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Exposures of children in Canada to 60-Hz magnetic and electric fields

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Objectives This study sought to characterize personal exposures of Canadian children to 60-Hz magnetic and electric fields and explain the variability.

Methods Altogether 382 Canadian children up to 15 years of age wore meters recording 60-Hz electric and magnetic fields over 2 days. Meter location was noted. Thereafter, meters measured fields in the center of the children's bedrooms for 24 hours. Personal exposures were calculated for home, school or day care, outside the home, bedroom at night, and all categories combined (total).

Results The arithmetic mean (AM) was 0.121 µT [geometric mean (GM): 0.085 µT), range 0.01—0.8 µT] for total magnetic fields. Fifteen percent of the total exposures exceeded 0.2 µT. The AM of the total electric fields was 14.4 (GM 12.3, range 0.82—64.7) V/m. By location category, the highest and lowest magnetic fields occurred at home during the day (0.142 µT) and during the night (0.112 µT), respectively. Measurements during sleep provided the highest correlation with total magnetic field exposure. Province of measurement explained 14.7% of the variation in the logarithms of total magnetic fields, and season accounted for an additional 1.5%.

Conclusions This study has identified differences in children's magnetic field exposures between provinces. Measurements at night provided the best surrogate for predicting total magnetic field exposure, followed by at-home exposure and 24-hour bedroom measurements. Electrical heating and air conditioning, wiring type, and type of housing appear to be promising indicators of magnetic field levels.

Key terms childhood cancer, electric fields, exposure estimation, extremely low frequency, magnetic fields.

In 1979 Wertheimer & Leeper first associated childhood cancer with nearby power-line wire configurations and suggested that these were a surrogate for magnetic fields inside residences (1). Since then some studies have linked childhood leukemia with wire configurations (2, 3) or with historically extrapolated magnetic fields (4—7), while others have not (8—11). In the studies that followed Wertheimer & Leeper's work, researchers have sought to improve exposure assessments by including daytime spot measurements of magnetic fields at the front doors of residences (10), daytime spot measurements of magnetic fields inside subjects' homes under high and low power conditions (2, 3) — the latter intended to evaluate the persistent fields from outside power lines — 24-hour measurements in the child's bedroom (3, 11), and calculated fields from power transmission lines (4).

As part of a prospective case-referent study in Canada designed to examine the possible association between 60-Hz electric and magnetic fields (ELF-EMF) and the subsequent risk of childhood leukemia, we measured personal exposures of cases and referents to 60-Hz magnetic and electric fields. These measurements were part of a broader exposure assessment protocol that included wire coding of subjects' residences, daytime spot measurements of EMF around the perimeter of residences, and the collection of information on electric blanket and electric heating use and type of housing. Results of the broader exposure assessment will be reported separately. This paper reports on the personal exposure measurements of 382 children of ages under 15 years, selected as potential referents. We have examined the distribution of exposures in 5 Canadian provinces and the variability of

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exposures between provinces, seasons, days of the week, and location categories inside and outside of the home. The exposure assessment described improves on previous work by (i) monitoring personal exposures over 2 days to capture exposures that reflected each child's pattern of behavior, (ii) monitoring of perturbed electric field exposures for each child, and (iii) monitoring of magnetic field exposures during the night. Previous studies of electric field exposures have found low correlations between these fields and wire configurations (1) or magnetic fields (12). Earlier studies have not assessed sleep exposures as a separate entity; yet evidence from animal studies suggests that exposures to ELF magnetic fields at night may suppress human nighttime melatonin synthesis (13).

Methods

Between 1990 and 1995, 382 children were recruited as potential referents in the Canadian provinces of British Columbia, Alberta, Saskatchewan, Manitoba, and Quebec. Children were identified exclusively from provincial health insurance rolls for all provinces except Quebec, where family allowance files were also used. The data presented include the 22 children who were ineligible for the epidemiologic study because they had not lived in their current homes for more than 6 months.

Children wore electric and magnetic field exposure meters (Positron Industries model 378108) over 2 consecutive 24-h periods. Older children wore meters in a waist pack or a small backpack. For very young children (<18 months) a parent kept the meter near the child. Parents kept an activity diary of the child's locations and times when locations changed, and they noted if the child was wearing the meter. Locations were predefined as the child's bedroom, other room, school or day care, or other location outside the home. To monitor exposures during sleep, the meter was placed under the bed in the child's current bedroom, oriented towards the head of the bed and at least 1 meter away from any visible source of electric or magnetic fields. During a 3rd 24-h period, the meter was placed in the center of the bedroom in which the child had slept 2 years prior to the date of diagnosis of the corresponding case if the bedroom was in the current residence. If not, then the meter was left in the same bedroom as the nighttime measurements.

Every 60 seconds during monitoring, the meter measured the magnetic flux density of the 3 orthogonal components of the 60-Hz magnetic field and 1 axis of the perturbed 60-Hz electric field perpendicular to the body surface while the meter was worn (frequency response of meter -28 dB at 400 hertz and -9 dB at 40 Hz). Each reading was classified by the meter into 1 of 16 magnetic or 16 electric logarithmically scaled exposure categories. The detailed operation, characteristics, and calibration of the meter have been described previously (14—15). The meter results were checked for validity after every measurement as described in the section on data analysis and calibrated (16) at every amplitude range 3 times over the data collection period using the facilities at Hydro Quebec. No drift of meter response was detected. The 42 meters employed in the study were distributed randomly among the study subjects. An analysis of magnetic and electric field exposures by meter revealed no differences beyond those attributable to chance.

Data analysis

On completion of the monitoring of each child, data were transferred to a computer, and the root-mean-squared (rms) magnetic fields were calculated. Meter software provided chronological displays of data that were checked for consistency with times recorded in the activity diaries. Where the start time recorded in the diaries differed by more than 5 minutes from the time displayed by the software, the displayed start time was reset. Since electric fields are easily perturbed by body motion, their patterns were used to indicate whether a meter was stationary or worn by the child. Following these checks, the activity diary and the exposure data of each child were reviewed to identify all periods corresponding to 1 of the 5 location categories for each day of measurement. For each period within each location category, the meter software was used to generate an intermediate histogram file consisting of the number of readings in each of the 16 magnetic and 16 electric field bins. Each intermediate histogram was classified into 1 of the 4 location categories. These were then summed into a final histogram for each 24-hour period and for the total 48-hour period. From the final histograms, arithmetic mean exposures and the durations of time spent in each of the 4 location categories were calculated. Finally, the total exposure of each child was calculated as the time-weighted average of measurements in all 4 categories over the 48-hour period.

When a meter had been removed by a child for more than 5 minutes, both the electric and the magnetic readings were excluded from the calculations of the daily means to avoid mixing perturbed and unperturbed electric field data. Similarly, electric field readings during the night were excluded from the calculation of the total 48-hour electric field exposure because the meter had recorded only the vertical component of the unperturbed electric field. Due to the perturbation of the electric field by the body, personal measurements were not expected to correlate well with measurements of the unperturbed electric field. From our data, correlations of electric field exposures over 48 hours while wearing and not wearing the meter were low [correlation coeficient (r)=0.11]. The same components for magnetic fields were correlated at r=0.41.

The correlations of exposures were examined in 2 ways: between the means of day 1 and the means of day 2, and between the means for the 5 location categories for days 1 and 2 combined.

Results

Personal exposures to 60-Hz electric and magnetic fields were monitored over 2 consecutive 24-hour periods for 365 children. Exposures were monitored in the bedrooms over an additional 24-hour period for 373 children. Figure 1 shows that the distribution of the children's total exposure to magnetic fields (home, school, outside and sleep combined) was skewed, with arithmetic (AM) and geometric (GM) means of 0.121 and 0.085 μT [geometric standard deviation (GSD) 2.25]. The minimum and maximum individual total 48-hour exposures were 0.01 and 0.8 μT, and the levels of 0.2, 0.3, 0.4, and 0.5 μT were exceeded respectively by 14.5, 7.9, 3.8, and 2.1% of the 365 total 48-hour exposures. By province, total exposures were greater than 0.2 μT in 21.4% of the measurements from Quebec, 17.4% from Manitoba, 12.1% from British Columbia, 1.6% from Alberta, and 0% from Saskatchewan. For electric fields, which also showed a skewed distribution (figure 2), the arithmetic mean of the total exposure measurements over 48-hours (excluding sleep) was 14.4 V/m, the geometric mean was 12.3 (GSD 1.77) V/m, the range was 0.82—64.7 V/m. Levels of 20, 25, 30, and 35 V/m were exceeded, respectively, by 18.3%, 8.2%, 5.4%, and 3% of the total 48-hour exposures.

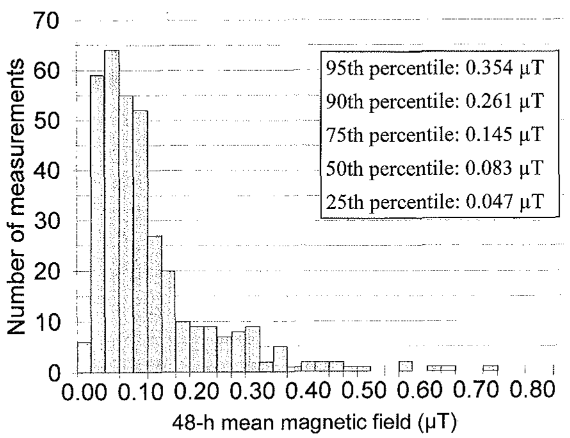

Figure 1. Distribution of the children's exposures to 60-Hz magnetic fields over 48 hours.

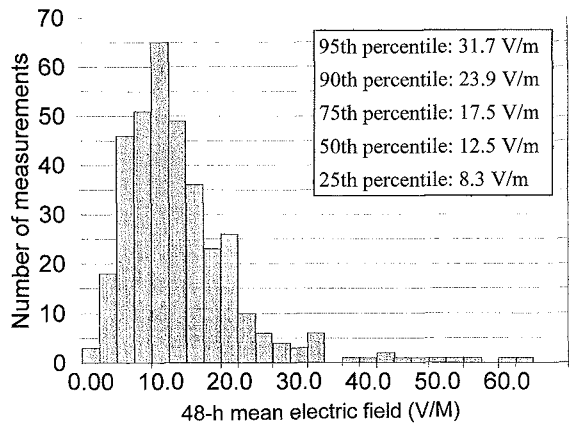

Figure 2. Distribution of the children's exposures to 60-Hz electric fields over 48 hours, excluding sleep.

For all the children combined (table 1) magnetic fields were highest at home during the day (0.141 μT) and lowest at home during the night (0.112 μT). Children in Quebec were generally exposed to the highest levels of magnetic fields whether at home (0.190 μT) outside the home (0.155 μT) or during sleep (0.145 μT). By location, exposures in this province were 2 to 3 times higher than those of children in the province with the lowest exposures (Alberta).

Total exposure to electric fields (table 2), which excluded sleep, varied very little by province at home or at school. Outside the home, exposures in Quebec and British Columbia were 1.6 to 1.8 times those of the other provinces. Activities at home appeared to produce the highest exposures (16.6 V/m for all children) and school the lowest (9.3 V/m for all children). The measurements taken during sleep should be interpreted cautiously because the meters only monitored a single axis of the unperturbed field.

The 24-hour bedroom measurements of magnetic fields (table 3) were very similar to those during sleep on the 2 previous days, whether examined by province or combined. Overall, the geometric mean of the 373 24-hour bedroom measurements was 0.062 (GSD 2.94) μT.

Comparison of exposures by season

To examine the effect of outdoor temperature on magnetic field levels, season was used as a surrogate. Data were classified as summer (April to October) or winter (November to March). Mean exposures across the 5 provinces were slightly higher during winter (0.137 μT) (95% CI 0.114—0.160 μT) than during summer (0.109 μT) (95% CI 0.096—0.123 μT), with the pattern most noticeable for Quebec. Electric fields showed no systematic differences by province (data not shown).

Comparison of magnetic and electric fields between days

Between days (table 4) magnetic fields were the most highly correlated for school or day-care measurements (r=0.85), and the weakest correlation was found for

Table 1. Mean 48-hour exposure of children to 60-Hz magnetic fields (μT), by province. (AM = arithmetic mean, 95% CI = 95% confidence interval)

Province	Daytime at home			School			Outside			Sleep			Total		
	N	AM	95% CI[a]	N	AM	95% CI[a]	N	AM	95% CI[a]	N	AM	95% CI[a]	N	AM	95% CI[a]
1. British Columbia	95	0.118	0.094—0.141	56	0.102	0.077—0.134	94	0.123	0.107—0.145	101	0.097	0.069—0.119	102	0.104	0.085—0.122
2. Alberta	62	0.062	0.053—0.076	37	0.070	0.049—0.089	57	0.073	0.060—0.088	61	0.059	0.041—0.075	62	0.060	0.050—0.070
3. Saskatchewan	18	0.120	0.080—0.184	16	0.093	0.059—0.188	16	0.087	0.063—0.140	19	0.078	0.057—0.136	19	0.091	0.072—0.131
4. Manitoba	23	0.155	0.125—0.205	13	0.156	0.097—0.343	21	0.119	0.091—0.178	23	0.111	0.085—0.161	23	0.133	0.112—0.167
5. Quebec	150	0.190	0.163—0.225	92	0.141	0.103—0.166	139	0.155	0.138—0.176	159	0.145	0.122—0.188	159	0.155	0.135—0.181
All	348	0.141	0.125—0.155	214	0.116	0.093—0.125	327	0.126	0.116—0.138	363	0.112	0.096—0.127	365	0.120	0.108—0.130
Significance of variation between provinces[b]		<0.001			0.011			<0.001			<0.001			<0.001	

[a] Exact 95% confidence limits (17).
[b] One-way analysis of variance on logarithms of the 48-hour mean values.

Table 2. Mean 48-hour exposure of children to 60-Hz electric fields (V/m), by province. (AM = arithmetic mean, 95% CI = 95% confidence intervals)

Province	Daytime at home			School			Outside			Sleep[a]			Total[b]		
	N	AM	95% CI[c]	N	AM	95% CI[c]	N	AM	95% CI[c]	N	AM	95% CI[c]	N	AM	95% CI[c]
1. British Columbia	95	16.2	14.4—18.4	56	8.8	7.3—11.8	94	17.5	12.7—19.8	101	21.0	17.8—27.4	99	14.9	13.2—17.0
2. Alberta	62	16.9	14.8—21.1	37	7.9	6.3—10.7	57	10.2	8.9—12.6	61	32.5	22.7—39.8	62	12.9	11.6—14.6
3. Saskatchewan	18	15.7	12.5—21.0	16	9.6	6.0—24.1	16	9.9	7.7—14.1	19	17.5	12.4—29.2	19	12.4	10.1—16.4
4. Manitoba	23	18.6	15.0—24.3	13	10.1	5.9—22.9	21	9.8	7.3—15.1	23	13.1	8.9—26.5	23	14.1	11.1—18.7
5. Quebec	150	16.5	15.1—18.6	92	10.1	8.0—13.5	139	15.3	14.1—19.7	159	20.7	17.5—26.0	155	15.0	13.7—17.1
All	348	16.6	15.7—17.9	214	9.3	8.2—10.9	327	14.4	12.9—15.9	363	22.1	19.6—25.0	358	14.43	13.6—15.5
Significance of variation between provinces[d]		0.82			0.99			0.11			0.005			0.88	

[a] Exact 95% confidence limits (17).
[b] One-way analysis of variance on logarithms of 48-hour mean values.
[c] Single axis measurement of unperturbed electric field (meter not worn).
[d] Total electric field exposure excludes sleep measurements.

Table 3. Mean 24-hour bedroom measurements of 60-Hz magnetic fields (μT), by province. (AM = arithmetic mean, 95% CI = confidence interval)

Province	N	AM	95% CI[a]
1. British Columbia	100	0.095	0.069—0.116
2. Alberta	60	0.066	0.039—0.070
3. Saskatchewan	18	0.069	0.051—0.127
4. Manitoba	23	0.112	0.086—0.177
5. Quebec	172	0.139	0.127—0.180
All	373	0.111	0.097—0.128
Significance of variation between provinces[b]		<0.001	

[a] Exact 95% confidence limits (17).
[b] One-way analysis of variance on logarithms of 48-hour mean values.

Table 4. Pearson correlations between day-1 and day-2 measurements of 60-Hz magnetic and electric fields. (AM = correlations of arithmetic mean, lnAM = correlations of logarithms)

	Magnetic fields		Electric fields[a]	
	AM	lnAM	AM	lnAM
Worn at home	0.605	0.821	0.373	0.561
Worn at school	0.847	0.825	0.466	0.675
Worn outside home	0.376	0.450	0.185	0.441
Sleep [b]	0.571	0.876	0.413	0.660
Total exposure	0.612	0.789	0.529	0.623[c]

[a] Excludes bedroom measurements.
[b] Meter not worn.

outside the home (r=0.38). Electric fields showed a pattern similar to that of the magnetic fields, but the correlations were lower overall. For the 2 consecutive days of measurement, the median estimated between-day geometric standard deviation was 1.2 for magnetic fields and 1.3 for electric fields, compared with the between-child geometric standard deviation of 2.3 and 1.8 for magnetic and electric fields, respectively. A comparison of the magnetic field levels on weekends and on weekdays within the 48-hour total exposure data or within the 24-hour bedroom measurement data showed no consistent pattern or any differences beyond those attributable to chance.

Comparison of the independent effects of province, season and day of week

When province of measurement, season, and day of the week were entered into a regression model, province explained 8.3% (adjusted R-squared) of the variation in the total 48-hour magnetic fields. The addition of season improved the adjusted R-squared marginally (9.7%), but day of week did not. The patterns for each variable were not substantially altered when adjusted for the others. With the use of the logarithms of the total 48-hour magnetic field, province explained 14.7% of the variation. The addition of season and day increased the adjusted R-square to 16.2% and 16.5%, respectively. For electric fields, province, season, and day of the week together explained only 2.3% of the variation in the total 48-hour exposures. The use of logarithms did not improve the fit of the model.

Comparisons of measurements between the location categories

Table 5 illustrates how personal exposures in the 5 location categories related to each other and to the total 48-hour exposure. For magnetic fields, the best correlations with total exposure were found for the sleep measurements (r=0.91) and those at-home during the day (r=0.74). The 24-hour bedroom measurements performed

Table 5. Pearson correlations between location categories for 48-hour measurements of 60-Hz magnetic and electric fields.[a] (NWH = not worn at home, WH = worn at home, WSCH = worn at school, WOUT = worn outside home, SLEEP = bedroom at night, 24BR = 24-hour bedroom)

	NWH[b]		WH[b]		WSCH[b]		WOUT[b]		SLEEP[b, c]		Total exposure[b, e]		24BR[b]	
NWH	1		0.14	(0.38)	0.06	(0.16)	0.02	(0.18)	0.08	(0.32)	0.11	(0.33)	0.05	(0.17)
WH	0.41	(0.77)	1		0.36	(0.35)	0.17	(0.30)	0.11	(0.29)	0.76	(0.82)	0.05	(0.24)
WSCH	-0.004	(0.08)	0.02	(0.16)	1		0.12	(0.30)	-0.02	(0.08)	0.72	(0.67)	-0.03	(0.08)
WOUT	0.17	(0.54)	0.32	(0.56)	0.26	(0.23)	1		-0.01	(0.06)	0.61	(0.63)	0.09	(0.09)
SLEEP[c]	0.25	(0.71)	0.57	(0.74)	0.01	(0.10)	0.34	(0.51)	1		0.06	(0.22)	0.80	(0.46)
Total exposure[d, e]	0.31	(0.72)	0.74	(0.84)	0.35	(0.46)	0.49	(0.65)	0.91	(0.87)	1		0.07	(0.19)
24BR[e]	0.67	(0.77)	0.57	(0.78)	0.09	(0.14)	0.33	(0.53)	0.68	(0.88)	0.68	(0.79)	1	

[a] Magnetic field correlations in lower left triangle and electric field correlations in upper right triangle.
[b] Values in parentheses are correlations of logarithms.
[c] Meter not worn.
[d] Total electric field exposure excludes sleep measurements.
[e] Restricted to 254 homes in which 24-hour bedroom measurements were in the same room as the nighttime bedroom measurements.

Table 6. Comparison of personal magnetic field exposures of children across studies. (AM = arithmetic mean, GM = geometric mean of AM, GSD = geometric standard deviation)

Geographic area	Season	N	AM	GM	GSD	Type	Population	Reference
United States								
Los Angeles (CA)		143	0.115	0.101		24-h bedroom	Random	London (3)
Washington (DC)		29	0.131	0.099	1.89	24-h personal	Volunteers (< 9 years)	Kaune et al, 1994 (27)
West Massachusetts (NC)	Spring	30	0.112	0.084	--	24-h personal	Volunteers (<18 years)	Kaune & Zaffanella, 1994 (18)
West Massachusetts (NC)	Winter	31	0.172	0.111	--	24-h personal	Volunteers (<18 years)	Kaune & Zaffanella, 1994 (18)
Maryland	Spring	12	0.133	0.112	1.81	24-h personal	Volunteers (<11 years)	Koontz & Dietrich, 1994 (19)
Maryland	Winter	11	0.194	0.145	2.2	24-h personal	Volunteers (<11 years)	Koontz & Dietrich, 1994 (19)
Canada								
British Columbia	Summer	53	0.087	0.067	2.15	48-h personal	Random	This paper
British Columbia	Winter	49	0.121	0.081	2.32	48-h personal	Random	This paper
Alberta	Summer	44	0.055	0.047	1.70	48-h personal	Random	This paper
Alberta	Winter	18	0.071	0.052	2.23	48-h personal	Random	This paper
Saskatchewan	Summer	8	0.096	0.085	1.79	48-h personal	Random	This paper
Saskatchewan	Winter	11	0.088	0.077	1.79	48-h personal	Random	This paper
Manitoba	Summer	13	0.145	0.131	1.65	48-h personal	Random	This paper
Manitoba	Winter	10	0.117	0.111	1.41	48-h personal	Random	This paper
Quebec	Summer	109	0.139	0.099	2.28	48-h personal	Random	This paper
Quebec	Winter	60	0.190	0.148	2.00	48-h personal	Random	This paper
All provinces	Combined	348	0.120	0.085	2.25	48-h personal	Random	This paper

slightly less well (r=0.68) than the at-home measurements. After logarithmic transformation, the sleep, the worn-at-home, and the 24-hour bedroom measurements all provided similar and high correlations with total exposure (r=0.87, 0.84, 0.88, respectively). Within the home, the highest correlations were found between the worn-at-home measurements and those taken in the bedroom at night (r=0.57) and in the bedroom over 24 hours (r=0.57). The exposures outside of the home did not relate well to those inside, and the correlations were low between the worn-at-home and the outside measurements (r=0.32) and negligible between the home and school or day-care measurements (r=0.02).

For electric fields, the highest correlation with total exposure (which excluded measurements during sleep) was found for the worn-at-home measurements (r=0.76). School or day-care and outside exposures also correlated well with the total exposure (r=0.72 and 0.61, respectively). Exposures at-home and outside the home correlated more highly for electric fields than they did for magnetic fields (r=0.36 for home-school/day-care and r=0.17 for home-outside).

Finally, when the magnetic and electric fields were compared, the total 48-hour exposures were not correlated (r=0.04), but the at-home, school, and outside components showed small-to-negligible correlations (r=0.28, 0.17 and 0.02, respectively).

Discussion

This is the first report of personal measurements of magnetic and electric fields on a large sample of children from the general population in Canada. The range of exposure intensities found was similar to values reported for the United States (table 6). Our observation of higher winter magnetic fields can also be seen in data from Northern California and Maryland (18, 19). Thus season should be noted when results between studies are compared. The reader should also bear in mind that the narrow-bandwidth of the Positron meter used in our study may produce slightly lower readings than a broadband instrument (eg, EMDEX) in the presence of harmonics. This difference is likely to be negligible with respect to the differences arising from the configurations of distribution and transmission wiring in the regions compared, or from housing attributes such as the extent of electrical heating.

Variation in magnetic and electric field exposures

The largest differences in magnetic field exposures were found between provinces, with slight differences between seasons and between days. To explore the sources of these differences further, statistics on electrical heating and air-conditioning (which together account for the largest portion of residential consumption of electricity) and the percentage of multiple dwelling homes (which are expected to have higher magnetic fields than single-family homes) were obtained for the 5 provinces (table 7) (20). The correlations of these 3 characteristics with the total magnetic fields were 0.91, 0.34, and 0.64, respectively. The 2 provinces with the highest percentages of air-conditioned homes (Saskatchewan and Manitoba) were also those in which magnetic field levels in summer exceeded those in winter.

Indicators of children's total exposure

For estimating total magnetic fields, sleep exposures were found to be the best surrogates for this group of children, but this result is not surprising given that the children spent an average of 41% of the measurement time sleeping. For electric fields, the best surrogate for total exposure (which excluded sleep) was the at-home exposure. Several previous studies have relied on spot measurements of magnetic fields during the day as an index of total exposure. For example, London et al (3) found correlations of 0.63 and 0.67 between spot measurements in the child's bedroom and 24-hour measurements in the same room under low power and normal power conditions, respectively. While we did not explicitly include spot measurements inside homes as part of our protocol, a proxy spot measurement was available from 277 children who had temporarily removed the exposure monitor during measurement, or had not worn it while at home. The median duration of these measurements was 2.3 hours. Locations where the meters were removed had been noted for half of all the occurrences. They were the bathroom (32%), child's bedroom (23%), kitchen (14%), family room (12%), parent's bedroom (3%), dining room (2%), and "elsewhere in the house" (13%). An analysis

Table 7. Characteristics of homes in five Canadian provinces. (AM = arithmetic mean, 95% CI = 95% confidence interval)

Province	Proportion of homes			Total 48-hour magnetic field (μT)	
	Electricity for space heating (%)[a]	Air conditioners (%)[a]	Multiple dwellings (%)[a]	AM	95% CI[b]
British Columbia	27	9	32	0.104	0.085—0.122
Alberta	-	8	26	0.060	0.050—0.070
Saskatchewan	4	32	19	0.091	0.072—0.131
Manitoba	29	48	24	0.133	0.112—0.167
Quebec	71	15	47	0.155	0.135—0.181

[a] Source: Household Facilities and Equipment, 1994, Statistics Canada, catalogue 64-202 (20).
[b] Exact 95% confidence limits (17).

of these proxy spot measurements (identified in table 5 as "not worn at home") revealed weak correlations with total exposure (r=0.31), which improved substantially when the logarithms of the measurements were used (r=0.72).

Determining how well the total 48-hour exposures predict long-term mean exposures, assumed to be the exposure metric of greater relevance, depends on exposure variability over the long-term period of interest. Because our 2 days of measurement were consecutive, the estimated between-day geometric standard deviations are likely to be underestimates of their long-term values (21). However, little is currently known about the long-term variability of exposures. Dovan et al (22), in 1990, reported correlations for spot measurements made 5 years apart in 81 homes in Denver, Colorado. The correlations ranged from 0.52 for low-power measurements in high-current configuration homes to 0.75 for high-power measurements in all homes (Pearson correlations of log-transformed values). In 1993, Bracken & Rankin (23) reported intraclass correlation coefficients for personal exposures measured during repeat visits to homes; the coefficients ranged from 0.44 for very low current configuration homes (VLCC) to 0.83 for ordinary high current configuration homes (OHCC). Kaune & Zaffanella (18), in 1994, examined the correlations between spot measurements and also the correlations between personal measurements taken 8 months apart in spring and winter. The spot measurements were correlated at 0.71, a value similar to that found by Dovan et al (22), but the personal exposures at home were very weakly correlated (r=0.10). In addition, previous personal exposures were found to be ineffective in explaining the between-subject variability in personal exposures measured 8 months later. (22) However, as the correlations between the personal exposure measurements and residential measurements reported by Kaune & Zafanella were generally lower (r=0.28—0.64) than our values (r=0.74—0.91), we expect the repeatability of personal exposure measurements in our study to be higher.

This report has focused on the arithmetic mean as the main index of the children's exposures to ELF fields. Examinations of the relationships of alternative indices of magnetic and electric field exposures among electric utility workers (24—26) indicate that the use of the arithmetic and geometric means at the level of job title generally sacrifices little information on most other indices. For the general population there are, to our knowledge, no published reports of correlations between various exposure indices. Our earlier study of the correlations among indices of occupational and nonoccupational exposures of 36 electric utility workers (26) suggests that the use of the arithmetic mean may be less effective in the nonoccupational setting in identifying the persons most highly exposed according to other indices.

Concluding remarks

This study has characterized the distribution and variability of ELF magnetic and electric field exposures of 365 randomly selected children in 5 Canadian provinces with the use of a measurement strategy combining personal exposure monitoring and activity diaries. Overall, magnetic fields were highest at home during the day and lowest during sleep, and they differed on an average by 18%. The exposures were highest for provinces in which the homes were more heavily heated or cooled electrically or situated in multiple dwelling units. The observation of seasonal differences suggests that residential magnetic fields are also influenced by exterior temperatures. Electric field exposures showed little variation between province, or between location categories. While personal monitoring provides substantial detail on exposures, fixed location monitoring during sleep provides a good surrogate of total exposure.

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References

1. Wertheimer N, Leeper E. Electrical wiring configurations and childhood cancer. Am J Epidemiol 1979;109:273—84.
2. Savitz DA, Wachtel H, Barnes FA, John EM, Tvrdik JG. Case-control study of childhood cancer and exposure to 60-hertz electric and magnetic fields. Am J Epidemiol 1988;128:21—38.
3. London SJ, Thomas DC, Bowman JD, Sobel E, Cheng TC, Peters JM. Exposure to residential electric and magnetic fields and risk of childhood leukemia. Am J Epidemiol 1991;134:923—37.
4. Feychting M, Ahlbom A. Magnetic fields and cancer in children residing near Swedish high-voltage power lines. Am J Epidemiol 1993;138:467—81.
5. Verkasalo PK, Pukkala E, Hongisto MY, Valjus JE, Jarvinen PJ, Heikkila KV, Koskenvuo M. Risk of cancer in Finnish children living close to power lines. Br Med J 1993;307:895—9.
6. Olsen JH, Nielsen A, Schulgen G. Residence near high voltage facilities and risk of cancer in children. Br Med J 1993;307:891-5.
7. Tynes T, Haldorsen T. Electromagnetic fields and cancer in

children residing near Norwegian high-voltage power lines. Am J Epidemiol 1997;145:219—26.
8. Fulton JP, Cobb S, Preble L, Leone L, Forman EJ. Electrical wiring configurations and childhood leukemia in Rhode Island. Am J Epidemiol 1980;111:292—6.
9. Myers A, Clayden AD, Cartwright RC, Cartwright SC. Childhood cancer and overhead power lines: a case-control study. Br J Cancer 1990;62:1008—14.
10. Tomenius L. 50-Hz electromagnetic environment and the incidence of childhood tumours in Stockholm County. Bioelectromagnetics 1986;7:191—207.
11. Linet MS, Hatch EE, Kleinerman RA, Robison LL, Kaune WT, Friedman DR, et al. Residential magnetic field exposures and childhood acute lymphoblastic leukemia. N Engl J Med 1997;337:1—7.
12. Kaune WT, Stevens RG, Callahan NJ, Severson RK, Thomas DB. Residential magnetic and electric fields. Bioelectromagnetics 1987;8(4):315—35.
13. Reiter RJ. Effects of light and stress on pineal function. In: Wilson BW, Stevens RG, Andersen LE, editors. Extremely low frequency electromagnetic fields: the question of cancer. Columbus (OH): Battelle Press, 1990:87—107.
14. Héroux P. A dosimeter for assessment of exposures to ELF fields. Bioelectromagnetics 1991;12:241—57.
15. Deadman JE, Camus M, Armstrong BG, Héroux P, Cyr D, Plante M, et al. Occupational and residential 60-Hz electromagnetic fields and high-frequency transients: exposure assessment using a new dosimeter. Am Ind Hyg Assoc J 1988;49(8):409—19.
16. Institute of Electrical and Electronic Engineers (IEEE). IEEE standard procedures for measurement of power frequency electric and magnetic fields from AC power lines. New York (NY): Institute of Electrical and Electronic Engineers Inc, 1987. ANSI/IEEE Std 644—1987.
17. Land CE, Greenberg LM, Hall CE, Drzyzgula CC. Exact confidence limits for linear functions of the normal mean and variance [computer program]. Bethesda (MD): Radiation Epidemiology Branch, National Cancer Institute / Information Management Systems, 1987.
18. Kaune WT, Zaffanella LE. Assessing historical exposures of children to power-frequency magnetic fields. J Exp Anal Environ Epidemiol 1994;4:149—70.
19. Koontz MD, Dietrich FM. Variability and predictability of children's exposure to magnetic fields. J Exp Anal Environ Epidemiol 1994;4:287—307.
20. Statistics Canada. Household facilities and equipment. Ottawa: Statistics Canada, 1994. Catalogue 64—202.
21. Buringh E, Lanting R. Exposure variability in the workplace: its implications for the assessment of compliance. Am Ind Hyg Assoc J 1991;52:6—13.
22. Dovan T, Kaune WT, Savitz DA. Repeatability of measurements of residential magnetic fields and wire codes. Bioelectromagnetics 1993;14:145—59.
23. Bracken TD, Rankin RF. EMDEX project residential study—interim report. Palo Alto (CA): Electric Power Research Institute, 1993. Report TR-102011.
24. Sahl JD, Kelsh MA, Smith RW, Aseltine DA. Exposure to 60-Hz magnetic fields in the electric utility work environment. Bioelectromagnetics 1994;15:21—32.
25. Savitz DA. Correlations among indices of electric and magnetic field exposures in electric utility workers. Bioelectromagnetics 1994;15:193—204.
26. Armstrong BG, Deadman JE, Thériault G. Comparison of indices of ambient exposure to 60-Hz electric and magnetic fields. Bioelectromagnetics 1990;11:337—47. [Adapted by Armstrong BG. Montreal: McGill University, School of Occupational Health, 1991].
27. Kaune WT, Darby SD, Gardner SN, Hrubec Z, Iriye RN, Linet MS. Development of a protocol for assessing time-weighted-average exposures of young children to power-frequency magnetic fields. Bioelectromagnetics 1994;15:33—51.

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