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Childhood Brain Tumor Occurrence in Relation to Residential Power Line Configurations, Electric Heating Sources, and Electric Appliance Use

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To assess the relation between childhood brain tumor occurrence and exposure to potential sources of residential magnetic fields, a population-based case-control study of incident brain tumors was conducted in the Seattle, Washington, area at the Fred Hutchinson Cancer Research Center from 1989 to 1994 among children younger than age 20 years who were diagnosed from 1984 to 1990. The specific aims were to evaluate whether proximity to high-current residential power lines, as defined by the Wertheimer-Leeper code, or use of electric appliances or electric heating sources by the mother while pregnant or by the child before diagnosis were associated with increased risks of brain tumor occurrence. The mothers of 133 cases and 270 controls (recruited by random digit dialing) participated. Risk of brain tumor occurrence did not increase with increasing exposure, as indicated by the five-level Wertheimer-Leeper code. When exposure was dichotomized as high versus low, the odds ratio was 0.9 (95% confidence interval 0.5–1.5) and did not vary significantly by sex, age, or histology. No elevations in risk were found for ever versus never use of electric blankets, water beds, or electric heating sources. Odds ratios were slightly elevated for nine appliances and were at or below 1.0 for eight others. These data do not support the hypothesis that exposure to magnetic fields from high-current power lines, electric heating sources, or electric appliances is associated with the subsequent occurrence of brain tumors in children. *Am J Epidemiol* 1996;143:120–8.

brain neoplasms; central nervous system neoplasms; child; electromagnetic fields; neoplasms

Little is known about the causes of childhood brain tumors. The few factors for which associations have been identified, most notably direct ionizing radiation exposure and certain genetic diseases, occur too infrequently to account for more than a small fraction of the brain cancer burden in children. Nor have other suspected risk factors, such as family history of brain tumors, head injury, epilepsy, exposure to industrial chemicals, or exposure to *N*-nitroso compounds, been shown to be likely important contributors to childhood brain tumor etiology (1).

Since the first report of a possible relation between childhood cancer mortality and high-current residential power lines by Wertheimer and Leeper in 1979 (2), several childhood cancer studies have included central nervous system tumors as subgroup analyses in evaluations of all tumor sites. Wertheimer and Leeper (2) found a 2.4-fold higher risk (95 percent confidence interval (CI) 1.1–5.1) of central nervous system cancer mortality among children in Denver, Colorado, who resided close to high-current power lines. Elevated risks for brain cancer incidence were also reported by Savitz et al. (3) in Denver (odds ratio (OR) = 2.0, 95 percent CI 1.1–3.8) and for central nervous system tumor incidence by Tomenius (4) in Stockholm, Sweden (OR = 4.0, 95 percent CI 0.8–26.8) (4). Associations between central nervous system tumor incidence and proximity to high-current power lines were not observed, however, in more recent case-control studies conducted in Sweden (5) and Denmark (6).

Although 50/60-Hz magnetic fields, such as those emitted from power lines and household electric devices, have not been shown experimentally to have genotoxic effects (7), there is some evidence to suggest that they may act as a tumor promoter (8–12). In the United States, the most commonly used surrogate measure of residential magnetic field exposure in human cancer studies is the Wertheimer-Leeper code, an empirically derived method of ranking homes according to electric current capacity in visible components

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Abbreviations: CI, confidence interval; OR, odds ratio.

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of the power delivery system and proximity to a residence. Electric appliances and electric heating are also sources of residential magnetic field exposure (13), although, in contrast to the relatively low, prolonged magnetic field exposure from power lines, electric appliances generally represent high, short-term exposure (13, 14).

The primary purpose of this study was to evaluate the possible association between high-current residential power line configurations and brain tumor occurrence in children. Secondary aims were to evaluate whether or not use of electric appliances or electric heating sources by the mother while pregnant or by the child before diagnosis are associated with increased risks of childhood brain tumor occurrence.

MATERIALS AND METHODS

This study was a Seattle, Washington-based component of a larger, multicenter case-control study that examined the association of potential dietary and environmental risk factors with brain tumor occurrence in children diagnosed from 1984 to 1990.

Case identification

Children younger than age 20 years with a primary tumor of the brain were identified through the Cancer Surveillance System, a population-based cancer registry in western Washington State and a participant in the National Cancer Institute's Surveillance, Epidemiology, and End Results program. To be eligible for participation in the study, each child's biological mother had to speak English, be available for interview, and have a telephone.

A total of 195 children with brain tumors were identified. Permission to contact the mother of each child was requested from the child's physician; for 10 patients, the physicians refused. We subsequently excluded 16 of the remaining 185 children for the following reasons: one had no telephone; seven did not have a biological mother available for interview; three were diagnosed outside the study area; one was diagnosed outside the study time period; and four were ineligible after a second pathology review indicated that their tumors did not fit study criteria. For the remaining 169 children, mothers of 25 could not be located and mothers of 11 others declined to participate, leaving 133 children available for the study. Assuming that children of all 21 refusals and all 25 children with unlocated mothers were eligible for participation, the participation response rate among cases was 74.3 percent (133/179).

Control identification

Controls were recruited using a two-step random digit dialing procedure (15). This involved calling computer-generated random telephone numbers (up to nine attempts at different times of the day and days of the week) to identify residences and then conducting brief screening interviews to assess eligibility of child household members on the basis of age and county of residence. There were 7,480 numbers called, of which 3,197 were nonworking, 1,344 were businesses, 50 were nonresidential and nonbusiness (such as nursing homes or pay telephones), 37 were not in an eligible county, 50 were "fast busy signals" on each attempt, 19 were "slow busy signals" on each attempt, and no answer was received at 242 numbers. Of the 2,541 telephone numbers determined to be residences in the study area, 96.0 percent were successfully screened. For children initially identified as eligible through the screening process, a stratified selection procedure was used to select 380 at random to yield a control group that was similar to cases with respect to age (within 2 years), sex, and general area of residence, at a ratio of approximately two controls per case. Similarly to cases, controls were required to have telephones and to have biological mothers who were available for interview and who spoke English. Each control was assigned a reference date that corresponded to a case diagnosis date. Of the 380 potential controls who were asked to participate, 23 were subsequently found to be ineligible: 11 were not residents of the study area at the time of their assigned reference date, seven mothers could not speak English, and five children did not have a biological mother available for interview. Among the remaining 357 mothers of potential controls, 62 declined to participate, 11 could not be located when we attempted to recontact them, and 14 who agreed to participate during the initial call were not needed because enough children in their age strata were already recruited. Thus, 270 control mothers participated in the study. Assuming that all children of the 62 refusals and all 11 children with unlocated mothers were eligible for participation, the participation response rate for controls among those screened and found to be eligible (excluding the 14 not needed) was 78.7 percent (270/343).

Exposure and covariate information

As part of the larger study on risk factors for childhood brain tumors, information was obtained by in-person interview on potential etiologic and confounding factors and on use of electric blankets and heated water beds by the child before the reference date and by the mother during pregnancy. A partial residence

history was also obtained. Subsequent to the in-person interview, a questionnaire was mailed to participating mothers requesting a residential history to include every home in which the child lived during the 3-year period up to their reference date and during the mother's pregnancy. This history included the dates the child moved into and out of each residence and the type of heating sources that were used in each. It was not feasible in this study for power lines to be characterized for all homes in which a child lived. This 3-year time frame was therefore chosen to be consistent with a hypothesized late (promotional) effect of magnetic field exposure, as well as for practical considerations. Also included on the questionnaire were questions on use of specific electric appliances by the child any time before the reference date and by the mother during her pregnancy. We received mail questionnaires from 98 (73.7 percent) case mothers and 208 (77.0 percent) control mothers.

External power distribution systems for homes at reference date (reference homes) were characterized by drawing scaled maps of all power distribution components within 130 feet of the residence. Homes were classified as having underground wiring if no components could be observed. Data from the maps were abstracted, and Wertheimer-Leeper codes were assigned by a computer algorithm. Field technicians were not informed of the case-control status of an assigned home. Reference homes could not be mapped for 13 (9.8 percent) cases and 30 (11.1 percent) controls. Thus, 360 (89.3 percent) of the 403 children for whom mothers were interviewed were successfully assigned a power line exposure level for their reference home. For the 306 mothers who responded to the mail questionnaire, 21 reference homes were not mapped. Thus, we had both a mail questionnaire and mapped reference home for 285 children (92 cases and 193 controls).

Additionally, to assess the extent to which power line configurations differed between the homes of study participants and those who chose not to participate, we attempted to map the homes of all potential subjects who were identified as eligible through our recruitment process, but who did not participate in the study. This was possible because power line configurations can be mapped from public streets without entry onto private property or participation from current residents. We successfully mapped 38 of 46 potentially eligible cases and 54 of 73 potentially eligible controls.

Table 1 summarizes the number of subjects for whom exposure data were available within each exposure collection instrument (interview, power line mapping, and mail questionnaire).

TABLE 1. Number of brain tumor cases and controls by eligibility status, participation, and mapping for the Wertheimer-Leeper code, western Washington State, 1984–1990

	Potential cases		Potential controls*	
	No.	Mapped†	No.	Mapped
Total	195		366	
Ineligible	16		23	
Eligible, did not participate in interview or questionnaire	46	38	73	54
Participated				
In-person interview‡	133	120	270	240
Mail questionnaire§	98	92	208	193

* Not including 14 individuals who were screened eligible and agreed to participate, but were not needed.

† The number of subjects with residential power lines mapped and characterized according to the Wertheimer-Leeper code.

‡ Information was collected on use of electric blankets and heated water beds and on demographic and potentially confounding characteristics.

§ Subsequent to the in-person interview, information was collected on use of electric heating sources and electric appliances other than electric blankets and water beds. The numbers shown are for those who returned the questionnaire and are a subset of those who were interviewed.

Statistical analysis

Multivariable relative risks (approximated as odds ratios) were estimated by unconditional logistic regression. Odds ratios related to the Wertheimer-Leeper code are presented in five exposure levels with underground wiring as the reference group. The other four levels, in increasing order of exposure, are very low current configuration, ordinary low current configuration, ordinary high current configuration, and very high current configuration. Associations were also evaluated using the two-level Wertheimer-Leeper code, for which the three lowest levels of the five-level code are combined into the reference category (low), and the two highest categories are combined into the exposed category (high) (3, 16).

Data on use of electric appliances were not sufficient to distinguish reliably between light versus heavy use; therefore only analyses of ever versus never use are presented. Ever use of electric heating sources, including radiant floor or ceiling heat, baseboard electric heat, use of a portable "space" heater, and any electric heating, were evaluated using two reference groups: no electric heating sources whatsoever and no use of the specific heating source being evaluated. Because results were similar, we report only the results of the analysis comparing ever versus never use of each specific heating source.

Potential confounding was evaluated for age (continuous); sex; race (white or nonwhite); county at reference date; reference year; mother's education

(three levels: no high school degree; high school degree, but no college degree; college degree); family history of brain tumors (yes/no), passive tobacco smoke exposure in the home (parent or other live-in adult smoked vs. no smokers); whether the child lived on a farm (yes/no); and, whether or not the child had a history of head injury (for which a doctor or nurse was consulted), x-ray to the head or neck, epilepsy, or fits from severe fevers. The procedure involved evaluating whether or not the extraneous factor was associated with both exposure and disease by using stratified analysis. If not, the factor was not considered further. If so, the factor was entered into the logistic regression model with the main exposure effect, and a judgment was made on whether or not a meaningful difference occurred in the risk estimate. None of the characteristics that were evaluated confounded the association with the Wertheimer-Leeper code or with exposure to electric blankets or heated water beds. Thus, unadjusted odds ratios are reported for these exposures. For electric heating sources and other electric appliances, only age was found to appreciably alter the unadjusted odds ratios, and age-adjusted odds ratios are reported.

For analyses stratified by type of brain tumor, we used histologic categories as described by Kuijten et al. (17). These were: astrocytomas and gliomas (astroglial, morphology codes (18) 9380–9384, 9400–9421, and 9424–9442); primitive neuroectodermal tumors (morphology codes 9470–9473, 9500, 9362, and 9392); and, as a third category, all other histologies.

TABLE 2. Characteristics of participating cases and controls, western Washington State, 1984–1990

	Cases (n = 133)		Controls (n = 270)	
	No	%	No.	%
Age (years)				
0–4	54	40.6	111	41.1
5–9	43	32.3	84	31.1
10–14	21	15.8	49	18.1
15–19	15	11.3	26	9.6
Sex				
Male	73	54.9	149	55.2
Female	60	45.1	121	44.8
County of residence*				
Urban/suburban	100	75.2	193	71.5
Rural	33	24.8	77	28.5
Passive smoke exposure†				
Yes	55	41.4	129	47.8
No	78	58.6	141	52.2
Mother's education				
No high school degree	18	13.5	27	10.0
No college degree‡	91	68.4	172	63.7
College degree	24	18.0	71	26.3
Mother's race				
White	119	89.5	256	94.8
Nonwhite	14	10.5	14	5.2

* Urban/suburban: King, Pierce, and Snohomish counties; rural: Clallam, Grays Harbor, Island, Jefferson, Kitsap, Mason, San Juan, Skagit, Thurston, and Whatcom counties.
† Child lived with an adult who smoked cigarettes.
‡ No college degree, high school degree; may have attended college but did not graduate.

RESULTS

Among cases, 56.4 percent of tumors were classified astroglial and 21.1 percent were classified as primitive neuroectodermal. The distributions for age at reference, sex, and county of reference (urban/suburban vs. primarily rural) were similar between cases and controls (table 2). Fewer case mothers (18.0 percent) than control mothers (26.3 percent) received college degrees. Case mothers were more likely than control mothers to be nonwhite, although, consistent with the demographics in Washington State, the proportion of nonwhite participants was very small for both groups.

Risk of brain tumor occurrence did not increase with increasing exposure, as indicated by the five-level Wertheimer-Leeper code (table 3). When exposure was dichotomized, the odds ratio for high relative to low exposure was 0.9 (95 percent CI 0.5–1.5). This risk did not vary by sex or age at diagnosis (≤4 vs. ≥5 years), and there was also little variation by histologic subtype. When the analysis was restricted to the 29 cases and 67 controls (of the 285 with available data) who lived in only one home from birth to reference date, no association was observed (OR = 1.1, 95 percent CI 0.4–3.4). In addition, the distribution of the five-level Wertheimer-Leeper code for study participants was similar to that of eligible nonparticipants. When the analysis of the Wertheimer-Leeper code was expanded to include both participants and potentially eligible children whose mothers did not participate in the study, the odds ratios relative to underground wiring were: very low current configuration: OR = 1.1, 95 percent CI 0.7–1.8; ordinary low-current configuration: OR = 0.9, 95 percent CI 0.4–1.8; ordinary high current configuration: OR = 0.9, 95 percent CI 0.5–1.6; and very high current configuration: OR = 0.9, 95 percent CI 0.3–2.2. For high relative to low exposure using the two-level code, the odds ratio for participants and nonparticipants combined was 0.8 (95 percent CI 0.5–1.4), which is quite close to the estimate of 0.9 based on only participants.

Few children were reported to have ever used an electric blanket before the reference date. Ever use of an electric blanket by the child was not found to be

TABLE 3. Association of brain tumor occurrence with the Wertheimer-Leeper code for home at reference date,* western Washington State, 1984–1990

Wertheimer-Leeper code	Cases (*n* = 120)		Controls (*n* = 240)		OR†	95% CI†
	No.	%	No.	%		
5-level						
Underground wiring‡	47	39.2	95	39.6	1.0	Reference
VLCC§	39	32.5	63	26.3	1.3	0.7–2.1
OLCC§	11	9.2	30	12.5	0.7	0.3–1.6
OHCC§	19	15.8	36	15.0	1.1	0.6–2.1
VHCC§	4	3.3	16	6.7	0.5	0.2–1.6
2-level‖						
Low	97	80.8	188	78.3	1.0	Reference
High	23	19.2	52	21.7	0.9	0.5–1.5

* Reference date, date of diagnosis for cases and a comparable date for controls.
† OR, unadjusted odds ratio; CI, confidence interval.
‡ Underground wiring, no visible power distribution components within 130 feet (39.91 m) of the home.
§ VLCC, very low current configuration; OLCC, ordinary low current configuration; OHCC, ordinary high current configuration; VHCC, very high current configuration.
‖ Low, underground wiring or VLCC or OLCC; high, OHCC or VHCC.

associated with an increased risk for brain tumor occurrence (OR = 0.5, 95 percent CI 0.2–1.4) (table 4), nor was use of a heated water bed (OR = 0.8, 95 percent CI 0.3–1.9). No increase in risk was observed for in utero exposure to heated water beds or electric blankets (table 4). When stratified by age, the odds ratio associated with in utero exposure to electric blankets for children younger than age 5 years was 1.4 (95 percent CI 0.5–3.7), and for the older children it was 0.7 (95 percent CI 0.4–1.4) (not shown). Electric heating sources were not associated with brain tumor occurrence (table 5).

Of the electric appliances evaluated (table 6), modest and likely chance elevations were observed for ever versus never use before reference date of bedside digital clocks (OR = 1.8, 95 percent CI 0.9–3.3), portable black-and-white televisions (OR = 1.6, 95 percent CI 0.6–3.9), having been placed in an incubator as an infant (OR = 1.5, 95 percent CI 0.8–3.1), and use of a baby monitor (OR = 1.6, 95 percent CI 0.8–3.1). There was no association with in utero exposure to dial clocks, digital clocks, microwave ovens, or desktop computers (table 6), and no consistent patterns of elevation were noted after stratification by age.

DISCUSSION

These data do not support the hypothesis that increased exposure to residential magnetic field sources is associated with the subsequent occurrence of brain tumors in children. We did not find high-current power lines at the reference home to be associated with increased risk, nor did we find evidence for a dose-response relation with increasing power line configuration levels. Electric heating sources were not associated with brain tumor occurrence, nor was use of electric blankets or heated water beds.

TABLE 4. Association of brain tumor occurrence with ever versus never use of electric blankets and heated water beds, western Washington State, 1984–1990

	Cases (*n* = 133)		Controls (*n* = 270)		OR*	95% CI*
	No.	%	No.	%		
Child's exposure						
Electric blanket	6	4.5	22	8.1	0.5	0.2–1.4
Heated water bed	8	6.0	20	7.4	0.8	0.3–1.9
In utero exposure						
Electric blanket†	20	15.2	45	16.9	0.9	0.5–1.6
Heated water bed‡	20	15.2	54	20.0	0.7	0.4–1.3

* OR, unadjusted odds ratio; CI, confidence interval.
† Information missing for one case and four controls.
‡ Information missing for one case.

TABLE 5. Association of brain tumor occurrence with residential electric heating sources,* western Washington State, 1984–1990

Heating sources	Cases (n = 98)		Controls (n = 208)		OR†	95% CI†
	No.	%	No.	%		
Child's exposure						
Any electric‡	54	55.1	140	67.3	0.6	0.4–1.0
Radiant§	6	6.1	13	6.3	1.0	0.4–2.6
Baseboard‖	34	34.7	70	33.7	1.0	0.6–1.7
Space heater¶	4	4.1	13	6.3	0.6	0.2–2.0
In utero exposure						
Any electric#	51	52.0	126	60.6	0.7	0.4–1.2
Extra bedroom heat**	18	18.4	27	13.0	1.5	0.8–2.9

* Ever versus never use of electric heating sources within 3 years before reference date.
† OR, unadjusted odds ratio; CI, confidence interval.
‡ Any primary electric heating source in the home or supplemental electric heating source in the child's bedroom.
§ Radiant floor or radiant ceiling heat as the primary heating source in the home.
‖ Baseboard electric heat in the home or as a supplemental heating source in the child's bedroom.
¶ Portable "space" heater as a supplemental heating source in the child's bedroom.
# Any primary electric heating source in the home during pregnancy or supplemental electric heating source in the mother's bedroom during pregnancy.
** Any supplemental electric heating source in the mother's bedroom during pregnancy.

We also did not find evidence that appliances used intermittently for short periods of time, such as hair dryers (which emit strong magnetic fields directly to the head), curling irons, or microwave ovens, were associated with brain tumor occurrence. For electric appliances that may be sources of more persistent magnetic field exposure, however, results were less consistent. Electric analog (dial-faced) clocks, for example, emit magnetic fields that are considerably stronger than those of digital clocks (13), yet we observed a lower point estimate for analog clocks than for digital clocks. While the odds ratio for portable black-and-white televisions was somewhat elevated, risks were lower for use of portable color televisions and larger black-and-white televisions, and an odds ratio of less than 1.0 was observed for color televisions with screens of 9 inches (228.6 mm) or larger. We found no evidence to suggest that exposure to magnetic field sources while pregnant increased subsequent brain tumor occurrence in children.

Several limitations of this study need to be considered. Certainly, the most general limitation is our inability to measure the actual time-specific magnetic field exposure that each child received before diagnosis of disease (or an equivalent reference date for controls). Given the elevated childhood cancer risks associated with the Wertheimer-Leeper code in previous studies (2, 3, 19), our primary objective was to evaluate the risk of childhood brain tumor occurrence in relation to this proxy measure. Because current load is correlated with magnetic field strength, it is assumed that power distribution systems designed to carry high-current loads emit relatively stronger magnetic fields than do systems designed to carry lower-current loads. Consistent with this assumption, mean residential magnetic fields have been shown to increase with increasing exposure levels of the Wertheimer-Leeper code, although there is only moderate correlation between the measures (13, 19–21).

Although we collected a residential history from questionnaire respondents, some historical addresses were incomplete, and many were not located in the study area. Since all study participants were in the study area at reference date and we were able to map almost 90 percent of these homes, we limited our analysis to the reference home. If an association truly exists between high-current power line configurations and cancer occurrence, then bias could have resulted from this restriction if cases and controls lived at their reference home for different average lengths of time. Although we do not have data to evaluate length of residence for study subjects who did not return the mail questionnaire, among those who did, cases lived at their reference home somewhat longer than did controls (mean of 49 months for cases and 37 months for controls; the age-adjusted mean difference was 9.2 months, 95 percent CI 0.3–18.1). If, conditional on case-control status, previous homes would have been classified at the same exposure level, then no systematic bias would result from our analysis restricted to reference homes. Bias in either direction is conceivable if previous homes would have been classified at different exposure levels, depending on the relative proportions and direction of the differences between

TABLE 6. Association of brain tumor occurrence with ever versus never use of electric appliances, western Washington State, 1984–1990

	Cases (n = 98)		Controls (n = 208)		OR*	95% CI*
	No.	%	No.	%		
Child's exposure						
Hair dryer†	47	48.0	108	52.4	0.7	0.4–1.2
Curling iron‡	20	41.7	36	38.7	1.0	0.5–2.1
Portable BW television§	9	9.2	12	5.8	1.6	0.6–3.9
Portable color television‖	5	5.1	8	3.9	1.3	0.4–4.0
Television video game¶	30	30.6	52	25.1	1.2	0.6–2.1
Desktop computer#	18	18.4	35	16.9	0.9	0.5–1.8
Large BW television**	25	26.0	42	20.3	1.2	0.7–2.3
Large color television††	74	76.3	167	81.1	0.7	0.4–1.3
Bedside dial clock‡‡	16	16.7	25	12.2	1.3	0.6–2.7
Bedside digital clock#	29	29.6	38	18.4	1.8	0.9–3.3
Microwave oven#	40	40.8	85	41.1	0.9	0.6–1.5
Incubator§§	16	16.3	23	11.1	1.5	0.8–3.1
Baby monitor	17	17.3	30	14.4	1.6	0.8–3.1
In utero exposure						
Bedside dial clock‖‖	30	31.6	75	36.6	0.7	0.4–1.2
Bedside digital clock‖‖	53	55.8	121	59.0	1.0	0.6–1.7
Microwave oven¶¶	38	39.2	85	40.9	1.1	0.6–2.0
Desktop computer	11	11.2	31	14.9	0.8	0.4–1.8

* OR, age-adjusted odds ratio; CI, confidence interval.
† Information missing for two controls.
‡ Girls only; percentages based on 48 cases and 93 controls.
§ Black-and-white television, 8-inch (203.2 mm) screen or smaller; information missing for two controls.
‖ Color television, 8-inch screen or smaller; information missing for four controls.
¶ Television video game: information missing for one control.
# Information missing for one control.
** Black-and-white television, 9-inch (228.6 mm) screen or larger; information missing for two cases and one control.
†† Color television, 9-inch screen or larger; information missing for one case and two controls.
‡‡ Information missing for two cases and three controls.
§§ Placed in an incubator as an infant.
‖‖ Information missing for three cases and three controls.
¶¶ Information missing for one case.

cases and controls. Our analysis of the 96 questionnaire respondents who lived in only one home from birth to reference date suggests that no important systematic bias was present from the restriction to reference homes.

As in all case-control studies, selection bias may occur if eligible nonparticipants differ from participants in relation to exposure status. For power line configurations, we did not find evidence of such a bias. We could not, however, evaluate differences with electric heating sources or electric appliances.

Statistical power to detect significant risk differences from some exposures was limited. For example, if the true proportion of control children exposed to high-current configuration power lines using the two-level Wertheimer-Leeper code was 15 percent, our sample size (n = 360) provided 80 percent power to detect a relative risk of 2.0 (one-tailed test at critical level 0.05). The power to detect a relative risk of 2.0 for ever versus never use of electric appliances was 74 percent on the basis of a control exposure frequency of 15 percent and our sample size of 308 children. For exposures that are notably less common, such as electric blankets and homes with very high current configurations, the power was considerably less. Additionally, because we limited our analysis of electric appliances to ever versus never use, we are assuming that, for those who used the appliances, the pattern of use was similar between cases and controls. Among subjects for whom appliance use was reported, if cases had greater intensity or duration of use than did controls, then our ability to detect an association, if one truly exists, would be diminished. Given that odds ratios for some appliances were elevated (n = 9), while others were not (n = 8), this scenario seems unlikely.

The primary focus of our research was on residential exposure; we had no measure of exposures that occurred outside the home. However, there exist some data suggesting that for children most magnetic field

exposure occurs in the home. In a pilot study that assessed 48-hour magnetic field exposure for 28 children using personal dosimeters, children younger than age 4 years spent over 80 percent of their time at home, and children age 8–11 years of age spent over 60 percent of their time at home (22). If, however, controls had substantially higher magnetic field exposure outside the home than did cases, our ability to detect risk differences based on residential exposure would be attenuated.

Only one previous study evaluated electric appliance use in relation to childhood brain tumor occurrence. Savitz et al. (23) did not find associations for child's ever versus never use of electric blankets, heated water beds, bedside electric clocks, or hair dryers. They did, however, find an association with in utero exposure to electric blankets (OR = 2.5, 95 percent CI 1.1–5.5) that was observed primarily among children younger than age 5 years (OR = 3.7, 95 percent CI 1.2–11.1). In our study, in utero electric blanket exposure was not observed to be a risk factor overall (OR = 0.9, 95 percent CI 0.5–1.6), and there was little indication of an elevated risk (OR = 1.4, 95 percent CI 0.5–3.7) among children younger than age 5 years.

Our power line findings are generally consistent with the negative results of recent European case-control studies that used proximity to transmission lines and calculated historical magnetic fields as exposure surrogates (5, 6), but are inconsistent with the two Denver studies in which elevated brain cancer risks were found in relation to the Wertheimer-Leeper code (2, 3). It is possible that our discrepant findings might reflect differences in the power distribution systems of the Seattle and Denver areas. This seems unlikely, however, because previous studies have found magnetic fields and the Wertheimer-Leeper code to have similar rank correlations in Seattle (r = 0.41) (20) and Denver (r = 0.44) (21) and because the Wertheimer-Leeper code has been shown to be reasonably well correlated with average magnetic field strengths in other areas of the country (13, 19). Alternatively, if residential magnetic field exposures are truly unrelated to brain tumor occurrence in children, the Wertheimer-Leeper code may be a surrogate for other risk factors that are present in Denver, but not in Seattle. Given our limited knowledge of brain tumor etiologies, it is only possible to speculate on the identity of such unaccounted for risk factors that are related strongly enough to both power lines and brain tumor occurrence in Denver, but not in Seattle, and thus explain the difference in findings between the two areas.

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