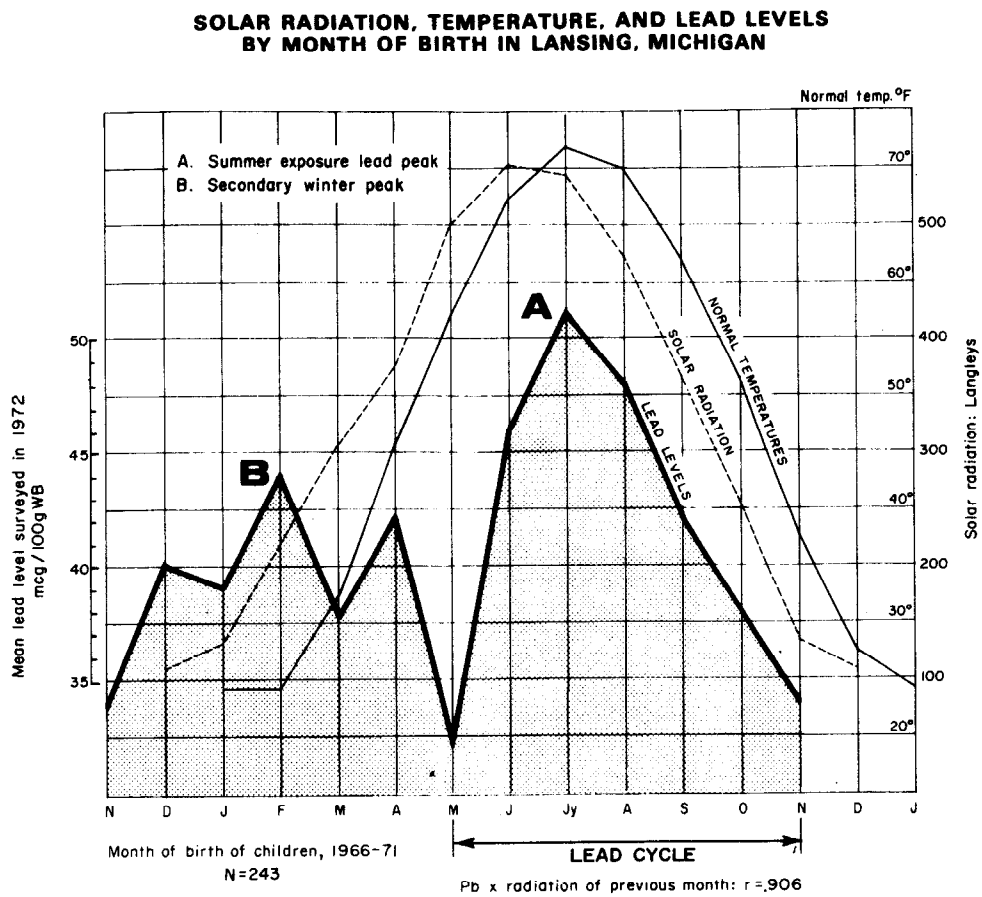

Fig. 5. Mean levels of blood-lead, ranked by month of birth, are strongly associated with normal levels of solar radiation of the preceding month, for May–November-born children ($R = 0.906$). Placental transfer in summer gestation is implicated. Source: author's survey. Radiation data from U.S. Department of Commerce.

hypocalcaemia select against dark skin in mid- and high-lattitudes [6]. Other things being equal, a relatively high density of skin pigments will result in hypo-vitaminosis-D in mid-latitude environments in winter months. The preponderance of black children with rickets in the clinics of northern U.S. cities in the 1930s and earlier, testifies to this. In recent decades, outbreaks of rickets among the children of Asia and West African migrants in northern British cities show that "normal" levels of vitamin D dietary fortification are insufficient to protect these children who are at special risk because of their skin color and lower levels of biosynthesis of vitamin D; although poor diets and cultural factors are also implicated [7].

With regard to the question of lead intoxication, it would appear that black and chicano children are subject to greater seasonal fluctuations of blood lead concentrations than whites, but all three groups are susceptible. The mechanism is apparently a lower winter level of vitamin D for blacks and chicanos, both for children and for pregnant women, followed by elevated levels with the advent of summer, giving a strong seasonal trend. In this way, stored lead will be mobilized and re-circulated in summer months. Depending upon circumstances, such an onset could precipitate a clinical crisis. For whites, the same mechanism obtains, but winter biosynthesis of vitamin D is greater, and therefore the seasonal trend is less pronounced. A further and possibly compounding factor for blacks is milk digestion. Those who have difficulties in digesting milk, because of low lactase levels, will gain less vitamin D dietary fortification than whites, and thus experience more depressed levels of vitamin D in winter. Vitamin D enrichment of milk and of other foods is now so widespread that hypercalcaemia is a potential hazard, yet the present evidence of the seasonality effect suggests that subclinical hypocalcaemia may be more common than expected, and is probably a greater risk than hypercalcaemia at least in winter months for children with denser skin pigmentation.

PUBLIC HEALTH RECOMMENDATIONS

Given that there is widespread contamination by lead in urban environments [8], the specific phenomenon of seasonality of lead poisoning seems to have implications for screening, diagnosis and treatment of both children and women. With regard to the screen-

Table 3. Correlations between lead in blood of children and seasonality factors

Independent variables Nos. 1–5	White $N = 106$			Black $N = 81$			Chicano $N = 53$			Total $N = 243$		
Simple correlation	R	$R2$	P	R	$R2$	P	R	$R2$	P	R	$R2$	P
No. 1 Child born in summer: 6–8	0.148	0.022	0.130	0.314	0.099	0.004	0.170	0.029	0.223	0.265	0.071	<0.0005
No. 2 Child born in fall: 9–11	−0.070	0.005	0.473	−0.066	0.004	0.559	−0.012	0.000	0.931	−0.059	0.004	0.360
No. 3 Child born in winter: 12–2	0.101	0.010	0.320	−0.076	0.006	0.500	−0.001	0.000	0.995	0.060	0.004	0.352
No. 4 Child born in spring: 3–5	−0.133	0.018	0.174	−0.193	0.037	0.085	−0.112	0.013	0.426	−0.219	0.048	0.001
Multiple correlation												
Nos. 1–4 season of birth	0.200	0.040	0.243	0.324	0.105	0.035	0.179	0.032	0.657	0.301	0.091	<0.0005
Simple correlation												
No. 5 summer exposure time	0.008	0.000	0.932	0.181	0.033	0.106	0.270	0.073	0.051	0.182	0.033	0.005
Multiple correlation												
Nos. 1–5 seasonality factor	0.200	0.040	0.385	0.393	0.155	0.012	0.341	0.117	0.194	0.345	0.119	<0.0005

Source: Author's survey of $N = 243$ children in Lansing, Mich.

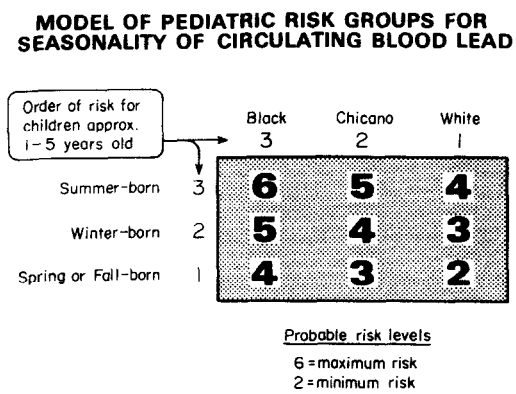

Fig. 6. Black children born in summer are at greatest risk to seasonal fluctuations of circulating lead. Spring-born whites are at least risk. Figure by author.

ing of children, it is now apparent that seasonal timing or phasing will substantially influence the survey results with the consequence that summer samples will be elevated and winter samples depressed. Thus, from the seasonal data presently available, a number of recommendations may be made.

The first is that community screening campaigns are best conducted in summer in order to identify the largest number of children with "exposed" or near-exposed lead levels [9]. In a sense, a better "harvest" of children at risk is assured. In situations where screening is a regular year-round activity, as in some pediatric clinics in poverty areas, some attempt should be made to adjust these readings to an annual curve. For instance, a "safe" winter reading of 30 μg may become an "exposed" reading of 50 μg in summer; that is an elevation of 67%, and the child could go untreated.

Secondly, physician diagnosis should include the seasonal risk factor. This is largely a matter of awareness. The physician "index of suspicion" should also apply to clinical treatment. For instance, chelation (with deleading compounds such as BAL, EDTA, and penicillamine) that commences in winter may have to be continued into the summer to cover the added risk period, even if levels have apparently been restored to normal. In other words, deleading protocols should be established that account for seasonal variations.

Thirdly, a consideration of pigmentation differences suggests that in many instances, the blood lead readings of black and chicano children under-estimate total body lead burdens, compared with similar readings for white children. This would appear to be most true for non-summer readings. An illustration will make this clear. Two children, one black and one white, are measured in winter and are found to have identical levels of lead in their blood. Yet they are not really at equal risk to lead mobilization and recirculation. The white child, because of a presumed greater biosynthesis of vitamin D, will have a bigger proportion of his body lead in circulation than the black child. Therefore, with equal levels of circulating lead, the black child will have a greater body burden of stored lead. From the physician standpoint, children with higher densities of skin pigments, such as blacks and chicanos, should be observed closely for seasonal crises of circulating lead; and chelation programs should be designed to offset these hazards. White children are also at risk to seasonal effects, but to a lesser degree.

Fourthly it is imperative that attention should be drawn in particular to maternal lead stores, and to neonatal lead inheritance. In this respect, females of reproductive age at risk to a pregnancy, and pregnant women with their foetuses, should be deleaded where necessary. This calls for screening of mothers as well as children. In the case of a pregnant woman with a significant body burden of lead, chelation, if clinically recommended, would have to be done slowly so as to avoid a circulating lead crisis that would damage the foetus. Techniques as to the rate of lead extraction and its duration by trimester need to be established; if indeed chelation during a pregnancy is advisable. Ideally, of course, chelation should occur in pre-pregnancy. One difficulty is the lack of a simple test to ascertain the body burden of lead in adults rather than blood lead. Exploratory dietary treatments might also be considered that could possibly reduce the mother's need to mobilize some of her calcium stores if the latter are seriously lead contaminated. Summer gestations should receive close attention for risk of placental transfer of lead. In addition, babies at birth should be chelated where they are found to have high lead levels. A neonate with a lead level of 40 μg has a very poor prognosis if untreated and returned with the mother to the same high-risk environment [10].

In considering the foregoing recommendations, it should be noted that many of the assumptions and conclusions presented here require further investigatory and experimental confirmation. Such ends are best achieved through the endeavors of many different disciplines. These are primarily medical and biomedical, supported by the social and environmental disciplines.

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