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Social inequality and exposure to magnetic fields in the metropolitan region of São Paulo, Southeastern Brazil

ABSTRACT

OBJECTIVE: To estimate the prevalence of exposure to magnetic fields generated by transmission lines (TL) and characterize the exposed population.

METHODS: Information about TL in the metropolitan region of São Paulo, Southeastern Brazil, was provided by the electricity companies and mapped out using geographic information system (GIS). Demographic and socioeconomic data were obtained from the 2000 Census and added to the GIS in another layer. Households and their inhabitants that were located at a distance from the TL that was sufficient to generate a magnetic field $\geq 0.3 \mu\text{T}$ (microteslas) were deemed to be exposed. The prevalence was estimated according to the area of the corridors of exposure along the TL. Two approaches were used to delimit the corridor width: one consisted of widths that were predefined by the TL voltage, and the other consisted of calculation of the magnetic field. The socioeconomic information on the exposed and non-exposed populations were compared by applying the two-proportion test ($\alpha = 5\%$).

RESULTS: In the corridors with predefined widths, the prevalence of exposure was 2.4%, and in the calculated corridors, the prevalence was 1.4%. Both methods indicated higher prevalence of exposure among the younger population, and among individuals with lower education and income levels ($p < 0.001$).

CONCLUSIONS: The prevalence of exposure to magnetic fields generated by TL in the metropolitan region of São Paulo was lower than what has been observed in other countries. The results indicate inequality in the exposure to magnetic fields in this urban area, with greater risk to vulnerable populations such as children and socioeconomically less favored individuals.

DESCRIPTORS: Electromagnetic Fields, adverse effects. Environmental Exposure. Risk Factors. Socioeconomic Factors. Health Inequalities. Cross-Sectional Studies.

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INTRODUCTION

Society lives with risks created by its own organizational system. So-called post-modernity⁴ has brought countless benefits for mankind's comfort and wellbeing. On the other hand, this has created threats such as the results from emissions of hazardous waste and effluents, which contaminate the air, ground and water and may have consequences for human health.¹¹

Among the risks generated through technological advances, electromagnetic pollution results from use of electricity and domestic electrical apparatus, such as microwave ovens, video monitors and cell phones.^a

Electromagnetic fields vary greatly with regard to frequency, measured in Hertz (Hz). Electricity produces electromagnetic fields of extremely low frequency (between 50 and 60 Hz). The greatest concern is in relation to magnetic fields (measured in microteslas, μT), which may cross through common construction materials, while electrical fields are attenuated by most of these materials.¹²

Controversy still exists with regard to the effects on health from exposure to magnetic fields, given that they induce weak electric currents and insufficient energy to directly damage the DNA and trigger the process of carcinogenesis.^{5,10} At the end of the 1970s, the first epidemiological studies evaluating residential exposure to magnetic fields and the risks of leukemia, cancer and other health outcomes were published.^{7,10} These studies have been carried out with various designs (case-control,^{1,2,6,8,9} cohort^{13,14} and ecological¹⁵ studies) and a variety of exposure assessment methods.

One of the main problems faced in characterizing the effects of magnetic fields on health in epidemiological studies is the methodological difficulty of quantifying the exposure. Many studies have estimated the exposure and its effects by means of marked-out corridors and distances from homes to the transmission line,^{1,2,6,8,13-15} while making the assumption that greater proximity of homes to transmission lines gives rise to greater exposure. The magnetic field in the exposure corridors along the lines is proportional to the current. Therefore, lines of different voltages and loads should be categorized by corridors of exposure in which the width varies according to the intensity and other characteristics, such as the cable geometry, pylon height, etc.

Studies have reported corridor widths of 500 m, such that they would include exposures $\geq 0.05 \mu\text{T}$,^{13,14} and between 40 m for 33 kV transmission lines and 300 m for 420 kV lines⁸ such that they would define exposures of $\geq 0.1 \mu\text{T}$,⁹ or corridors of 100 m on each side of transmission lines, for estimated exposures $\geq 0.2 \mu\text{T}$,¹⁴ or along 110 kV and 380 kV lines.¹

Several studies have presented statistically significant results correlating exposure to magnetic fields and development of outcomes such as cancer and leukemia.²⁻⁴ Many of them use techniques involving geographic

information systems (GIS) to mark out corridors and determine the distances of homes from transmission lines, as an assessment of exposure. The present study had the objectives of estimating the prevalence of exposure to magnetic fields generated by transmission lines and characterizing the population exposed.

METHODS

This was a cross-sectional study developed as part of the EMF-SP project EMF-SP,^b which was conducted in the metropolitan region of São Paulo, Southeastern Brazil. Currently, the metropolitan region has a population of 19,697,337 inhabitants and a population density of approximately 2,479.6 inhabitants/km².^c Data on the transmission lines that cross this area were furnished by the electricity companies that participated in the project, and the lines were mapped using MapInfo GIS software (Professional version 8.5; MapInfo Corporation, New York, NY, USA).

The IBGE base map of census tracts for the municipalities of the metropolitan region of São Paulo, which contains information relating to household, population, age and socioeconomic characteristics and the schooling and income levels of heads of households, was added to the GIS in another layer, along with the information on the transmission lines and exposure corridors.

To evaluate exposure, households (and their inhabitants) that were within the limits of a corridor along a transmission line with an estimated magnetic field $\geq 0.3 \mu\text{T}$ were defined as exposed. The width of these exposure corridors was determined based on two methods:

Corridors of predefined width for each transmission line, based on epidemiological studies that used similar methods for evaluating exposure.^{8,9} The width of the corridors along the transmission lines varied according to the voltage (88 kV line, 60 m; 138 kV line, 100 m; 230 kV line, 150 m; 345 kV line, 200 m; and ≥ 440 kV line, 250 m), in order to correspond to a magnetic field $\geq 0.3 \mu\text{T}$. If there were several transmission lines within the same area served, the width of the corridor was based on the line with the highest voltage.

Corridors calculated such that the mean exposure to magnetic fields would be $\geq 0.3 \mu\text{T}$. The calculations were performed by the Instituto de Pesquisas Tecnológicas (Institute of Technological Research), using technical information on each of the lines crossing the study region, such as the mean annual load, voltage, positioning and phase distance, among others. The

^a World Health Organization. What are electromagnetic fields? Geneva; 2006 [cited 2008 Jun 9]. Available from: <http://www.who.int/peh-emf/about/WhatIsEMF/en/>

^b The EMF-SP project was coordinated by the Brazilian Association for Electromagnetic Compatibility and funded by the National Electricity Agency (Project No. 0390-041/2004), with participation by electricity transmission and distribution companies in the state of São Paulo.

^c Fundação Sistema Estadual de Análise de Dados. Município de São Paulo. São Paulo: 2008 [cited 2008 Sep 29]. Available from: <http://www.seade.sp.gov.br/producao/msp/index.php>

width of these corridors varied according to the intensity of the magnetic field and the characteristics of the respective transmission lines, with widths between 20 m and 200 m along each line.

The cutoff point of $0.3 \mu\text{T}$ to characterize exposure was adopted based on the meta-analysis of Greenland et al.³ In this, from the results of 12 epidemiological studies, the odds ratio for childhood leukemia and exposure $\geq 0.3 \mu\text{T}$ was estimated to be 1.7 (95% CI: 1.2; 2.3), compared with exposure $\leq 0.1 \mu\text{T}$ (reference group).

In both methods, the GIS software summed the population and household values of the census tracts within the areas of interest, in the case of tracts completely within the corridors. In addition, through proportional sums, the software estimated values relating to census tracts that were partially contained within each corridor. The population values were proportionally corrected for the year 2008 through information obtained from the website of the SEADE Foundation.^c

For the socioeconomic analysis, indicators for the head of household that would represent the extremes of schooling levels (up to five years of schooling and ≥ 13 years of schooling) and income levels (up to two minimum monthly salaries and ≥ 20 minimum monthly salaries) were used. These would show greater or lesser socioeconomic vulnerability. The proportions of these income and schooling categories between exposed

and non-exposed individuals were compared using a proportions test ($\alpha = 5\%$).

RESULTS

The metropolitan region of São Paulo is crossed by a network of 2,571 km of aerial transmission lines (Figure 1), among which 88 kV lines are the most frequent type (879.2 km; 34.2% of the total), followed by 345 kV lines (26.1%) (Table 1).

The corridors of predefined width wholly or partially included 2,568 census tracts with a total of 474,011

Table 1. Length of electricity transmission lines. Metropolitan Region of São Paulo, Southeastern Brazil, 2008.

Voltage (kV)	Length (km)	%
88	879.2	34.2
138	264.2	10.3
230	162.9	6.3
345	671.8	26.1
440	267.2	10.4
≥ 500	325.7	12.7
Total	2,571	100.0

Source: Bandeirante, CPFL, CTEEP, AES Eletropaulo, Elektro and Furnas

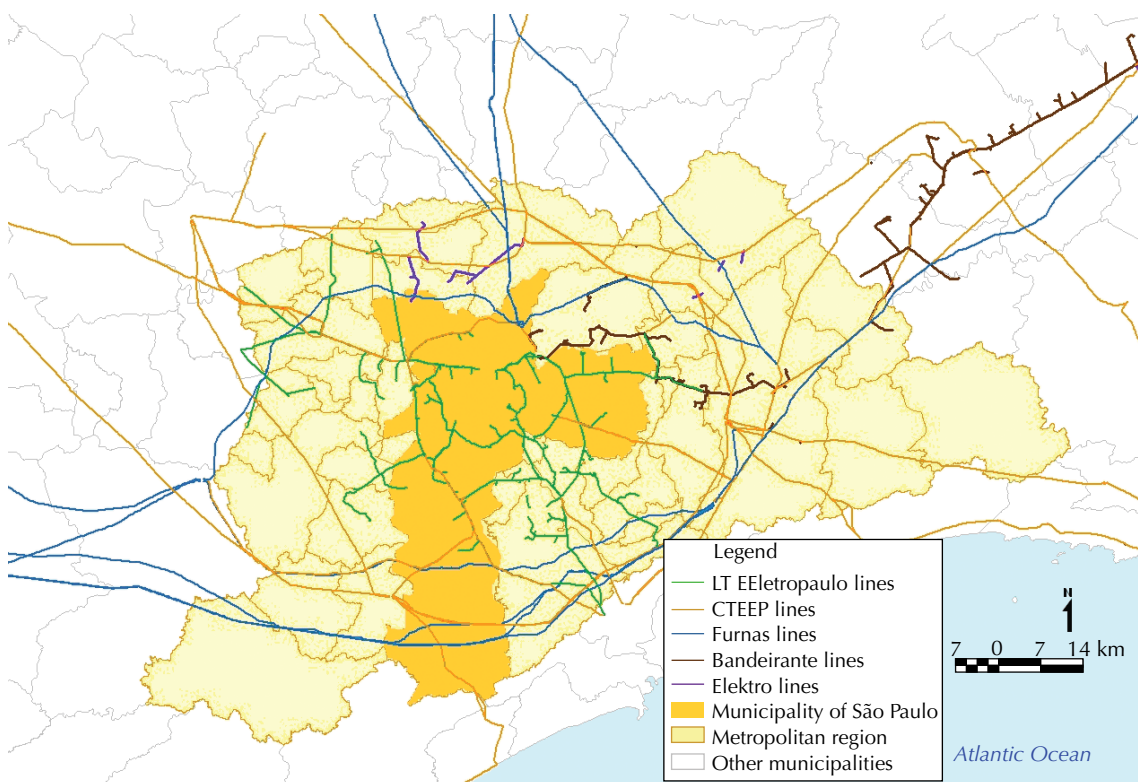


Figure 1. Transmission lines in the Metropolitan Region of São Paulo, Southeastern Brazil, 2008.

Table 2. Distribution of the population living in the metropolitan region of São Paulo according to corridors of exposure to magnetic fields generated by transmission lines. Metropolitan Region of São Paulo, Southeastern Brazil, 2008.

Age	Population ^a	%	Corridors with predefined widths			Calculated corridors		
			Exposed population ^a	%	Prevalence (%)	Exposed population ^a	%	Prevalence (%)
≤ 10	3,768,592	19.3	99,288	21.0	2.6	54,750	20.4	1.4
11 to 14	1,427,690	7.2	36,041	7.6	2.5	20,003	7.5	1.4
15 to 24	3,873,462	19.7	94,777	20.0	2.5	53,106	19.8	1.4
25 to 29	1,784,450	9.0	43,968	9.3	2.5	24,681	9.2	1.4
30 to 39	3,216,148	16.3	77,641	16.4	2.4	43,786	16.3	1.4
40 to 49	2,505,962	12.7	57,120	12.0	2.3	32,723	12.2	1.3
50 to 59	1,523,740	7.7	33,392	7.0	2.2	19,470	7.3	1.3
60 to 69	909,798	4.6	18,859	4.0	2.1	11,348	4.2	1.2
70 to 79	507,120	2.6	9,701	2.0	1.9	6,045	2.3	1.2
≥ 80	180,374	0.9	3,223	0.6	1.8	2,012	0.8	1.1
Total	19,697,337	100	474,011	100	2.4	267,924	100	1.4

^a Results corrected for the year 2008

inhabitants. The prevalence of exposure in these corridors was 2.4%. The calculated corridors included 2,316 census tracts with a total of 269,924 inhabitants and a prevalence of exposure of 1.4%.

As shown by Table 2, around half of the individuals within the corridors, using both methods, were under 24 years of age. On the other hand, the proportion of elderly individuals (≥ 70 years) living in the areas of the corridors was lower than the proportions of other age groups.

The prevalence gradually diminished towards older age groups, with lower values found from the age of 40 years onwards. The group ≥ 80 years of age presented the lowest prevalence of exposure.

The prevalence of exposure was highest in the group of heads of households with the lowest schooling levels, and the prevalence was lower in the groups with higher schooling levels (Figure 2).

The analysis on income levels among the heads of households showed results that resembled those relating to schooling levels and followed the trend of increasing prevalence in groups with lower income. Households whose heads had the lowest incomes were predominantly in corridors close to transmission lines. This prevalence was highest among groups of heads of households without any income or with not more than three minimum monthly salaries. On the other hand, the lowest prevalences were among households whose heads had incomes greater than ten minimum monthly salaries (Figure 3).

By comparing income and schooling levels together between the exposed and unexposed populations, it was observed that among the exposed individuals, there was

a greater proportion of heads of households with not more than five years of schooling and monthly income of not more than two minimum salaries. On the other hand, among the individuals who were not exposed, the proportion of heads of households with 13 years of schooling or over and monthly income greater than or equal to 20 minimum salaries was greater. All these differences between exposed and unexposed individuals were statistically significant in relation to corridors delimited using both methods ($p < 0.001$).

DISCUSSION

The prevalence of exposure to magnetic fields generated by transmission lines ranged from 1.4% to 2.4%, depending on the method used to define the exposure

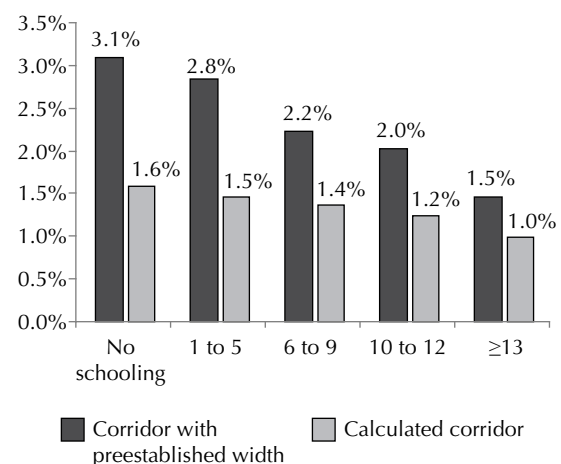


Figure 2. Percentage of heads of households living in exposure corridors, according to schooling level. Metropolitan Region of São Paulo, Southeastern Brazil, 2008.

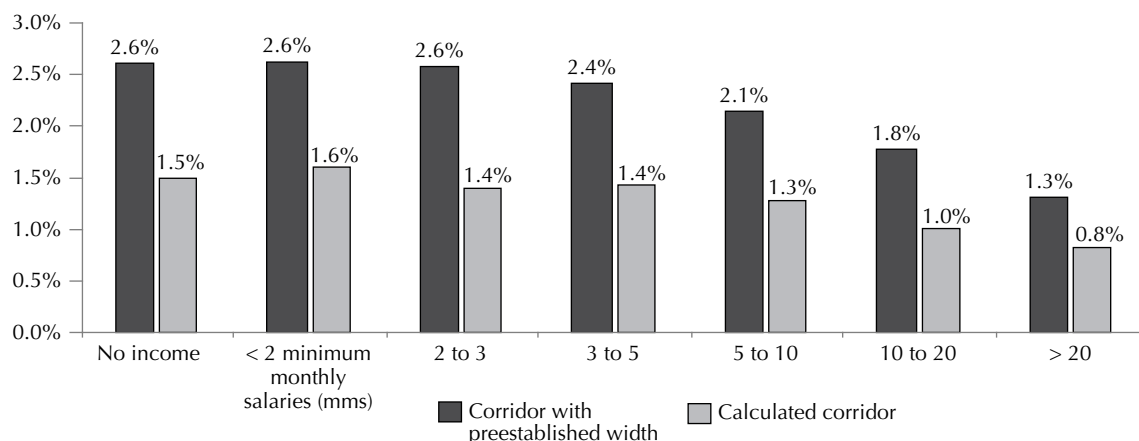


Figure 3. Percentage of heads of households living in the exposure corridors, according to monthly income. Metropolitan region of São Paulo, Southeastern Brazil, 2008.

corridors. The highest prevalence rates occurred among the child and adolescent populations (up to 18 years of age), and the lowest prevalence was among the elderly population over the age of 70 years.

There was greater exposure among populations living in situations of socioeconomic vulnerability, given that there was greater prevalence among populations with lower schooling and income levels. However, the cross-sectional design of the present study only indicates these inequalities: it does not allow the mechanisms to be defined.

Comparison between the results from the present study and the results in the literature, regarding the prevalence of exposure to magnetic fields shown by the two methods for delimiting corridors, showed that the prevalence values from the present study were lower than those found in other countries. However, the other studies used corridors of widths that differed from those in the present study, thereby impairing comparisons.

To evaluate occurrences of breast cancer, Kliukiene et al⁸ estimated corridors of widths ranging from 40 m for 33 kV transmission lines to 300 m for 420 kV lines, such that the corridors included exposures $\geq 0.05 \mu\text{T}$. They found that the prevalence of exposure was 5% among women in Norway. The corridors in the study by Olsen et al⁹ also varied according to the transmission line voltage, such that they defined exposures $\geq 0.1 \mu\text{T}$, in order to investigate childhood cancer.

Baumgardt-Elms et al¹ used corridors of 100 m in width along 110 kV and 380 kV lines in Hamburg, Germany, to evaluate the risk of testicular cancer. The exposure prevalence found was 6.9% among the cases and 5.8% among the controls (OR = 1.3; 95% CI: 0.56; 2.8).¹

In a study on childhood cancer in Finland, Verkasalo et al¹³ used corridors of 500 m along transmission lines, making the assumption that within this width

there would already be a magnetic field $\geq 0.01 \mu\text{T}$. In another study to evaluate depression,¹⁴ using a similar method, a statistically significant risk for the outcome of exposure was found.

Draper et al², in the United Kingdom, used distances ≤ 600 m from 275 and 400 kV transmission lines to evaluate exposure and found a statistically significant association, such that there was greater risk of childhood leukemia and exposure prevalence of 4% among children ≤ 14 years.

As an aid in evaluating residential exposure in Japan, Kabuto et al⁶ used the distances of homes from transmission lines of 22 to 500 kV, such that people living not more than 99 m from a line were considered to be exposed, while ≥ 100 m was taken to be the reference group. At distances of up to 50 m, the results were statistically significant, with an increased risk of acute lymphoblastic leukemia among children.

It is possible that the lower prevalence of exposure found in our study may have been due to the fact that many transmission lines in São Paulo go through regions with lower densities of homes: areas with other uses such as industrial zones, commercial zones, rural areas, forested areas (Serra da Cantareira, for example) or riverbanks (such as along the Pinheiros and Tietê rivers).

The low prevalence values may have two interpretations. On the one hand, this may be a positive factor, given that these fields have harmful effects on health. On the other hand, the higher prevalence among child and adolescent populations may have the consequence of development of leukemia and cancer, caused by this exposure.^{2-4,6} Furthermore, as a negative result, the greater prevalence among the population of lower schooling and income levels shows that magnetic fields are yet another burden on populations in situations of greater socioeconomic vulnerability.

Regarding the low prevalence compared with the results from other studies, the real exposure may have been underestimated through using corridor widths based on the mean load carried by the transmission lines, given that the load and magnetic field of the transmission lines vary during the day, according to the demand for

electric power from the population.

In conclusion, the prevalence of exposure estimated from the present study may contribute towards the discussion on this important environmental exposure in the metropolitan region of São Paulo.

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