

Distance-Weighted Traffic Density in Proximity to a Home Is a Risk Factor for Leukemia and Other Childhood Cancers

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ABSTRACT

occupational exposure to elevated concentrations of benzene is a known cause of leukemia in adults. Concentrations of benzene from motor vehicle exhaust could be elevated along highly trafficked streets. Several studies have reported significant associations between proximity to highly trafficked streets and the occurrence of childhood cancers and childhood leukemia. These associations may be due to chronic exposure to benzene or other carcinogenic components of vehicle exhaust from these nearby streets or to some other factor (e.g., noise, increased light exposure, or some unaccounted-for socioeconomic variable). We used data for homes studied in an earlier childhood cancer study conducted in Denver, CO, in the 1980s. No air pollution measurements were made in the original study. We identified the highest trafficked street near each study home and obtained the traffic density in 1979 and 1990. Traffic density was weighted for the distance from the street to the home using 3 different widths of Gaussian curves to approximate the decay of the emissions into the surrounding neighborhoods. The associations between the 750-ft-wide distance-weighted traffic density metric and all childhood cancers

and childhood leukemia are strongest in the highest traffic density category ($\geq 20,000$ vehicles per day [VPD]). The odds ratio is 5.90 (95% confidence interval [CI] 1.69–20.56) for all cancers and 8.28 (95% CI 2.09–32.80) for leukemia. The results are suggestive of an association between proximal high traffic streets with traffic counts $\geq 20,000$ VPD and childhood cancer, including leukemia.

INTRODUCTION

Many occupational studies have linked chronic exposure to high levels of benzene to the occurrence of leukemia in adults.¹⁻⁵ The association has been mainly with acute myeloid leukemia (AML).^{1,2} Although AML is rare in children, this raises the possibility that leukemia and other cancers in children could also be associated with chronic exposure to elevated levels of benzene, a major constituent of volatile organic compounds (VOCs) from motor vehicles.^{6,7} It has been estimated that over 80% of the total benzene emissions in the United States originate from motor vehicles. Benzene has also been found in tobacco smoke. Elevated levels of motor vehicle exhaust are likely to be localized (from a few hundred up to one thousand feet) near heavily traveled roadways,¹⁰⁻¹² which could produce localized high levels of VOCs containing benzene^{13,14} that could also deposit in soil, but no measurements are available. Although traffic-related ambient air concentrations of benzene are well below occupational exposure levels normally considered leukemogenic,¹⁵ the U.S. Environmental Protection Agency (EPA) believes chronic exposures may pose a risk for leukemia or cancer in general.¹³ The causal agents for the most common childhood leukemia, acute lymphocytic leukemia (ALL), are largely unknown, although several studies suggest an association with some measure of traffic density.¹⁵⁻¹⁷ Traffic density may act as a surrogate exposure indicator for elevated levels of VOCs containing benzene.

IMPLICATIONS

Motor vehicles are a significant source of air pollution emissions, including benzene, which may be carcinogenic. This study presents further evidence that children who live near heavily traveled streets or highways may be at elevated risk of developing cancer, including leukemia. Children living near such streets could be exposed via inhalation or exposure to soil where emissions deposit. Alternative hypotheses for these results could involve noise, increased light exposure, or some socioeconomic variable. Future studies with actual exposure measurements are needed.

Savitz and Feingold¹⁶ reported that traffic density is associated with all childhood cancers and with childhood leukemia in Denver, CO. In their study, traffic density was defined as the traffic count on the street of address of the home, usually located in front of the home. They reported an odds ratio for children living on streets with traffic densities of 210,000 vehicles per day (VPD) of 3.1 (95% confidence interval [CI] 1.2–8.0) for total childhood cancers and 4.7 (95% CI 1.6–13.5) for childhood leukemias. These results suggest that children living on streets with traffic counts of more than 10,000 VPD are 3–5 times more likely to contract cancer than are children who live on streets with fewer than 500 VPD.

More recently, Feychting et al.¹⁷ retrospectively modeled concentrations of nitrogen dioxide (NO₂) from motor vehicle exhaust in Sweden. They reported that at NO₂ levels >80 µg/m³ outside a child's home, the total childhood cancer odds ratio was 3.8 (95% CI 1.2–12.1). The NO₂ concentrations were estimated using mobile source air pollution models from the Swedish Environmental Protection Agency as the 99th percentile of the 1-hr averages for one year.

Knox and Gilman¹⁸ examined spatial clustering patterns among 22,458 children who died from leukemia or other cancers in England, Scotland, or Wales from 1953 to 1980. They found excess childhood leukemias in proximity to motorways and industrial plants likely to be sources of airborne toxic substances such as VOCs. The largest excesses of cancer associated with traffic were found 1 km or less from motorways. Knox and Gilman concluded, "Childhood cancers are geographically associated with two main types of industrial atmospheric effluent, namely: (1) petroleum-derived volatiles and (2) kiln and furnace smoke and gases, and effluent from internal combustion engines" (p. 151).

This study is an extension of the work by Savitz and Feingold.¹⁶ We developed an exposure metric based on the highest trafficked street surrounding the house, not simply the street of address (usually located in front of the house), and took into account the decay of air pollution concentration with distance from the street. These improvements are intended to reduce exposure misclassification for traffic air pollution. The results are presented to allow for a direct Comparison of the results of this improved traffic density exposure metric with the results reported by Savitz and Feingold.¹⁶

Parents of case and control children were interviewed in the original study to obtain data about their child's past exposure to agents and activities potentially associated with cancer, including parents' cigarettes smoking and the use of pesticides in and around the home. In order for a factor to be a confounder, it must be associated with both the disease and exposure of interest. Savitz et al.

evaluated many factors as potential confounders, including the child's age, gender, year of disease diagnosis, and residential stability. Savitz et al. also controlled for family electricity consumption, parents' ages, parents' occupations, parents' education levels, per capita income, traffic density, and family cancer history. Also evaluated as confounders were the child's prenatal exposure to tobacco smoke and alcohol, birth order, birth weight, medications, illnesses, and X-rays.

Savitz et al. found evidence of an elevated cancer risk associated with young maternal age, lower father's education, lower per capita income, maternal smoking during pregnancy, and traffic density, all of which were taken into account as potential confounders of the association between cancer and proximity to power lines. The odds ratios for these factors were not large, and taking them into account did not change the point estimates, indicating that they were not confounders. Subsequent analyses (Savitz and Feingold¹⁶) supported the suggestion that there are few, if any, confounding factors in these data.

EXPERIMENTAL METHODS

We employed the case-control childhood cancer epidemiologic data used by Savitz and Feingold.¹⁶ The data are from a study conducted by Savitz et al.¹⁹ of the association between magnetic fields from electric power lines and childhood cancer in the Denver metropolitan area. Details of the methods used to identify cases and controls have been provided elsewhere.¹⁹ In summary, eligible cases were children from 0 to 14 years of age who were diagnosed with cancer from 1976 to 1983 and who lived in the greater Denver metropolitan area. The 320 eligible cases consisted of 97 leukemias (including 78 ALL), 59 brain cancers, 30 lymphomas, 32 soft tissue cancers, and 102 other forms of cancer. Data on these children were obtained from the Colorado Central Cancer Registry; 259 controls were selected by random digit dialing with individual matching on gender, age ± 3 years, and telephone exchange area.

The Colorado Central Cancer Registry of the Colorado Department of Health was the principal source of cases, with complete coverage of the study area from 1979 to 1982. To complete case ascertainment for 1976–1978 and 1983, records were reviewed of area hospitals that provided diagnosis and treatment for childhood malignancies. Over 95% of the cases were microscopically confirmed, with an additional 3% confirmed by direct visualization or radiography. Diagnostic accuracy was also assured through review by pediatric oncologists.¹⁹

Savitz et al. found elevated traffic density to be associated with childhood cancer, but no assessment of air pollution exposure was made in their study. To follow up this observation, we used other publicly available data that could act as markers for air pollution exposure for

the homes of the case and control children. We obtained 1979 traffic density data from the Colorado Department of Transportation and 1990 traffic count data for Denver area streets and highways from the Denver Regional Council of Governments. These years were chosen because they were the two years closest in time to the period of exposure of the cases studied by Savitz et al.¹⁹ when coordinated traffic counts were made across the Denver metropolitan area. If a street did not have a traffic count, we assigned the average of the traffic counts for all streets with the same traffic-carrying capacity code from a geographic information system (GIS) digital map²⁰ of all of the streets and highways in the Denver metropolitan area. Streets with low traffic-carrying capacity codes without traffic measurements (narrow residential and cul-de-sac streets) were assigned a default traffic count of 100 VPD.

We compared the traffic density measurements for these two years for all streets near the study homes and noted the similarities and trends between the years. Although the 1979 traffic density data were collected closer in time to the other data collected in the Savitz et al. study,¹⁹ we preferred to use the 1990 traffic density data because traffic counts for more streets were available. We compared the 1990 traffic density with the traffic density for 1979 (Figure 1) for those homes that had measured traffic density on the nearby highest trafficked street for both years ($n = 110$). Traffic density increased on average 22% from 1979 to 1990 and is highly correlated between these years. The R^2 is 0.93. The straight line in Figure 1 is the least-squares linear regression. Therefore, we used the 1990 traffic data because there is a high correlation for traffic counts between these years

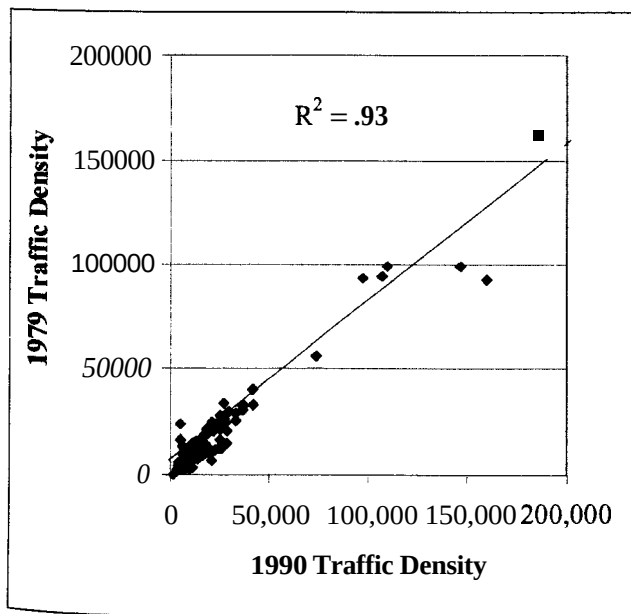


Figure 1. A comparison of traffic density measurements in VPD for 1979 and 1990 for 110 study homes in the Savitz and Feingold study.¹⁴

with a fairly uniform trend of increasing traffic. A high-traffic street in 1979 also would be a high-traffic street in 1990 with about the same rank ordering by traffic count, because few streets fall far from the least-squares regression line in Figure 1.

Each of the study homes was geocoded for location from its street address. Using GIS methods, we identified the highest trafficked street within 1500 ft in any direction from each home and calculated the perpendicular distance from the center line of the street to the center of the home.

The concentration profile of airborne exhaust pollution from motor vehicles traveling on a street could approximate a Gaussian (normal) distribution^{11,12,21,22} similar to that shown in Figure 2. This idealized profile may vary due to many factors such as prevailing winds, turbulence generated by passing vehicles, and the dispersion blocking effect of nearby buildings and hillsides.^{23,24} To bracket the spatial action that these and other factors may have on air pollution concentration profiles, 3 different widths (250, 500, and 750 ft) of Gaussian curves were used to distance-weight the traffic counts. The width of each Gaussian curve was determined at one-half of its maximum height (Figure 2). Distance-weighted traffic density was computed by multiplying the traffic counts in VPD for the highest trafficked street by the values derived from each of the 3 weighting curves at the street to home distance. For instance, a street with a traffic count of 10,000 VPD located at the distance from the home shown on the left in Figure 2 would have a distance-weighted traffic density of 2500 VPD at the home.

Odds ratios (OR) and 95% confidence intervals (CI) were computed between childhood cancer and childhood leukemia and the different distance-weighted traffic density metrics using standard statistical programs for stratified analysis.²⁵

RESULTS

Savitz and Feingold¹⁶ evaluated the association between childhood cancer and traffic counts up to 210,000 VPD for 328 case and 262 control homes, using the traffic counts on the street of address of each home. The associations for all childhood cancers and leukemias reached statistical significance in the highest category despite small numbers. Using their street of address data, we recomputed odds ratios for traffic counts up to 220,000 VPD (Table 1). The associations were not statistically significant or consistently elevated, except in the highest category, where the odds ratios abruptly increased. The associations were not precise because of the small number of controls, particularly in the higher-VPD categories.

We determined 3 distance-weighted traffic density metrics for the highest trafficked street proximate to the home for 579 of the 590 homes analyzed by Savitz and

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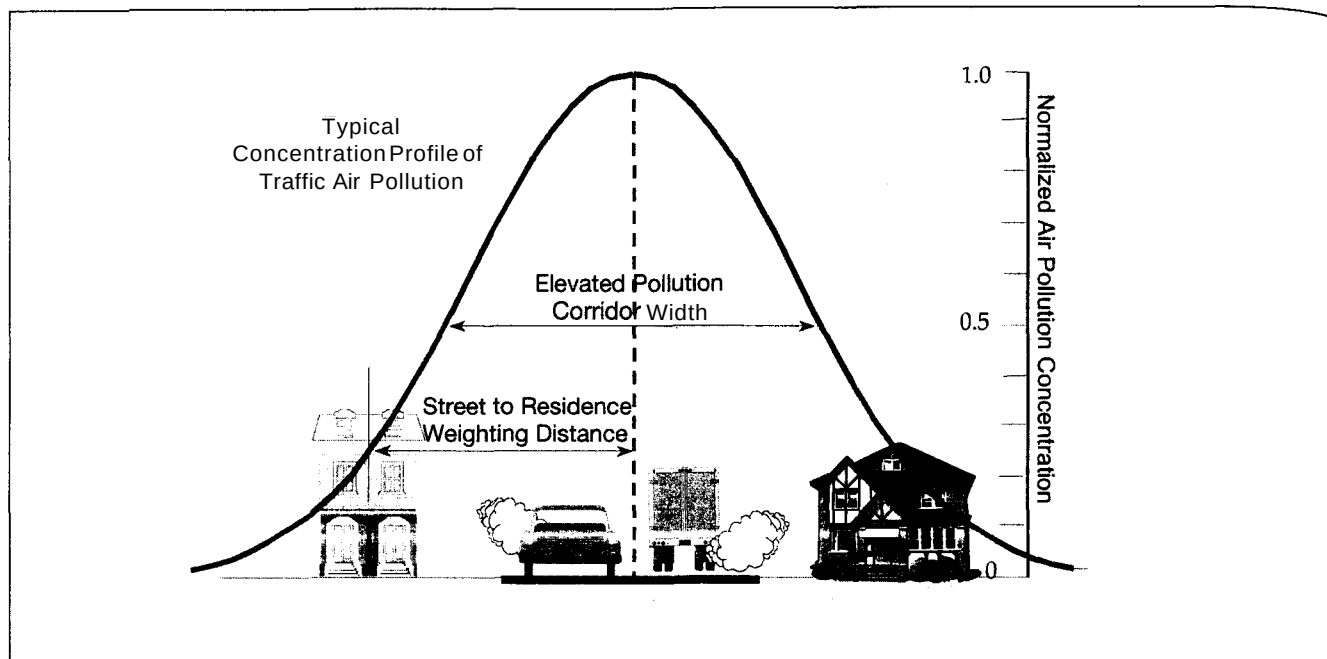


Figure 2. Generalized profile of concentration of airborne exhaust pollution from vehicular traffic in the absence of a crosswind. In this example, the distance-weighting value for the home on the left will be 0.25. If the traffic density on the street is 10,000 VPD, then the distance-weighted traffic density at the home on the left would be 2500 VPD.

Table 1. Odds ratios between traffic density on the street of address and all childhood cancers and childhood leukemias using data reported by Savitz and Feingold.¹⁶ This table extends the earlier analysis to traffic strata above 10,000 VPD.

Distance-Weighted Traffic Density (VPD)	Controls		All Cancers		Leukemias		
	N	N	OR	95% CI	N	OR	95% CI
<500	238	280	1.0	Reference	81	1.0	Reference
500-4999	10	19	1.62	0.74-3.54	4	1.18	0.36-3.85
5000-9999	9	11	1.04	0.42-2.55	5	1.63	0.53-5.01
10,000-14,999	3	6	1.70	0.42-6.87	1	0.98	0.10-6.87
15,000-19,999	0 ^a	4			2		
220,000	2	8	3.40	0.72-16.17	5	7.35	1.40-38.60

^aOdds ratios cannot be computed due to lack of controls in this category. N = number of children in each category, OR = odds ratio, and 95% CI = 95% confidence interval.

Table 2. Odds ratios between 750-ft distance-weighted traffic density and all childhood cancers and childhood leukemias.

Distance-Weighted Traffic Density (VPD)	Controls		All Cancers		Leukemias		
	N	N	OR	95% CI	N	OR	95% CI
<500	118	121	1.0	Reference	38	1.0	Reference
500-4999	86	101	1.15	0.78-1.68	26	0.94	0.53-1.66
5000-9999	32	55	1.68	1.02-2.80	21	2.04	1.05-3.95
10,000-14,999	14	18	1.26	0.60-2.66	2	0.48	0.10-2.21
15,000-19,999	6	7	1.15	0.37-3.51	2	1.04	0.20-5.34
≥20,000	3	18	5.90	1.69-20.56	8	8.28	2.09-32.80

Feingold¹⁶ (11 of the 590 homes did not have complete data). Table 2 shows the associations between all childhood cancers and childhood leukemias and the 750-ft distance-weighted traffic density metric. Note the shift of homes to the higher traffic density strata in Table 2 compared to Table 1 when taking the highest trafficked street into account. The association between traffic density and all cancers and leukemia only becomes elevated and significant in the 220,000 VPD category. The results for the 500-ft-width weighting curve are similar with odds ratios for 220,000 VPD of 9.45 (95% CI 1.19–74.79) for all cancers and 12.18 (95% CI 1.33–111.8) for leukemia. Both of these odds ratios are statistically significant. For the 250-ft distance-weighted traffic density metric, there were no controls with 15,000 or more VPD, so odds ratios could not be computed.

If the children are grouped by exposure to greater than 500 VPD (750-ft distance-weighted) versus less than 500 VPD, the odds ratios become 1.70 (95% CI 1.01–2.86) for all cancers and 2.08 (95% CI 1.06–4.07) for leukemia. Even though these risks are small, they are statistically significant.

CONCLUSION AND DISCUSSION

This study has several limitations. As in most studies of childhood cancer, the number of cases and controls in the high-exposure category is small, due to the relative rarity of childhood cancer. These small numbers affect the precision of the observed associations. The confidence limits are wide because of the small number of cases and controls, but some of the point estimates are still statistically significant. To make the group of children as large as possible, Savitz et al.¹⁹ made their diagnosis period fairly wide (1976–1983). The cumulative pre-diagnosis exposure period for these children may have stretched for more than 10 years, but most of the children were less than 10 years old when diagnosed.

Savitz et al. did not directly measure traffic density for each child. Citywide coordinated traffic counts are only made in the Denver area about every 10 years. Retrospective estimates of exposure for the pre-diagnosis time period for each child could be extrapolated from these periodic traffic counts, assuming the child had lived in one residence for the whole period. However, data collected by Savitz et al. on the residential mobility showed that many children had moved. Therefore, we did not attempt to retrospectively estimate the traffic exposure during the pre-diagnosis exposure period for each child. To do so would require knowledge of each child's residential history during the relevant (and unknown) etiologic period.

The results suggest that distance-weighted traffic density is a risk factor for all childhood cancers and for childhood leukemias. This is consistent with the earlier findings

of Savitz and Feingold,¹⁶ Feychting et al.,¹⁷ and Knox and Gilman.¹⁸ Elevated risks are found for 220,000 VPD for the 500- and 750-ft metrics. There are cases but no controls with 220,000 VPD for the 250-ft metric, so odds ratios cannot be computed. There is no evidence of elevated risk for distance-weighted traffic densities less than 20,000 VPD. At $\geq 20,000$ VPD, the risks of childhood cancers and leukemia increase with decreasing distance-weighting from the street, although the numbers are small and the confidence intervals overlap. These results are suggestive of a threshold effect for highly exposed children when distance-weighted traffic density near a home rises well above the average value for the area.

This apparent threshold effect is to be expected where high densities of VPD increase the concentration of vehicle exhaust far above the ambient background in the surrounding neighborhoods. The gradient of traffic air pollution may be very steep (Figure 2) and diminish very rapidly with distance from the street. Thus, only those children who live very near high-traffic streets (within 750 ft) will have an exposure that is far above "ambient background" for the community. Noise, increased light exposure, or some socioeconomic factor may also help explain these results.

For distance-weighted traffic densities 220,000 VPD, the associations we observe are stronger than those reported by Savitz and Feingold.¹⁶ This may be due to possible misclassifications of exposure in the Savitz and Feingold study, which only analyzed traffic density on the street of address in front of a home. This would not account for high exposure coming from a busy street either behind or beside the home. Feychting et al. used a retrospective estimate of mobile source NO_x concentration as their metric.¹⁷ The metrics used in our analyses are simpler to construct than estimating NO_x concentrations and are also strongly associated with cancer. The confidence limits are wide because of the small number of cases and controls, but some of the point estimates are still statistically significant.

Together, these results are suggestive but do not constitute conclusive evidence of an association between living near a high-traffic street and increased incidence of childhood cancer, particularly leukemia. Further studies specifically designed to test this and other hypotheses are needed. Measurements of ambient or personal exposure to various pollutants are also needed.

This study used distance-weighted traffic density as an exposure surrogate for mobile source air pollution. This metric can be improved. Concentrations of motor vehicle VOCs containing carcinogens such as benzene can be retrospectively estimated for each home using mobile source models. The models could be used to estimate emissions from passing vehicles and the ambient concentrations

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resulting after dispersion into the neighborhood. Finally, measurements are highly desirable. If benzene and other emissions in motor vehicle exhaust are associated with childhood cancer, then estimates of these concentrations should be more strongly associated with childhood cancer than is distance-weighted traffic density.

ACKNOWLEDGMENTS

We would like to thank Dr. David Savitz for sharing the data from his epidemiologic study as well as his encouragement and helpful suggestions in conducting this research. The authors would like to thank David Simpson and Suzanne Strasser for their statistical analyses presented in this article, and Jim Rowe and Jim Crawford for performing the GIS analysis of nearby streets. Finally, we would like to thank Dr. Leeka Kheifets and Dr. Ron Wyzga for their support and constructive suggestions. This work was sponsored by the Electric Power Research Institute under Contract No. WO2964-22.

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