Dirty electricity, chronic stress, neurotransmitters and disease

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ABSTRACT

Dirty electricity, also called electrical pollution, is high-frequency voltage transients riding along the 50 or 60 Hz electricity provided by the electric utilities. It is generated by arcing, by sparking and by any device that interrupts current flow, especially switching power supplies. It has been associated with cancer, diabetes and attention deficit hyperactivity disorder in humans. Epidemiological evidence also links dirty electricity to most of the diseases of civilization including cancer, cardiovascular disease, diabetes and suicide, beginning at the turn of the twentieth century. The dirty electricity level in a public library was reduced from over 10 000 Graham/Stetzer (G/S) units to below 50 G/S units by installing plug-in capacitive filters. Before cleanup, the urinary dopamine level of only one of seven volunteers was within normal levels, while four of seven phenylethylamine levels were normal. After an initial decline, over the next 18 weeks the dopamine levels gradually increased to an average of over 215 µg/g creatinine, which is well above 170 µg/g creatinine, the high normal level for the lab. Average phenylethylamine levels also rose gradually to slightly above 70 µg/g creatinine, the high normal level for the lab. Neurotransmitters may be biomarkers for dirty electricity and other electromagnetic field exposures. We believe that dirty electricity is a chronic stressor of electrified populations and is responsible for many of their disease patterns.

Keywords: biomarkers, capacitive filters, catecholamines, chronic stress, dirty electricity, diseases of civilization, dopamine, phenylethylamine

Introduction

Chronic urinary neurotransmitter changes in residents near a new cell tower erected in Rimbach, Austria, were recently reported (Buchner & Eger, 2011). Microwave radiation from the tower was presumed to be the active agent. The catecholamine neurotransmitters were studied in volunteers over a period of a year and a half. Epinephrine, norepinephrine, dopamine and phenylethylamine (PEA) all had significant changes in level, indicating chronic dysregulation of the stress system. Dopamine levels dropped significantly during the first year of study. PEA levels were unchanged for 6 months and then dropped significantly over the next year. The authors postulated that cell tower radiation generated a chronic stress response in the residents, accounting for the great variety of morbidity and mortality that has been reported in residents near cell towers.

All cell towers have switching power supplies to convert the grid alternating current (AC) into direct current (DC) to operate the cell tower transmitter and to charge the batteries used for backup power during grid outages. These switching power supplies interrupt the AC current flow and create dirty electricity (high-frequency voltage transients), which flows back into the grid. All transmitters, computers, compact fluorescent lights, DC chargers and variable speed motors contain switching power supplies. Dirty electricity is a term coined by the electrical utilities to describe electrical pollution contaminating the 60 and 50 Hz electricity on the electrical grid. It is generated by arcing, sparking and any device that interrupts the current flow. Each interruption of current flow results in a voltage spike described by the equation $V = L \times di/dt$, where V is the voltage, L is the inductance of the electrical wiring circuit and di/dt is the rate of change of the interrupted current. The voltage spike decays in an oscillatory manner. The oscillation frequency is the resonant frequency of the electrical circuit. The Graham/Stetzer (G/S) Microsurge meter measures the average magnitude of the rate of change of voltage as a function of time (dV/dT). This preferentially measures the higher frequency transients. The measurements of dV/dT read by the Microsurge meter are defined as G/S units. They are a function of voltage and frequency. Dirty electricity can be measured using an oscilloscope or multimeter set for peak-to-peak voltage or a Microsurge meter that provides a digital readout (G/S units) and is easily used by non-professionals. G/S capacitive filters short out high frequencies and reduce transients on electrical wiring with an optimal filtering capacity between 4 and 100 kHz. (Microsurge meters and filters are available from http://www.stetzerelectric.com/.) We have observed that structures near cell towers have high levels of measurable dirty electricity in their electric outlets and in air.

Dirty electricity was shown to be a potent universal carcinogen in a study of cancer in teachers at a La Quinta, California, middle school (Milham & Morgan, 2008). A single year of employment at the La Quinta school increased cancer incidence by 21%. In 2010, one of us (SM) studied a cluster of cancers in personnel at Vista del Monte elementary school in North Palm Springs, CA, with a cell tower on campus within a few feet of a classroom wing. The cancer cases were overrepresented in the classroom wing closest to the cell tower. The dirty electricity readings were highest in classrooms closest to the cell tower base and decreased linearly with distance from the cell tower base (Milham, 2010a, 2010b). Cell tower microwave radiation decreases with the square of the distance from the transmitter. A fourth grade teacher at this school complained that her students were hyperactive and unteachable. Filtering this classroom made an immediate and dramatic improvement in student behavior. The teacher removed and plugged the filters a number of times and reported that she could change student behavior in about 45 min (Milham, 2011). At this time, the cell tower was functioning normally, and classroom microwave levels were high. This suggests that the behavioral response of the students was driven by dirty electricity and not the cell tower microwaves.

Unfortunately, historical US mortality and electrification data suggest that all the so-called diseases of civilization including cancer, cardiovascular disease, diabetes and suicide are caused by electromagnetic field (EMF) exposure, most likely dirty electricity (Milham, 2010b). This was observable in US mortality records very early in the twentieth century before the invention of microwaves.

In the summer of 2011, at a book signing at the Olympia Timberland Public Library in Olympia, WA, SM measured very high levels (>20 000 G/S units) of dirty electricity in the outlets of the room where the book signing took place. The recommended level for no effects is 50 G/S units or less. In the hundreds of dirty electricity measurements made by us over the years, only a very few were this high. Excess mortality in 2608 female librarians dying in Washington State between 1970 and 2010 was seen for the following causes: cancers of the tongue, breast, ovary and brain; Alzheimer's disease: diseases of the veins and pulmonary embolus (https://fortress.wa.gov/doh/occmort/). Since the La Quinta school teachers study showed a dose/response between increasing dirty electricity classroom levels and increasing cancer incidence, we felt it important to offer to reduce the dirty electricity exposure of the library employees.

With the permission of the City of Olympia, and the cooperation of the library manager and library staff, on 10 October 2011, we reduced the dirty electricity levels in the library and measured urinary dopamine and PEA in seven volunteers a few days before and after the cleanup, and every 2 weeks for the next 18 weeks beginning 1 December 2011. A final sampling is planned 1 year after the cleanup.

Methods

After a meeting with library staff to explain the project, mail-in kits were distributed to each of the seven volunteers for collection of urine before and after the cleanup. A consent form was signed by the volunteers. The second morning urine was collected. There were six female and one male volunteer, between ages 40 and 59. We collected information from volunteers about the use at home of digital enhanced cordless telephone (DECT) cordless telephones, wireless routers and compact fluorescent lights.

A count of computers, copy machines and television sets in the library was made to estimate the number of capacitors needed to short-out the dirty electricity in the library wiring. Urine collecting kits were obtained from Pharmasan Labs, a division of NeuroScience in Osceola, WI. The Rimbach study used the same lab.

On 10 October 2011, a Fluke 199 B ScopeMeter was plugged into an outlet in the library manager's office for continuous monitoring of the dirty electricity in the library wiring during the cleanup. A modified G/S Microsurge meter was used to make simultaneous dirty electricity readings in the same outlet. Forty-four G/S plug strips each containing 2 G/S filters were plugged in, one at each computer, and 20 single G/S filters were plugged into library wall outlets to reduce the outlet reading to below 50 G/S units. Filters were also provided to clean up dirty electricity in the volunteers' homes after the library cleanup.

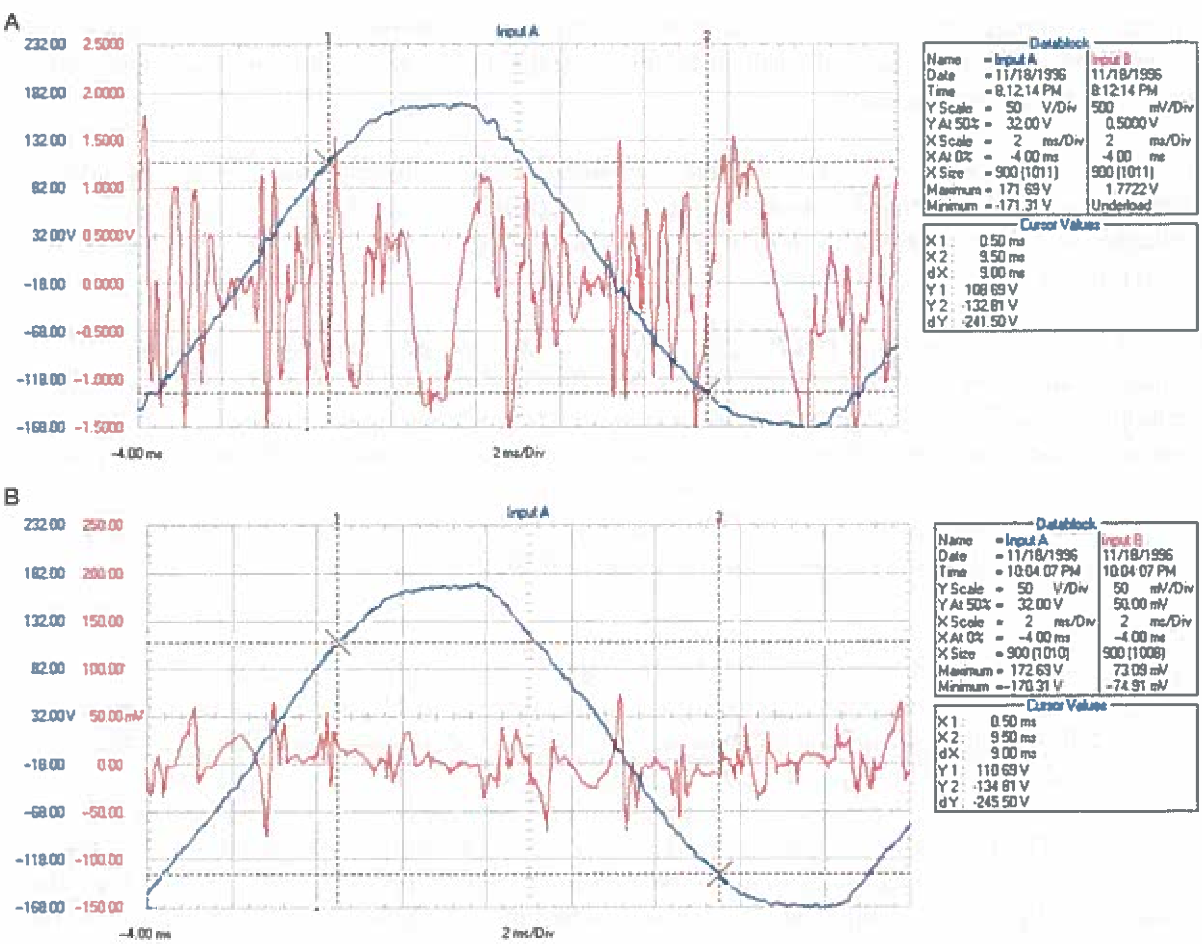
Results

Figure 1 shows the oscilloscope tracings taken in the manager's office before and after the cleanup. The Microsurge meter readings in the same outlet were 11 190 G/S units before the cleanup, 540 G/S units during the cleanup and 39 G/S units at the end of the library cleanup, which took about 2 h. The upper tracing in Figure 1 is the corrupted utility 60 Hz sine wave. The lower tracing shows the dirty electricity riding on the sine wave by filtering out the low frequencies. The change in the lower tracing before and after oscilloscope tracings shows the attenuation of the dirty electricity in the library wiring by the filters. The time stamp in the data blocks in the figures is wrong. The time between when the two figures were recorded is 2 h and

12 min, and is accurate. The cleanup began at about 9 am and ended shortly after 11 am on 11 October 2011.

[View larger version(84K)]

Figure 1. Oscilloscope tracing of the dirty electricity in a wall outlet in the director's office of the Olympia Timberland Library before and after installing G/S filters. (The date and time in the data blocks are incorrect. These tracings were taken on 10 October 2011 between 9 and 11 am.) Channel A was connected to the 120 V AC wall receptacle. Channel B was connected to the same potential, except through the ubiquitous filter (removes the 60 cycle). (A) No G/S filters were used at the time. The Microsurge meter readings were 11 190 after filtering. (B) Several G/S filters were used at the time. The Microsurge meter readings were 39 at the time.



Each one of the seven volunteers had an abnormal urinary level of either dopamine or PEA in the sampling in the days before the cleanup. In four of them, the dopamine levels were elevated, two were low and one was normal. Three of the PEA levels were elevated, and four were normal. After an initial decrease, over the next 6 months, the average urinary dopamine concentration in the volunteers who provided urine after the cleanup gradually increased to an average of over 215 µg/g creatinine, which is well above 170 µg/g creatinine, the high normal level for the lab. Average PEA levels also rose gradually to slightly above 70 µg/g creatinine, the high normal level for the lab. After the initial post-cleanup urinary sampling, the volunteers' homes also had their dirty electricity levels reduced with filters. Table I shows the average urinary dopamine and PEA levels in the volunteers before and after the dirty electricity cleanup.

Table 1. Olympia Library study: average urinary dopamine and phenylethylamine levels before and by weeks after dirty electricity cleanup (µg/g creatinine).

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Weeks	Number of samples	Dopamine	Phenylethylamine
Before	7	180	65
1	7	134	53
6	7	196	56
8	7	157	61
10	7	200	54
12	7	172	67
14	6	227	58
16	6	215	70
18	6	217	73

Discussion

Beginning with Thomas Edison's Pearl Street generating station in New York City in 1882, the generation and distribution of electricity introduced a new chronic environmental stressor into the environment, which was probably responsible for the epidemic of diseases of civilization that continues to this day. The initial source of dirty electricity was brush arcing in his "Jumbo" generators. Brushed generators and motors still generate dirty electricity. In the 1970 s, with the advent of computers and other devices with nonlinear loads that generate dirty electricity, the existing utility-neutral return wires were unable to handle the high frequencies returning to the substations due to the so-called skin effect. It takes a larger diameter wire to conduct high-frequency currents, because they travel on the outside or skin of the wire. Because of wire fires, building codes were changed to require thicker return wires in buildings, but the utilities did not change the grid neutrals. Instead, they connected the neutral return wires to the earth by running a wire from the center tap of their transformers to the ground to use the earth as a primary neutral return to the substations. In some areas of the USA, 80% of delivered electricity returns to the substation via the earth. These dirty currents get into houses and buildings on conductive water and sewer pipes and through ground rods. In rural areas, these currents called "stray voltage" cause serious health problems to farm animals and farm families. To compound the electrical exposure problems, the proliferation of cell towers and cell phones, terrestrial transmitters, WiFi and WiMax systems, broadband Internet over power lines and deployment of smart meters have caused an exponential rise in radiofrequency radiation and dirty electricity especially in urban areas. There truly is no place to hide from or to escape these chronic electrical stressors.

Selye (1955) is considered the father of stress research and described how the body responds and adapts to stressors of various types. His 1955 paper shows how chronic stress leads to disease. Chronic psychic stress has long been linked to a variety of morbidity and mortality end points. The initial fight or flight reaction causes increased sympathetic nervous system activity and the adrenal glands release epinephrine and norepinephrine into the bloodstream. The adrenal glands also release corticosteriod hormones. Digestion stops, blood pressure and pulse rate increase and the heart pumps more blood to the muscles. Blood sugar levels increase. If stress is chronic, epinephrine and norepinephrine levels decline, but corticosteriod secretion continues at above-normal levels. Chronic disturbance of the catecholamine system inevitably results in disease. *In vitro* studies of cellular stress show that heat shock or stress proteins are induced in cells by non-thermal EMFs (Goodman & Blank, 2002). EMFs cause single and double strand DNA breaks (Lai & Singh, 2005), increase permeability of the blood–brain barrier (Salford et al., 1994) and cause efflux of calcium from cells (Blackman et al., 1985). A 4.5 million dollar Air Force-supported study of pulsed 2450 MHz microwave radiation exposure of germ-free rats at the University of Washington showed midlife immune system changes and an increase in benign and malignant tumors in the exposed rats (Chou et al., 1992). In cows, the persistent, intermittent electrical shocks associated with stray voltage produce a typical stress syndrome characterized by increase of blood adrenal hormones and cortisol (Drenkard et al., 1985; Lefcourt, Kahl, & Akers, 1986). A recent study in mice shows that exposure for 1 h a day for 14 days to extremely low-frequency magnetic fields (ELF-MF) caused hyperactivity lasting for 3 months and activation of the dopaminergic D1 receptor in the brain for 1 year (Shin et al., 2011). ELF-MF exposure measured for 1 day during pregnancy predicts asthma incidence in offspring up to 16 years later (Li et al., 2011a). Early life stress, particularly childhood maltreatment, predicts systemic inflammation and levels of proinflammatory cytokines like interleukin 6 in adulthood (Carpenter et al., 2010). Evidence that neurotransmitter abnormalities are associated with disease are the number of conditions for which drugs targeting neurotransmitters are used. These include but are not limited to depression, attention deficit hyperactivity disorder (ADHD), schizophrenia, Parkinson's disease, restless leg syndrome, eating disorders, anxiety disorders, insomnia and chronic fatigue syndrome.

Since there were only very low levels of microwave exposure in this library environment, we believe that the neurotransmitter changes in the Olympia library employees and in residents near the Rimbach cell tower were also caused primarily by cell tower dirty electricity. The gradual increase in urinary dopamine and PEA in the Olympia librarians after the dirty electricity cleanup is in sharp contrast to the decline in these neurotransmitters in the Rimbach population after exposure to dirty electricity and radiofrequency from the new cell tower.

The ADHD-like symptoms in the children in a classroom near a cell tower were changed by modifying dirty electricity exposure while cell tower microwave exposure was constant. Levels of a neuromodulator, β-PEA, are lower in urine of children with ADHD (Matsuishi & Yamashita, 1999). The mortality patterns linking EMF exposure to the diseases of civilization were evident long before the development of microwave transmitters in the 1940 s. An Egyptian group (Eskander, Estefan, & Abd-Rabou, 2011) has reported that plasma adrenocorticotropic hormone and serum cortisol levels decreased over a 6-year period in people exposed to cell phones or cell phone base stations compared with controls.

A group from Nippon Medical School in Tokyo has recently reported that forest environments as compared with city environments reduce blood pressure, urinary adrenaline, noradrenaline and dopamine and increase natural killer cell activity and expression of anticancer proteins. They thought that these effects might be due to the presence of phytoncides like α- and β-pinene in forest air (Li, 2010; Li et al., 2008, 2011b). We believe that their findings are due to low levels of dirty electricity in the forest as compared with city environments. These results are evidence that the neuroendocrine and immune systems are linked and function in parallel.

The Old Order Amish (OOA) in North America live without electricity. They have less than half the cancer incidence of the US population (Westman et al., 2010) and about half the type 2 diabetes prevalence as other US citizens despite having the same body mass index (Hsueh et al., 2000). Cardiovascular disease (Hamman, Barancik, & Lillienfeld, 1981), Alzheimer's disease (Holder & Warren, 1998) and suicide (Kraybill, Hostetler, & Shaw, 1986) are reported to be less common in the OOA. A pediatric group practice in Jasper, Indiana, that cares for 800 Amish families has not diagnosed a single child with ADHD, and childhood obesity is almost unseen in this population (Ruff, 2005). Remarkably, the life expectancy of the OOA has been about 72 years for the past 300 years for both men and women. In 1900, the life expectancy of US males was 46.3 and 48.3 years for females (http://gerontology.umaryland.edu/, fall 2003, V6, No. 2). If the rest of the US population had the disease incidence and prevalence of the OOA, the US medical care and pharmaceutical industries would collapse.

The average urinary dopamine and PEA levels in these library workers increased gradually to levels above lab normals after the dirty electricity levels in the library wiring were reduced. We believe that neurotransmitters in blood and urine are biomarkers for dirty electricity exposure. Since most of the electrified populations of the world are exposed to dirty electricity, we think it is important to study those few remaining populations like the OOA, which are not exposed to or have low levels of exposure to dirty electricity, to learn what "normal" levels of neurotransmitters are.

Buchner and Eger's surmise that the morbidity and mortality associated with cell tower EMF exposure is mediated through a chronic stress reaction seems accurate and suggests that the body recognizes EMF as a foreign invader and mounts an acute stress response to it. With chronic exposure and stress, neuroendocrine and immune system dysregulation results in a wide spectrum of human morbidity and mortality. Our work shows that lowering of dirty electricity in an office environment results in increased urinary levels of dopamine and PEA in exposed persons. This is evidence that dirty electricity and probably other types of EMF exposure act as chronic stressors, causing neurotransmitter changes and disease. Neurotransmitters may be biomarkers of dirty electricity and EMF exposures.

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Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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Historical evidence that residential electrification caused the emergence of the childhood leukemia peak

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Summary A peak in childhood leukemia, ages two through four, emerged de novo in the 1920s in the United Kingdom and slightly later in the United States (US). Electrification in US farm and rural areas lagged behind urban areas until 1956. In recent years, childhood leukemia has been associated with residential electromagnetic fields. During 1928–1932, in states with above 75% of residences served by electricity, leukemia mortality increased with age for single years 0–4, while states with electrification levels below 75% showed a decreasing trend with age (P = 0.009). During 1949–1951, all states showed a peak in leukemia mortality at ages 2–4. At ages 0–1, leukemia mortality was not related to electrification levels. At ages 2–4, there was a 24% (95% confidence interval (CI), 8%–41%) increase in leukemia mortality for a 10% increase in percent of homes served by electricity. The childhood leukemia peak of common acute lymphoblastic leukemia may be attributable to electrification.

BACKGROUND

In 1961, Court Brown and Doll (1) suggested that, '... a new leukemogenic agent ...', had been introduced first into Britain in about 1920, and later into the United States and other countries. This was based on the remarkable observation that a new peak in childhood leukemia mortality between ages two and four had emerged in Britain in the 1920s and that in the 50 years starting in 1911, leukemia mortality had increased an average of 4.5% per year at ages under 10. They noted that the childhood peak was not present in mortality data for US blacks or in Japanese children. In the US, a leukemia mortality peak between ages two and four was first demonstrated in hospital data by Cooke in 1942 (2), but years of death of the cases were not specified. In a 1958 review of US leukemia mortality, Gilliam and Walter (3) demonstrated a childhood peak for white boys dying in 1929–1931, and for white girls dying in 1939–1941. They did no analysis for intracensal years, 1932–1938. No such peak was evident for black children. For the years 1921–1955, they also showed a dramatic increase in the age-adjusted leukemia mortality rate for all ages in both whites and non-whites and in both sexes. For the entire US population, leukemia increased by 64 percent between 1930 and 1940, and by 43 percent between 1940 and 1950. Fraumeni and Miller (4) demonstrated that the childhood peak, missing in US blacks and in the Japanese in earlier years had emerged in both groups after 1960. They also demonstrated that after 1955, leukemia rates in the US and in England and Wales have tended to level off. Burnett, in 1958 (5) commented that whatever was causing these changes in leukemia mortality represented, '...some widespread change, not something peculiar to one country.' In the last two decades, with the development of population-based tumor registries, it has been shown that there are ten-fold differences in the incidence of childhood leukemia around the world from a low of 0.4 per 100 000 in black African children to a high of about 4.5 per 100 000 in Hispanic children in Costa Rica (6). A number of authors have decided that the time

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trends and racial and ethnic differences indicate that common acute lymphoblastic leukemia (cALL) is somehow linked to an improving standard of living (7), increased socioeconomic status (8), increased industrialization, and urbanization of the population (9). Greaves and Alexander (10,11) discuss the evidence for in utero initiation of childhood leukemia and point out that cALL which arises from B cell precursors, makes up 75% of all childhood acute lymphoblastic leukemia and 60% of all childhood leukemia, and is solely responsible for the peak in childhood leukemia between ages two and five.

A number of theories explaining the etiology of acute lymphoblastic leukemia have arisen as the result of recent studies in Great Britain. Alexander (12), suggests a viral etiology, Kinlen (13), favors population mixing and an unusual exposure to a common infection, and Greaves and Alexander (11) favor immunologic isolation in infancy followed by a rare response to a common infection. Small area analysis supports the association between higher socioeconomic status of areas and the incidence of childhood leukemia. Rodrigues et al. (14) and Greaves and Alexander (11) note that the area results are stronger than individually based results, suggesting that '.... community characteristics are themselves of etiological importance.'

Since 1979 there has been accumulating epidemiologic evidence that leukemia and certain other cancers are somehow linked with exposure to electromagnetic fields (EMFs). Wertheimer and Leeper (15) reported that Denver area children who had died of childhood cancers had visible electric wiring at their houses which differed from that at non-cancer comparison houses. The difference suggested that the cancer houses were served with higher electric currents, and therefore had higher residential magnetic fields. In 1982, one of the authors (SM) showed that occupations with an intuitive exposure to EMFs had increased mortality due to leukemia (16). Since the early 1980s about 100 occupational and 40 residential epidemiologic studies of the EMF-cancer association have been published (17). Interestingly, of the approximately 500 separate risk ratios published in these studies, six are elevated for every one that is reduced. A recent meta-analysis of 16 childhood leukemia studies (18) concludes that, '... the data provide relatively strong and consistent support for a somewhat weak elevated risk of leukemia for children living in proximity to power lines.' A working group of the National Institute of Environmental Health Sciences recently decided that EMFs are probable carcinogens, and that the leukemia–EMF link demonstrated a 'fairly consistent pattern' in epidemiologic studies of both children and electrical workers (17). If some facet of EMF exposure is indeed carcinogenic, a simultaneous examination of the history of electrification and leukemia in the US should be revealing. Childhood leukemia with death under age 5 years was chosen as the cancer to study, because until about 1960, it was uniformly fatal, and was well reported on death records. Also, the descriptive epidemiology of childhood leukemia strongly suggests an environmental etiology (19). We decided to concentrate on the early years of electrification in the US, since, in the developed world, electrical exposures are now so widespread that it is nearly impossible to find unexposed comparison groups.

In the US, in 1920, about half of urban and rural non-farm homes had electric service as compared to 1.6% of farm homes (20). By 1940, 90% of non-farm residences had electric service compared to 35% of farm homes. It took until 1956 for farm homes to have the same percentage of electric service (98%) as non-farm homes. The great distances and expense delayed rural electrification in the US until the Rural Electrification Act was passed in 1935. The delay of a generation in the electrification of farm homes in the US created an opportunity to examine the epidemiology of leukemia in this time period in relationship to electrification. Interestingly, as late as 1955, only 20% of generated electricity was used in residences (20).

MATERIALS AND METHODS

Mortality records of the US, 1920–1960 (21) and US census bureau data (US Census of population, 1930, 1940, 1950) for populations and electrification (20) were examined, abstracted and keyed. Childhood leukemia deaths by year, state, race and age (single years of age through age four) and state population data were entered into a personal computer. National data was available for all years, but state data by single years of age was only available for years around the 1930 and 1950 censuses. Additional US Bureau of the Census population data was downloaded from the Internet (22). Poisson regression was used to study the relationship between electrification and leukemia mortality. S-Plus (23) was used for analysis.

For 1940 and 1950, the percentage of homes by state with electricity is available for three classes of homes: urban, rural non-farm and farm. For 1930, only the number and percentage of farm homes by state with electric service is available. The 1930 urban and rural non-farm electrification levels were estimated by applying the 1940 electrification data to the 1930 population data. On the national level, there was little change between 1930 and 1940 in the percent of urban and rural non-farm homes with electric service (20). These estimates are certainly higher that the true 1930 data, since electrification rates were higher in 1940 than 1930.

Childhood leukemia rates by single years of age through age four were calculated for each state 1928–1932 and 1949–1951 by using the annual death counts and the census population data for 1930 and 1950. Some states entered the death registration system

Part 2 of 8, Additional information found TheBrainCan.com , SolomonSeries.com, and https://www.youtube.com/solomonseries

during 1928–1932. For these states, the leukemia death rate was calculated using the years for which information was available. Data was missing for the following states in the years noted: Nevada, 1928; New Mexico, 1928; South Dakota, 1928–1929; Texas, 1928–1932; and Alaska, all years. Hawaii entered the death registration system in 1929, but no state data was available for Hawaii.

White infant mortality rates by state for 1950 were compared to childhood leukemia mortality rates ages two through four, and to percent of residences served by electricity by state.

RESULTS

The results are based on 1333 leukemia deaths in children under the age of five in 1928–1932, and 2640 such deaths in 1949–1951.

Figure 1 shows the development of the childhood leukemia peak for white children in the US in the period 1920–1960. No such peak is seen for black children in the same time period. During 1928–1932, states with a

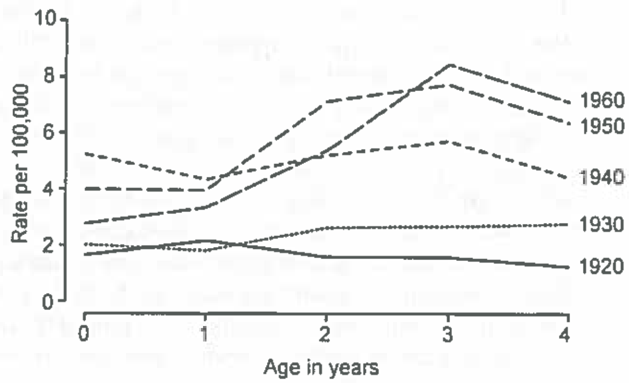

Fig. 1 Childhood leukemia mortality for US whites by single years of age 0–4, US, 1920, 1930, 1940, 1950, and 1960.

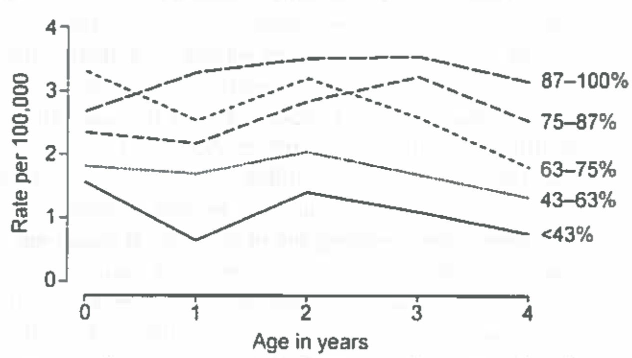

Fig. 2 Childhood leukemia mortality rates in death registration states, all races, 1928–1932, by percent residential electrification and age at death. (States were grouped by quintile of percent of homes with electric service, and rates were computed for each quintile.)

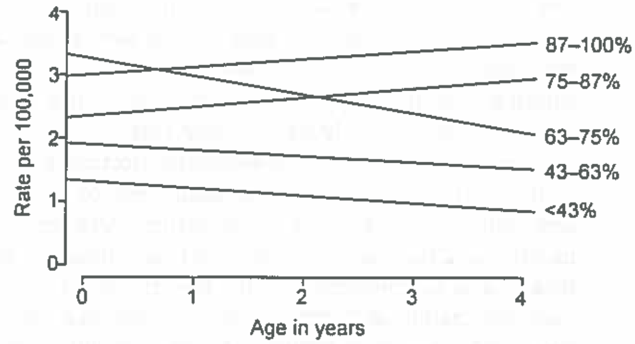

Fig. 3 Linear regression on childhood leukemia mortality rates in death registration states, all races, 1928–1932, by percent residential electrification and age at death. (States were grouped by quintile of percent of homes with electric service, and rates were computed for each quintile.)

higher percentage of homes served by electricity had higher childhood leukemia mortality (see Figure 2).

For 1928–1932 the authors fit a model using state mortality data in five age categories (single years of age through age four) and state electrification data as percent of homes served. In this model electrification significantly modified the relationship between age and leukemia mortality ($P = 0.009$). Figure 3 shows the trend in leukemia mortality rates across age up through age four for five categories of electrification. In states with electrification levels of 75% or more, leukemia mortality increased with age while states with electrification levels below 75% showed a decreasing trend with age.

In the final model for 1949–1951 data, age was entered as a categorical factor with two levels, age less than two, and ages two through four, and electrification was entered as a linear factor. During 1949–1951, all states showed a peak in mortality at ages two through four (see Figure 4).

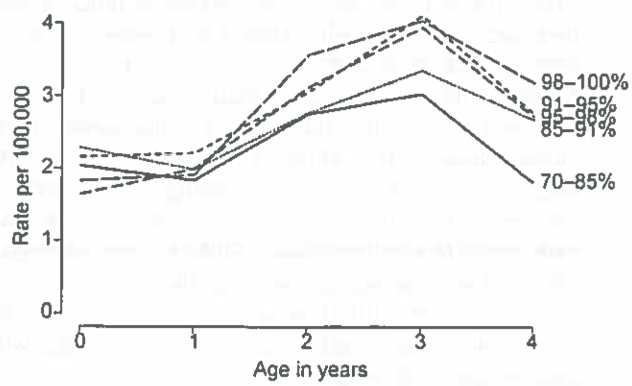

Fig. 4 Childhood leukemia mortality rates in all US states, all races, 1949–1951, by percent residential electrification and age at death. (States were grouped by quintile of percent of homes with electric service, and rates were computed for each quintile.)

The peak was highest in states with the highest levels of electrification. At age less than two, leukemia mortality was not related to electrification levels. At ages two through four, there was a 24% (95% confidence interval 8–41%) increase in leukemia mortality for each 10% increase in percent of homes served by electricity.

In 1950, in states with less than 95% of residences electrified, there was no relationship between white infant mortality rates and residential electrification, while these states clearly demonstrated the childhood leukemia peak association with residential electrification. Also, no association was seen between infant mortality rates by state and leukemia rates at ages two through four.

DISCUSSION

The most remarkable feature of childhood leukemia has been the development of a childhood peak of incidence at ages two through four. This peak has been shown to be made up of the single leukemia subtype, common acute lymphoblastic leukemia. The results of our study suggest that the childhood leukemia peak was present in 1930 in the United States in states with more than 75% of residences served by electricity. By 1950, the peak was evident in all states, but was more pronounced in those states with a higher percentage of homes with electric service. In the non-peak ages less than two years in the years 1949–1951, childhood leukemia mortality rates were not related to electrification levels. Our results suggest the childhood leukemia peak occurred earlier in states with high levels of residential electrification.

World-wide, the emergence of this peak tracks electrification. Even today, places without electrification do not show this peak. Similarly, the association between social class, urbanization, modernization, and industrialization and leukemia incidence could all be explained by electrification. In an attempt to explain the shift from childhood lymphoma to leukemia which occurred in Gaza Strip Arabs in the 1970s, Ramot and McGrath noted dramatic increases in '... available housing and owned appliances' and hypothesized that the environment '... is a major determinant...' of the childhood cancer patterns they observed. In the same time period Israeli Jewish children already showed the childhood leukemia pattern which Israeli Arab children were developing. Black Africans do not demonstrate the childhood leukemia peak, and in the early years of electrification, US blacks who were primarily rural without electric service, also did not show the peak. As electrification spread to rural areas, and blacks moved to urban (electrified) areas, blacks like whites demonstrated the peak.

The international pattern of childhood leukemia incidence reviewed by Linet and Devesa (19) also fits nicely with electrification. Costa Rica's high incidence is not surprising, since it has the health characteristics of developed countries and has a high level of electrification. The highest leukemia rates are seen in North America, Scandinavia, in New Zealand and Australian whites, and in Hong Kong. In small area studies in the UK, the fact that community characteristics outweigh individual characteristics in predicting leukemia risk, is consistent with an effect of electrification. The fact that the childhood leukemia peak was first seen in the UK, may be due to the fact that Britain and Europe electrified their farms much earlier than those in the US, and UK mortality registration was more complete at that time.

Power-frequency (50 and 60 Hz) alternating magnetic fields are the most likely active agents in the electrification effect. In the EMF literature, childhood leukemia incidence has been associated with historical calculated magnetic fields above one mG (milligauss) (24) and acute lymphoblastic leukemia incidence in children has been associated with measured magnetic fields above three mG (25). Residential magnetic fields above one mG are uncommon today, and must have been rare in the early days of electrification. In the US in the period 1920–1940 electricity in homes was used primarily for lighting, with the radio and electric iron often being the only electrical appliances. With the great increase in appliance use after 1940, residential electric currents and magnetic fields must have increased. Residential power consumption rose by a factor of eight between 1940 and 1960 (20). The delay in the appearance of the childhood leukemia peak until the 1930s may be due to the fact that residential magnetic fields were not high enough to induce leukemia until then. The rise in leukemia rates over time may reflect rising population exposure to alternating magnetic fields. Improved reporting of leukemia incidence and mortality could account for some of the time trend increase, but the emergence of the childhood peak would necessitate the unlikely scenario that leukemia at ages two through four was better diagnosed and ascertained than at other ages. Infant mortality rates by state, a surrogate for level of medical care and, therefore diagnosis and ascertainment of childhood leukemia, were not related to leukemia mortality in the peak years or to residential electrification. The fact that the childhood leukemia peak first appeared with electrification and is seen only in electrified areas suggests that a large percentage of childhood cALL is attributable to electrification. The leveling off of leukemia rates after 1950 may reflect the leveling off of residential magnetic field exposures. Modern home construction which uses nonmetallic water and sewer pipes results in lower ground currents and residential magnetic fields. Similarly, the under-grounding of residential electric service results in lower residential magnetic fields.

It could be argued that some other new urban factor in the 1920s and 1930s caused the childhood leukemia

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peak to emerge when it did. However, this could not account for the fact that rural areas in the US developed the peak only after they received electric service while retaining their essentially rural nature. In the decade between 1930 and 1940 when the childhood leukemia peak first emerged, the urbanization of the US population increased less than 1% (20). Kinlen hypothesized that population mixing caused by inward migration into a region and consequent unusual exposure to a common infectious agent could increase childhood leukemia incidence (13). US census data does not show larger population increases in regions with more electrification than in other regions between 1920 and 1930 (20). By 1950, the childhood peak was apparent in all states, including those where the population had decreased. Unfortunately, US states are too large to test the 'new town' hypothesis.

In the US in the period 1920–1960, the great distances, sparse population in rural areas, and the great expense of electrification delayed the extension of the new worldwide technology of electric power into the population for a period of nearly 35 years. This resulted in two large populations, one exposed to and one not exposed to residential EMFs. Fortunately, both populations were covered by the same mortality registration system, and the large number and heterogeneity of the US states for which single year of age childhood leukemia mortality data was available allowed clear differences in childhood leukemia mortality to be seen.

Until poles and wires were first extended into our communities, humans had never been exposed to alternating power-frequency fields. Similarly, radio, television, radar, microwaves, cell phones, and the other indispensable devices of our modern world, all expose humans to EMFs which are completely new to human evolutionary experience. There is some evidence that other parts of the electromagnetic spectrum may be leukemogenic (26,27). Weak alternating magnetic fields have been shown to affect reaction time (28), slow the heart (29), and affect the electroencephalogram in humans (30). Nocturnal secretion of the pineal hormone melatonin, a powerful anti-cancer agent, is suppressed by chronic exposure to alternating magnetic fields in electrical workers (31).

A criticism of the EMF/cancer epidemiologic studies is that calculated risks have usually been low (two or three times as high as expected). We believe that this is due to the fact that there are no truly unexposed comparison or control groups in developed (electrified) societies, and that EMF exposure assessment has been limited to the power-frequencies. The analyses of the twentieth century rise in residential electric consumption along with flat cancer and leukemia incidence in the US (32) and Canada (33) are often cited as evidence against any EMF-cancer association. Both analyses are seriously flawed, since they begin their cancer trend analyses in the 1970s, 40 years after the childhood leukemia peak emerged.

We must ask why others who have studied the emergence of the childhood cALL peak did not arrive at the same conclusion. As early as 1960, Court Brown and Doll [1] recognized that a new leukemogen had been introduced into the UK and the US in the 1920s and 1930s, but did not make the connection to electrification. This is understandable in that none of the epidemiologic studies linking leukemia with EMFs had been done yet, and there was no evidence then that low energy power-frequency fields were either biologically active or carcinogenic. The urban–rural spread of leukemia in Europe happened over a much shorter time period than it did in the US, and in the US, where there was a long delay in rural electrification, the leukemia mortality data and US census data was missing or discontinuous for urban–rural status and for electrification. Before 1932, mortality data was available for only a fraction of the US population. There is no mention of urban–rural status in the otherwise detailed analysis done by Gilliam and Walter (3).

To follow up on our observations, childhood leukemia deaths before 1960 in the peak age years could be compared to childhood leukemia deaths at other ages to see whether they had in utero or early infancy exposure to an electrified residence. An area covered by a tumor registry which has a large number of electrified and non-electrified residences could examine cALL cases in the childhood peak in a similar design.

The authors conclude the childhood leukemia peak of common acute lymphoblastic leukemia (cALL) is attributable to residential electrification. 75% of childhood acute lymphoblastic leukemia and 60% of all childhood leukemia may be preventable.

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A New Electromagnetic Exposure Metric: High Frequency Voltage Transients Associated With Increased Cancer Incidence in Teachers in a California School

Samuel Milham, MD, MPH*,† and L. Lloyd Morgan, BS‡

Background *In 2003 the teachers at La Quinta, California middle school complained that they had more cancers than would be expected. A consultant for the school district denied that there was a problem.*
Objectives *To investigate the cancer incidence in the teachers, and its cause.*
Method *We conducted a retrospective study of cancer incidence in the teachers' cohort in relationship to the school's electrical environment.*
Results *Sixteen school teachers in a cohort of 137 teachers hired in 1988 through 2005 were diagnosed with 18 cancers. The observed to expected (O/E) risk ratio for all cancers was 2.78 ($P = 0.000098$), while the O/E risk ratio for malignant melanoma was 9.8 ($P = 0.0008$). Thyroid cancer had a risk ratio of 13.3 ($P = 0.0098$), and uterine cancer had a risk ratio of 9.2 ($P = 0.019$). Sixty Hertz magnetic fields showed no association with cancer incidence. A new exposure metric, high frequency voltage transients, did show a positive correlation to cancer incidence. A cohort cancer incidence analysis of the teacher population showed a positive trend ($P = 7.1 \times 10^{-10}$) of increasing cancer risk with increasing cumulative exposure to high frequency voltage transients on the classroom's electrical wiring measured with a Graham/Stetzer (G/S) meter. The attributable risk of cancer associated with this exposure was 64%. A single year of employment at this school increased a teacher's cancer risk by 21%.*
Conclusion *The cancer incidence in the teachers at this school is unusually high and is strongly associated with high frequency voltage transients, which may be a universal carcinogen, similar to ionizing radiation.* Am. J. Ind. Med. 2008. *© 2008 Wiley-Liss, Inc.*

KEY WORDS: high frequency voltage transients; electricity; dirty power; cancer; school teachers; carcinogen

Abbreviations: EMF, electromagnetic fields; O, observed cases; E, expected cases; O/E, risk ratio; p, probability; Hz, Hertz or cycles per second; OSHA, Occupational Safety and Health Administration; OCMAP, occupational mortality analysis program; AM, amplitude modulation; GS units, Graham/Stetzer units; G/S meter, Graham/Stetzer meter; MS II, Microsurge II meter; mG, milligauss; EKG, electrocardiogram; LQMS, La Quinta Middle School.

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BACKGROUND

Since the 1979 Wertheimer–Leeper study [Wertheimer and Leeper, 1979] there has been concern that exposure to power frequency (50/60 Hz) EMFs, especially magnetic fields, may contribute to adverse health effects including cancer. Until now, the most commonly used exposure metric has been the time-weighted average of the power-frequency magnetic field. However, the low risk ratios in most studies suggest that magnetic fields might be a surrogate for a more important metric. In this paper we present evidence that a

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new exposure metric, high frequency voltage transients existing on electrical power wiring, is an important predictor of cancer incidence in an exposed population.

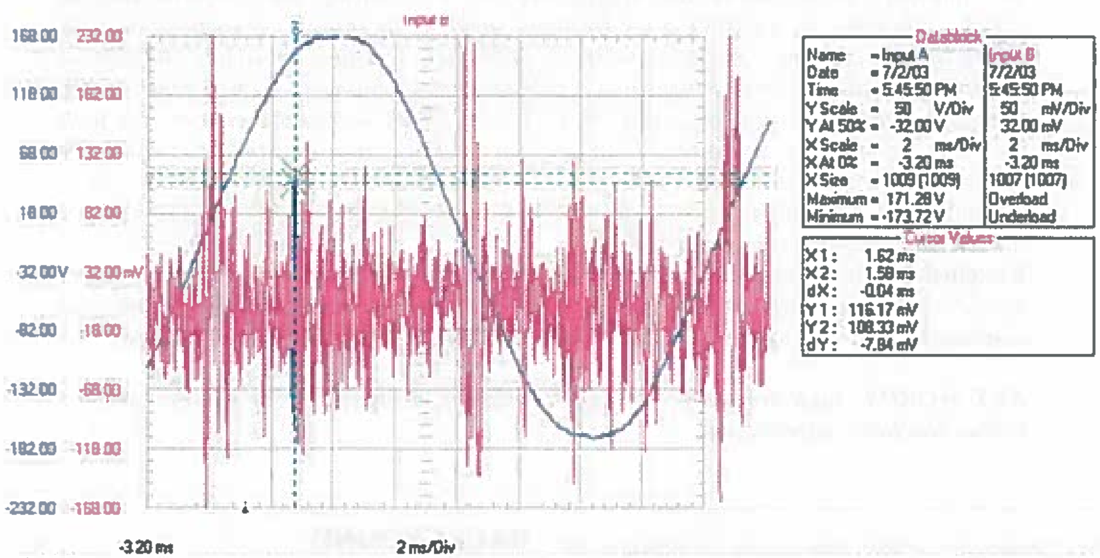
The new metric, GS units, used in this investigation is measured with a Graham/Stetzer meter (G/S meter) also known as a Microsurge II meter (MS II meter), which is plugged into electric outlets [Graham, 2005]. This meter displays the average rate of change of these high frequency voltage transients that exist everywhere on electric power wiring. High frequency voltage transients found on electrical wiring both inside and outside of buildings are caused by an interruption of electrical current flow. The electrical utility industry has referred to these transients as "dirty power."

There are many sources of "dirty power" in today's electrical equipment. Examples of electrical equipment designed to operate with interrupted current flow are light dimmer switches that interrupt the current twice per cycle (120 times/s), power saving compact fluorescent lights that interrupt the current at least 20,000 times/s, halogen lamps, electronic transformers and most electronic equipment manufactured since the mid-1980s that use switching power supplies. Dirty power generated by electrical equipment in a building is distributed throughout the building on the electric wiring. Dirty power generated outside the building enters the building on electric wiring and through ground rods and conductive plumbing, while within buildings, it is usually the result of interrupted current generated by electrical appliances and equipment.

Each interruption of current flow results in a voltage spike described by the equation $V = L \times di/dt$, where V is the voltage, L is the inductance of the electrical wiring circuit and di/dt is the rate of change of the interrupted current. The voltage spike decays in an oscillatory manner. The oscillation frequency is the resonant frequency of the electrical circuit. The G/S meter measures the average magnitude of the rate of change of voltage as a function of time (dV/dT). This preferentially measures the higher frequency transients. The measurements of dV/dT read by the meter are defined as GS (Graham/Stetzer) units.

The bandwidth of the G/S meter is in the frequency range of these decaying oscillations. Figure 1 shows a two-channel oscilloscope display. One channel displays the 60 Hz voltage on an electrical outlet while the other channel with a 10 kHz hi-pass filter between the oscilloscope and the electrical outlet, displays the high frequency voltage transients on the same electrical outlet [Havas and Stetzer, 2004, reproduced with permission].

Although no other published studies have measured high frequency voltage transients and risk of cancer, one study of electric utility workers exposed to transients from pulsed



THE WAVEFORM WAS COLLECTED IN ROOM 114 AT THE ELGIN/MILLVILLE MN HIGH SCHOOL. CHANNEL 1 WAS CONNECTED TO THE 120 VAC UTILITY SUPPLIED POWER RECEPTACLE. CHANNEL 2 WAS CONNECTED TO THE SAME POTENTIAL, EXCEPT THROUGH THE GRAHAM UBIQUITOUS FILTER. (REMOVES THE 60 HERTZ) THE AREA BETWEEN THE CURSORS REPRESENTS A FREQUENCY OF 25 KILO HERTZ. A TEACHER WHO PREVIOUSLY OCCUPIED THE ROOM DIED OF BRAIN TUMORS AND THE TEACHER IN THE ADJOINING ROOM DIED OF LUEKEMIA.

FIGURE 1. Oscilloscope display of dirty power: 60 Hz electrical power (channel 1) with concurrent high frequency voltage transients (channel 2). A 10 kHz hi-pass filter was used on channel 2 in order to filter out the 60 Hz voltage and its harmonics. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

electromagnetic fields found an increased incidence of lung cancer among exposed workers [Armstrong et al., 1994].

INTRODUCTION

In February 2004, a Palm Springs, California newspaper, The Desert Sun, printed an article titled, "Specialist discounts cancer cluster at school," in which a local tumor registry epidemiologist claimed that there was no cancer cluster or increased cancer incidence at the school [Perrault, 2004]. An Internet search revealed that the teacher population at La Quinta Middle School (LQMS) was too small to generate the 11 teachers with cancer who were reported in the article. The school was opened in 1988 with 20 teachers hired that year. For the first 2 years, the school operated in three temporary buildings, one of which remains. In 1990, a newly constructed school opened. In 2003, the teachers complained to school district management that they believed that they had too many cancers. Repeated requests to the school administration for physical access to the school and for teachers' information were denied. We contacted the teachers, and with their help, the cancers in the group were characterized. One teacher suggested using yearbooks to develop population-at-risk counts for calculating expected cancers. We were anxious to assess the electrical environment at the school, since elevated power frequency magnetic field exposure with a positive correlation between duration of exposure and cancer incidence had been reported in first floor office workers who worked in strong magnetic fields above three basement-mounted 12,000 V transformers [Milham, 1996]. We also wanted to use a new electrical measurement tool, the Graham/Stetzer meter, which measures high frequency voltage transients.

The Graham/Stetzer Microsurge II meter measures the average rate of change of the transients in Graham/Stetzer units (GS units). Anecdotal reports had linked dirty power exposure with a number of illnesses [Havas and Stetzer, 2004]. We decided to investigate whether power frequency magnetic field exposure or dirty power exposure could explain the cancer increase in the school teachers.

METHODS

After the school administration (Desert Sands Unified School District) had refused a number of requests to assist in helping us evaluate the cancers reported by the teachers, we were invited by a teacher to visit the school after hours to make magnetic field and dirty power measurements. During that visit, we noted that, with the exception of one classroom near the electrical service room, the classroom magnetic field levels were uniformly low, but the dirty power levels were very high, giving many overload readings. When we reported this to Dr. Doris Wilson, then the superintendent of schools (retired December, 2007), one of us (SM) was threatened with prosecution for "unlawful.. trespass," and the teacher who had invited us into the school received a letter of reprimand. The teachers then filed a California OSHA complaint which ultimately lead to a thorough measurement of magnetic fields and dirty power levels at the school by the California Department of Health Services which provided the exposure data for this study. They also provided comparison dirty power data from residences and an office building, and expedited tumor registry confirmation of cancer cases.

Classrooms were measured at different times using 3 meters: an FW Bell model 4080 tri-axial Gaussmeter, a Dexsil 310 Gaussmeter, and a Graham-Stetzer (G/S) meter. The Bell meter measures magnetic fields between 25 and 1,000 Hz. The Dexsil meter measures magnetic fields between 30 and 300 Hz. The G/S meter measures the average rate of change of the high frequency voltage transients between 4 and 150 KHz.

All measurements of high frequency voltage transients were made with the G/S meter. This meter was plugged into outlets, and a liquid crystal display was read. All measurements reported were in GS units. The average value was reported where more than one measurement was made in a classroom.

We measured seven classrooms in February 2005 using the Bell meter and the G/S meter. Later in 2005, the teachers measured 37 rooms using the same meters. On June 8, 2006, electrical consultants for the school district and the California Department of Health Services (Dr. Raymond Neutra) repeated the survey using the G/S meter and a Dexsil 320 Gaussmeter, measuring 51 rooms. We used results of this June 8, 2006 sampling in our exposure calculations, since all classrooms were sampled, multiple outlets per room were sampled, and an experienced team did the sampling. Additionally, GS readings were taken at Griffin Elementary school near Olympia, Washington, and Dr. Raymond Neutra provided GS readings for his Richmond California office building and 125 private California residences measured in another Northern California study.

All the cancer case information was developed by personal, telephone, and E-mail contact with the teachers or their families without any assistance from the school district. The local tumor registry verified all the cancer cases with the exception of one case diagnosed out of state and the two cases reported in 2007. The out-of state case was verified by pathologic information provided by the treating hospital. The teachers gathered population-at-risk information (age at hire, year of hire, vital status, date of diagnosis, date of death, and termination year) from yearbooks and from personal contact. The teachers also provided a history of classroom assignments for all teachers from annual classroom assignment rosters (academic years 1990–1991 to 2006–2007) generated by the school administration. The school administration provided a listing of school employees, including the teachers, to the regional tumor registry after the teachers involved the state health agency by submitting an OSHA complaint. The information we obtained anecdotally from the teachers, yearbooks, and classroom assignment rosters was nearly identical to that given to the tumor registry. None of the cancer cases were ascertained initially through the cancer registry search.

Published cancer incidence rates by age, sex, and race for all cancers, as well as for malignant melanoma, thyroid, uterine, breast, colon, ovarian cancers, and non-Hodgkin's lymphoma (NHL) were obtained from a California Cancer Registry publication [Kwong et al., 2001]. We estimated the expected cancer rate for each teacher by applying year, age, sex, and race-specific cancer incidence rates from hire date until June 2007, or until death. We then summed each teacher's expected cancer rate for the total cohort.

Using the California cancer incidence data, the school teacher data, and the GS exposure data, we calculated cancer incidence and risks. A replicate data set was sent to Dr. Gary Marsh and to Mike Cunningham at the University of Pittsburgh School of Public Health for independent analysis using OCMAP software. We calculated cancer risk ratios by duration of employment and by cumulative GS unit-years of exposure. We calculated an attributable risk percent using the frequencies of total observed and expected cancers, and performed trend tests [Breslow and Day, 1987] for cancer risk versus duration of employment and cumulative GS unit-years of exposure. Poisson *P* values were calculated using the Stat Trek website (Stat Trek, 2007). We also performed a linear regression of cancer risk by duration of employment in years and by time-weighted exposure in GS unit-years.

Since neither author had a current institutional affiliation, institutional review board approval was not possible. The teachers requested the study, and their participation in the study was both voluntary and complete. All the active teachers at the school signed the Cal OSHA request. The authors fully explained the nature of the study to study participants and offered no remuneration to the teachers for participation in the study. The authors maintained strict confidentiality of all medical and personal information provided to us by the teachers, and removed personal identifiers from the data set which was analyzed by the University of Pittsburgh. Possession of personal medical information was limited to the two authors. No patient-specific information was obtained from the tumor registry. With the individual's permission we provided the registry with case information for a teacher with malignant melanoma diagnosed out of state. The exposure information was provided by the California Department of Health Services. The basic findings of the study were presented to the Desert Sands Unified School District School Board and at a public meeting arranged by the teachers.

RESULTS

Electrical Measurements

In our seven-room survey of the school in 2005, magnetic field readings were as high as 177 mG in a classroom adjacent to the electrical service room. A number of outlets had overload readings with the G/S meter. Magnetic fields were not elevated (>3.0 mG) in the interior space of any of the classrooms except in the classroom adjacent to the electrical service room, and near classroom electrical appliances such as overhead transparency projectors. There was no association between the risk of cancer and 60 Hz magnetic field exposures in this cohort, since the classroom magnetic field exposures were the same for teachers with and without cancer (results not shown).

This school had very high GS readings and an association between high frequency voltage transient exposure in the teachers and risk of cancer. The G/S meter gives readings in the range from 0 to 1,999 GS units. The case school had 13 of 51 measured rooms with at least one electrical outlet measuring "overload" (≥2,000 GS units). These readings were high compared to another school near Olympia Washington, a Richmond California office building, and private residences in Northern California (Table I). Altogether, 631 rooms were surveyed for this study. Only 17 (2.69%) of the 631 rooms had an "overload" (maximum, ≥2,000 GS units) reading. Applying this percentage to the 51 rooms surveyed at the case school, we would expect 1.4 rooms at the school to have overload GS readings ($0.0269 \times 51 = 1.37$). However, thirteen rooms (25%) measured at the case school had "overload" measurements above the highest value (1,999 GS units) that the G/S meter can

TABLE I. Graham/Stetzer Meter Readings: Median Values in Schools, Homes and an Office Building

Place	Homes	Office bldg	Olympia WA School	LQMS	Total
No. of rooms surveyed	500	39	41	51	531
Median GS units	159	210	160	750	<270[a]
Rooms with overload GS units (≥2,000)	4	0	0	13*	17

[a]Excludes homes as specific room data was not available.
*$P = 3.14 \times 10^{-9}$.

TABLE II. Risk of Cancer by Type Among Teachers at La Quinta Middle School

Cancer	Observed	Expected	Risk ratio (O/E)	P-value
All cancers	18	6.51	2.78*	0.000098
Malignant melanoma	4	0.41	9.76*	0.0008
Thyroid cancer	2	0.15	13.3*	0.011
Uterus cancer	2	0.22	9.19*	0.019
Female breast cancer	2	1.5	1.34	0.24
All cancers less melanoma	14	6.10	2.30*	0.0025

*$P \leq 0.05$.

measure. This is a highly statistically significant excess over expectation (Poisson $P = 3.14 \times 10^{-9}$).

We noticed AM radio interference in the vicinity of the school. A teacher also reported similar radio interference in his classroom and in the field near his ground floor classroom. In May 2007, he reported that 11 of 15 outlets in his classroom overloaded the G/S meter. An AM radio tuned off station is a sensitive detector of dirty power, giving a loud buzzing noise in the presence of dirty power sources even though the AM band is beyond the bandwidth of the G/S meter.

Cancer Incidence

Three more teachers were diagnosed with cancer in 2005 after the first 11 cancer diagnoses were reported, and another former teacher (diagnosed out-of-state in 2000) was reported by a family member employed in the school system. One cancer was diagnosed in 2006 and two more in 2007. In the years 1988–2005, 137 teachers were employed at the school. The 18 cancers in the 16 teachers were: 4 malignant melanomas, 2 female breast cancers, 2 cancers of the thyroid, 2 uterine cancers and one each of Burkitt's lymphoma (a type of non-Hodgkins lymphoma), polycythemia vera, multiple myeloma, leiomyosarcoma and cancer of the colon, pancreas, ovary and larynx. Two teachers had two primary cancers each: malignant melanoma and multiple myeloma, and colon and pancreatic cancer. Four teachers had died of cancer through August 2007. There have been no non-cancer deaths to date.

The teachers' cohort accumulated 1,576 teacher-years of risk between September 1988 and June 2007 based on a 12-month academic year. Average age at hire was 36 years. In 2007, the average age of the cohort was 47.5 years.

When we applied total cancer and specific cancer incidence rates by year, age, sex, race, and adjusted for cohort ageing, we found an estimate of 6.5 expected cancers, 0.41 melanomas, 0.15 thyroid cancers, 0.22 uterine cancers, and 1.5 female breast cancers (Table II). For all cancers, the risk ratio (Observed/Expected = 18/6.5) was 2.78 ($P =$ 0.000098, Poisson test); for melanoma, (O/E = 4/0.41) was 9.8 ($P = 0.0008$, Poisson test); for thyroid cancer (O/E = 2/0.15) was 13.3 ($P = 0.0011$, Poisson test); for uterine cancer (O/E = 2/0.22), was 9.19 ($P = 0.019$, Poisson test).

Table III shows the cancer risk among the teachers by duration of employment. Half the teachers worked at the school for less than 3 years (average 1.52 years). The cancer risk increases with duration of employment, as is expected when there is exposure to an occupational carcinogen. The cancer risk ratio rose from 1.7 for less than 3 years, to 2.9 for 3–14 years, to 4.2 for 15+ years of employment. There was a positive trend of increasing cancer incidence with increasing duration of employment ($P = 4.6 \times 10^{-10}$). A single year of employment at this school increases a teacher's risk of cancer by 21%.

Using the June 8, 2006 survey data (Table IV), the cancer risk of a teacher having ever worked in a room with at least one outlet with an overload GS reading (≥2000 GS units) and employed for 10 years or more, was 7.1 ($P = 0.00007$, Poisson test). In this group, there were six teachers diagnosed

TABLE III. Cancer Risk by Duration of Employment

Time at school	Average time	Teachers	% of teachers	Cancer observed	Cancer expected	Risk ratio (O/E)	Poisson p
<3 years	1.52 years	68	49.6	4	2.34	1.72	0.12
3–14 years	7.48 years	56	40.9	9	3.14	2.87*	0.0037
15+ years	16.77 years	12	8.8	5	1.02	4.89*	0.0034
Total		137	100	18	6.51	2.78*	0.000098

Positive trend test (Chi square with one degree of freedom = 38.8, $P = 4.61 \times 10^{-10}$).
*$P \leq 0.05$.

TABLE IV. Cancer in Teachers Who Ever Taught in Classrooms With at Least One Overload GS Reading (≥2000 GS Units) by Duration of Employment

Ever in a room >2,000 GS units	Employed 10 + years	Total teachers	Cancers observed	Cancers expected	Risk ratio (O/E)	Poisson p
Yes	Yes	10	7[a]	0.988	7.1*	0.00007
Yes	No	30	3[a]	0.939	3.2	0.054
Total		40	10	1.93	5.1*	0.00003
No	Yes	19	2	1.28	1.6	0.23
No	No	78	6	3.25	1.8	0.063
Total		97	8	4.56	1.8*	0.047
Grand total		137	18	6.49	2.8*	0.000098

[a]One teacher had two primary cancers.
*$P < 0.05$.

with a total of seven cancers, and four teachers without a cancer diagnosis, who were employed for 10 or more years and who ever worked in one of these rooms. Five teachers had one primary cancer and one teacher had two primary cancers. These teachers made up 7.3% of the teachers' population (10/137) but had 7 cancers or 39% (7/18) of the total cancers. The 10 teachers who worked in an overload classroom for 10 years or more had 7 cancers when 0.99 would have been expected ($P = 6.8 \times 10^{-5}$ Poisson test). The risk ratio for the 8 teachers with cancer and 32 teachers without cancer, who ever worked in a room with an overload GS reading, regardless of the time at the school, was 5.1 ($P = 0.00003$, Poisson test). The risk ratio for 8 teachers with cancer and 89 teachers without cancer who never worked in a room with an overload G-S reading was 1.8 ($P = 0.047$, Poisson test). Teachers who never worked in an overload classroom also had a statistically significantly increased risk of cancer.

A positive dose-response was seen between the risk of cancer and the cumulative GS exposure (Table V). Three categories of cumulative GS unit-years of exposure were selected: <5,000, 5,000 to 10,000, and more than 10,000 cumulative GS unit-years. We found elevated risk ratios of 2.0, 5.0, and 4.2, respectively, all statistically significant, for each category. There was a positive trend of increasing cancer incidence with increasing cumulative GS unit-years of exposure ($P = 7.1 \times 10^{-10}$). An exposure of 1,000 GS unit-years increased a teacher's cancer risk by 13%. Working in a room with a GS overload (≥2,000 GS units) for 1 year increased cancer risk by 26%.

An attributable risk percentage was calculated: (observed cancers-expected cancers)/observed cancers = (18−6.51)/18 = 63.8%.

The fact that these cancer incidence findings were generated by a single day of G/S meter readings made on June 8, 2006 suggests that the readings were fairly constant over time since the school was built in 1990. For example, if the 13 classrooms which overloaded the meter on June 8, 2006 were not the same since the start of the study and constant throughout, the cancer risk of teachers who ever worked in the overload rooms would have been the same as the teachers who never worked in an overload room.

Although teachers with melanoma and cancers of the thyroid, and uterus, had very high, statistically significant risk ratios, there was nothing exceptional about their age at hire, duration of employment, or cumulative GS exposure. However, thyroid cancer and melanoma had relatively short latency times compared to the average latency time for all 18 cancers. The average latency time between start of

TABLE V. Observed and Expected Cancers by Cumulative GS Exposure (GS Unit-Years)

Exposure group	<5,000 GS unit-years	5,000 to 10,000	>10,000 GS unit-years	Total
Average GS unit-years	914	7,007	15,483	
Cancers obs.	9	4	5	18
Cancers exp.	4.507	0.799	1.20	6.49
Risk ratio (O/E)	2.01*	5.00*	4.17*	2.78*
Poisson p	0.0229	0.0076	0.0062	0.000098

Positive trend test (Chi square with one degree of freedom = 38.0, $P = 7.1 \times 10^{-10}$).
*$P < 0.05$.

employment at the school and diagnosis for all cancers was 9.7 years. The average latency time for thyroid cancer was 3.0 years and for melanoma it was 7.3 years (with three of the four cases diagnosed at 2, 5, and 5 years).

An independent analysis of this data set by the University of Pittsburgh School of Public Health using OCMAP software supported our findings.

DISCUSSION

Because of access denial, we have no information about the source, or characterization of the high frequency voltage transients. We can assume, because the school uses metal conduit to contain the electrical wiring, that any resultant radiated electric fields from these high frequency voltage transients would radiate mainly from the power cords and from electrical equipment using the power cords within a classroom.

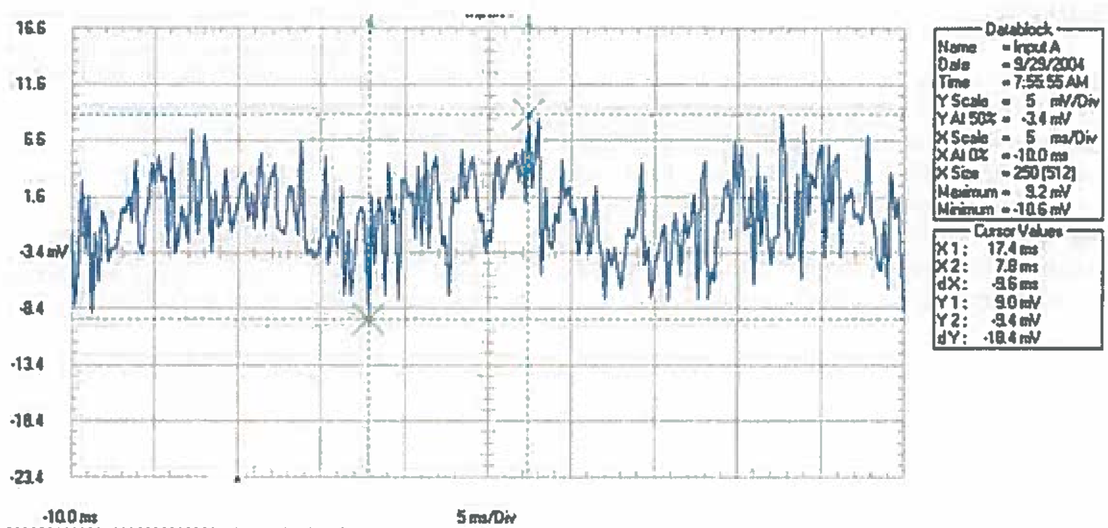
The school's GS readings of high frequency voltage transients are much higher than in other tested places (Table I). Also, teachers in the case school who were employed for over 10 years and who had ever worked in a room with an overload GS reading had a much higher rate of cancer. They made up 7.3% of the cohort but experienced 39% of all cancers.

The relatively short latency time of melanoma and thyroid cancers suggests that these cancers may be more sensitive to the effects of high frequency voltage transients than the other cancers seen in this population.

In occupational cohort studies, it is very unusual to have a number of different cancers with an increased risk. An exception to this is that cohorts exposed to ionizing radiation show an increased incidence of a number of different cancers. The three cancers in this cohort with significantly elevated incidence, malignant melanoma, thyroid cancer and uterine cancer, also have significantly elevated incidence in the large California school employees cohort [Reynolds et al., 1999].

These cancer risk estimates are probably low because 23 of the 137 members of the cohort remain untraced. Since exposure was calculated based on 7 days a week for a year, this will overstate the actual teachers' exposure of 5 days a week for 9 months a year.

We could not study field exposures in the classrooms since we were denied access to the school. We postulate that the dirty power in the classroom wiring exerted its effect by capacitive coupling which induced electrical currents in the



The waveform was recorded between 2 EKG patches placed on the ankles of XXXXXX XXXXXXXXX standing in front of his kitchen sink at his home near Bright Ontario. It shows a distorted 60 cycle sine wave containing high frequencies applied to each foot, allowing high frequency current to freely oscillate up one leg and down the other. XXXXXX has been diagnosed with prostrate cancer since moving to the house in less than a year. He was standing with feet shoulder width apart, wearing shoes, at the time of the readings. The amplitude increased as the feet were placed farther apart.

FIGURE 2. Oscilliscope display of 60 Hz current distorted with high frequencies taken between EKG patches applied to the ankles of a man standing with shoes on at a kitchen sink. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

teachers' bodies. The energy that is capacitively coupled to the teachers' bodies is proportional to the frequency. It is this characteristic that highlights the usefulness of the G/S meter. High frequency dirty power travels along the electrical distribution system in and between buildings and through the ground. Humans and conducting objects in contact with the ground become part of the circuit. Figure 2 [Havas and Stetzer, 2004, reproduced with permission] shows an oscilloscope tracing taken between EKG patches on the ankles of a man wearing shoes, standing at a kitchen sink. The 60 Hz sine wave is distorted by high frequencies, which allows high frequency currents to oscillate up one leg and down the other between the EKG patches.

Although not demonstrated in this data set, dirty power levels are usually higher in environments with high levels of 60 Hz magnetic fields. Many of the electronic devices which generate magnetic fields also inject dirty power into the utility wiring. Magnetic fields may, therefore, be a surrogate for dirty power exposures. In future studies of the EMF-cancer association, dirty power levels should be studied along with magnetic fields.

The question of cancer incidence in students who attended La Quinta Middle School for 3 years has not been addressed.

CONCLUSION

The cancer incidence in the teachers at this school is unusually high and is strongly associated with exposure to high frequency voltage transients. In the 28 years since electromagnetic fields (EMFs) were first associated with cancer, a number of exposure metrics have been suggested. If our findings are substantiated, high frequency voltage transients are a new and important exposure metric and a possible universal human carcinogen similar to ionizing radiation.

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Teachers' Cancer Cluster La Quinta Middle School

Sam Milham, MD and Lloyd Morgan

Who We Are: Introductions

Sam Milham Jr. MD

- Albany Medical College, September 1954-June 1958, MD, Alpha Omega Alpha
- Intern, U.S. Public Health Hospital, Boston, Massachusetts, July 1958-July 1959
- U.S. Public Health Service Residency in Public Health. Assigned to Monroe County Health Department, Rochester, New York, July 1959-August 1960
- Johns Hopkins School of Hygiene and Public Health, September 1960-June 1961, M.P.H.
- Senior Resident in Epidemiology. Epidemiology Residency Program, New York State Department of Health, June 1961-1962.
- Development Consultant, New York State Department of Health, 1962-1967.
- Assistant Professor, Department of Pediatrics, Albany Medical College, July 1966-1967
- Diplomate, American Board of Preventive Medicine, June 1966.
- Associate Professor, University of Hawaii School of Public Health and Medical School, 1967-1968
- Travel Fellowship, International Agency for Research on Cancer (IARC) 1971.
- Section Head, Epidemiology Section, Washington State Department of Health, 1968-1976.
- Travel Fellowship, International Cancer Research Technology Transfer, 1981
- Washington State Public Health Association Annual Award, 1986.
- Chronic Disease Epidemiologist, Washington State Department of Health, 1976-1990
- Clinical Associate Professor, University of Washington School of Public Health, 1968-.
- Section Head, Chronic Disease Epidemiology Section, Washington State Department of Health, 1990-May 1993.
- Adjunct Professor, Mount Sinai School of Medicine, 1986-.
- Robert Carl Braun Foundation Humanitarian Award, 1990.
- Member of Bioelectromagnetics Society, 1984-
- Self-employed, June 1993.
- Elected to Fellowship, Collegium Ramazzini, October 1994
- Ramazzini Award, 1997
- 100 + peer reviewed scientific publications

Who We Are: Introductions

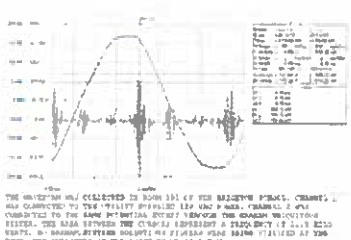
Lloyd Morgan

- Director, Central Brain Tumor Registry of the United States (CBTRUS)
- Member, Bioelectromagnetics Society (BEMS)
- Member, Brain Tumor Epidemiology Consortium (BTEC)
- Former Board Member, North American Brain Tumor Coalition (NABTC)
- Bachelors of Science, Electronic Engineering, University of California, Berkeley
- Electronic Engineer (38 years experience, retired 2002)
- Columnist for Powerwatch (http://www.powerwatch.org.uk/columns/morgan/index.asp)
- Listed author, Long-term use of cellular phones and brain tumours - increased risk associated with use for > 10 years. Occup Environ Med. 2007 Apr 4; [Epub ahead of print]
- Introduced the Benign Brain Tumor Registries Amendment Act into Congress (became law in 2002)
- Twelve year brain tumor survivor
- Twelve year's research and investigation into the health effects from exposure to electromagnetic fields (EMFs)

Cluster Abbreviated: Introductions

- Teachers ask for our involvement about 3 years ago
  - 11 cancers, then
  - What has happened since
    - District's non-cooperation
    - District's cover-up
- Now
  - 18 cancers among 137 teachers
    - One possibility in 10,000 that this is due to chance
  - Strong evidence that cancer cluster is the result of excessive "dirty power"

Sidebar: What is Dirty Power?



2nd Sidebar: Calculation Methodology

- Expected cancer rate
  - Used published California Cancer Registry cancer incidence rates by age, gender, non-Hispanic white
  - Beginning with the age of the teacher at hire
    - Determine the specific incidence rate
  - With each additional year, add a year to the teacher's age
    - Determine the specific incidence rate
  - End on June 2007 or upon death
    - Assumes no additional cancer diagnoses

The Cover-up Begins

Today, 18 cancers have been diagnosed in 16 teachers at LQMS

"… it appears that the teachers' cancer rates were not abnormally high."

April 2007 — Dr. Sam Milham & Lloyd Morgan [illegible]

Brief History of Cancer Cluster

- Late 03 Teachers, alarmed by 11 cancers, contact Dr. Wilson
- Feb 04: Dr. Milham reads news report
  - Offers to investigate at no charge
    - District rebuffs offer
- Feb 05: Teacher invites Dr. Milham and Mr. Morgan, after school, to examine 7 rooms
  - High dirty power and high magnetic fields
    - Letter to Dr. Wilson explaining possible violation of electrical code and potential fire hazard
    - Response: "unlawful trespass" and "Homeland security" breach
- Mar 05: District hires Hygienetics
  - To measure LQMS magnetic fields
    - Confirms findings of Milham and Morgan
  - District takes no action

April 2007 — Dr. Sam Milham & Lloyd Morgan [illegible] — 8

Brief History of Cancer Cluster

- May 05: CAL-OSHA complaint
  - President, Desert Sands teacher's union refuses to file complaint
  - Thirty LQMS teachers file complaint
- May 05 to May 06: OSHA tells cancer registry to search for cancers using list of LQMS teacher's names
  - Dr. Wilson delays providing names for a year
- May 06: Dr. John Morgan & Dr. Milham present their findings to District's Board of Education
  - Now, 15 cancers, 3-fold more than expected
  - Dr. Morgan: Melanoma >1/3 of all cancers, above expected
  - Dr. Milham: Melanoma, 11-fold more than expected
    - Risk of cancer increases with time at LQMS
    - Recommends dirty power filters and investigation of source of dirty power
- Jun 06: Dirty power and magnetic field measurements-problems found
  - 13 rooms found to have dirty power values larger than meter can measure
  - Rooms 304 and 404 have magnetic field problems
- Aug 06: District tells media, "no problem at LQMS"

April 2007 — Dr. Sam Milham & Lloyd Morgan [illegible] — 9

Brief History of Cancer Cluster

- Mar 07: Cal-DHS "Dirty Power" report
  - Now 18 cancers – a significant excess
  - Dr. Neutra reports dirty power levels are "unusual"
    - Recommends letting teachers install filters in their classrooms
      - Dr. Wilson states OK if teachers install filters
  - Dr. Milham reports, 13 rooms had dirty power levels higher than meter could measure (≥2,000)
    - Cancer risk at LQMS increases as cumulative dirty power exposure increases
    - Highest cancer risk in the 13 rooms
- Apr 3, 07: "Official" DHS report emailed to Dr. Wilson
  - Teachers request Dr. Wilson to send a copy
    - As of Apr 15, no teacher or District Board member has received a copy
  - No admission of cancer cluster by District nor leadership to find and fix health hazards

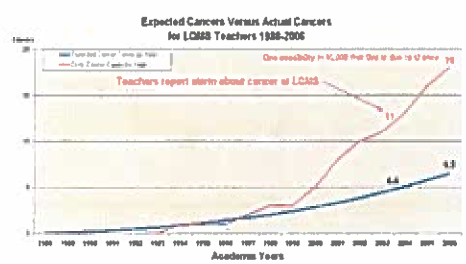
April 2007 — Dr. Sam Milham & Lloyd Morgan [illegible] — 10

Excess Teachers' Cancer at LQMS

- There are nearly 3 times more cancer than expected at LQMS
  - Adjusting for age, aging, sex and race
    - 18 primary cancers
    - 6.5 expected
    - One possibility in 10,000 that this is due to chance

April 2007 — Dr. Sam Milham & Lloyd Morgan [illegible] — 11

All Cancers at LQMS



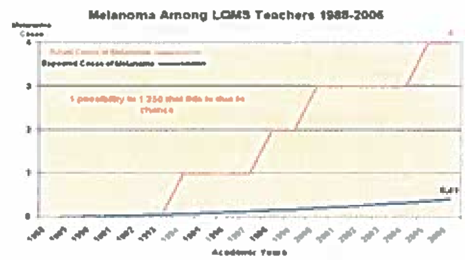
April 2007 — Dr. Sam Milham & Lloyd Morgan [illegible] — 12

Melanoma at LQMS

- Melanoma: 4 cases at LQMS
  - Nearly 10-fold excess above expected
    - Is this because LQMS is in a desert?
      - Melanoma incidence rates
        - Nevada: 17.7 per 100K people per year
        - Clark County (Las Vegas): 17.7 per 100K people per year
        - California: 16.3 per 100K people per year
        - LQMS: *159.7 per 100K people per year*
    - LQMS melanoma cannot be explained because it is in a desert

April 2007 — Dr. Sam Milham & Lloyd Morgan — 13

Melanoma at LQMS



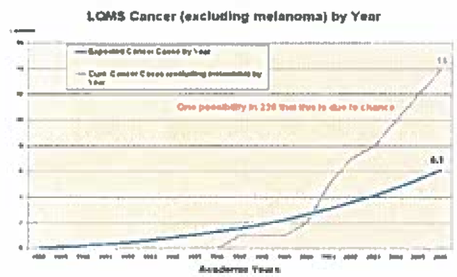
April 2007 — Dr. Sam Milham & Lloyd Morgan — 14

Cancer at LQMS (Excluding Melanoma)

- There are greater than 2 times more cancer (excluding melanomas) than expected at LQMS
  - Adjusting for age, aging, sex and race
    - 14 primary cancers
    - 6.1 expected
    - One possibility in 238 that this is due to chance

April 2007 — Dr. Sam Milham & Lloyd Morgan — 15

LQMS Cancer (excluding melanoma)



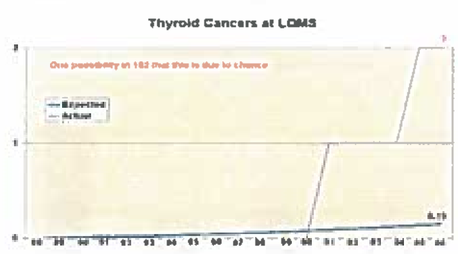
April 2007 — Dr. Sam Milham & Lloyd Morgan — 16

Other Cancers at LQMS

- Thyroid cancer: 2 cases at LQMS
  - Over 13-fold excess above expected
    - One possibility in 102 that this is due to chance
- Uterine cancer: 2 cases at LQMS
  - Over 9-fold excess above expected
    - One possibility in 52 that this is due to chance
- Breast cancer: 2 cases at LQMS
  - 1.3-fold excess at above expected
- Other cases at LQMS (1 case each)
  - Colon, pancreas, ovary, larynx, lymphoma, polycythemia, multiple myeloma, leiomyosarcoma

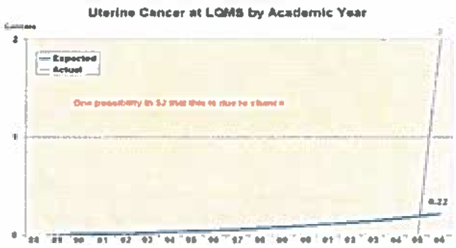
April 2007 — Dr. Sam Milham & Lloyd Morgan — 17

Thyroid Cancer at LQMS



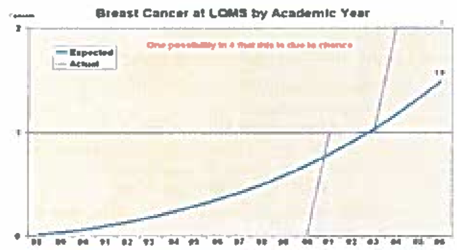
April 2007 — Dr. Sam Milham & Lloyd Morgan — 18

Uterine Cancer at LQMS



April 2007 — Dr. Sam Milham & Lloyd Morgan — 19

Breast Cancer at LQMS



April 2007 — Dr. Sam Milham & Lloyd Morgan — 20

How Much Time for a Cancer Diagnosis at LQMS?

- Average time from hire to diagnosis: all cancers, 9.7 years
- Average time for melanoma, 7.3 years
- Average time for thyroid cancer, 3.0 years
- Melanoma and thyroid cancer *appear* to be more sensitive to dirty power

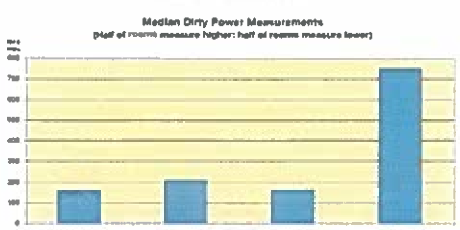
April 2007 — Dr. Sam Milham & Lloyd Morgan — 21

Why a Cancer Cluster at LQMS?

- LQMS has unusual levels of "dirty power" when compared to homes, offices and another school
  - Dirty power meter
    - Microsurge II meter (MS II)
      - Designed by Professor Emeritus, Electrical Engineering University of California Berkeley
      - Measurement is in "MS II units"
      - Meter "overloads" for reading ≥2000
        - 25.5% of all rooms at LQMS have reading above what the meter can measure (an "overload" condition)

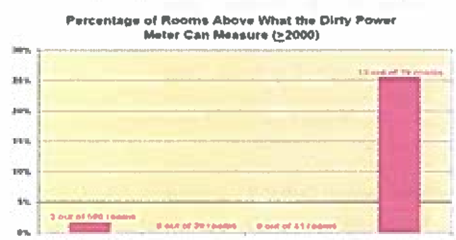
April 2007 — Dr. Sam Milham & Lloyd Morgan — 22

Dirty Power at LQMS and Other Places

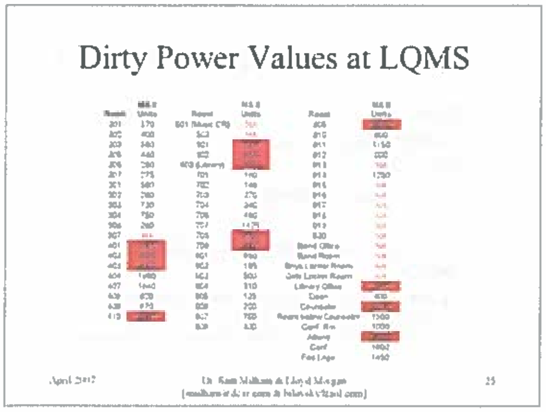


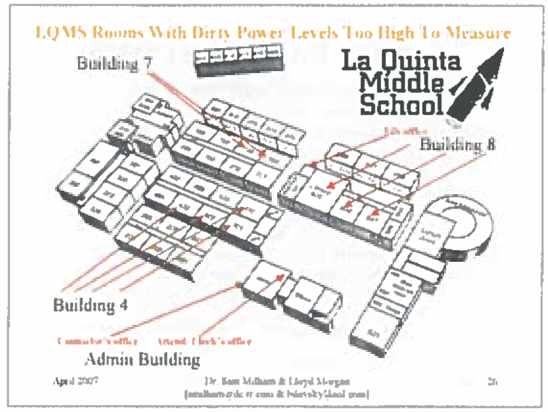
April 2007 — Dr. Sam Milham & Lloyd Morgan — 23

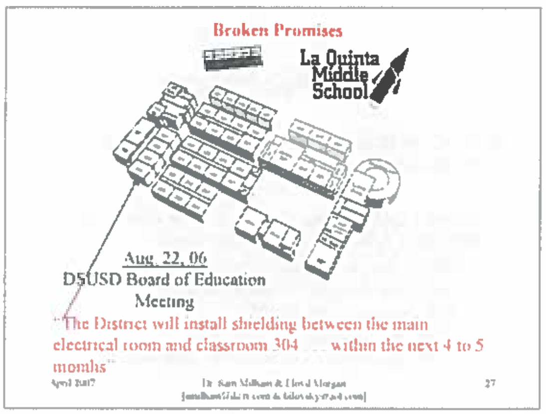
What Percentage of Rooms Have Readings Above What the Meter Can Measure?



April 2007 — Dr. Sam Milham & Lloyd Morgan — 24







Is Dirty Power a Risk for Cancer at LQMS?

- Risk of cancer from ever being in ≥2000 room
  - 5.1-fold
- Risk of cancer from ever being in >2000 room and employed at LQMS >10 years
  - 7.1-fold
- Risk of cancer from never being in ≥2000 room
  - 1.8-fold

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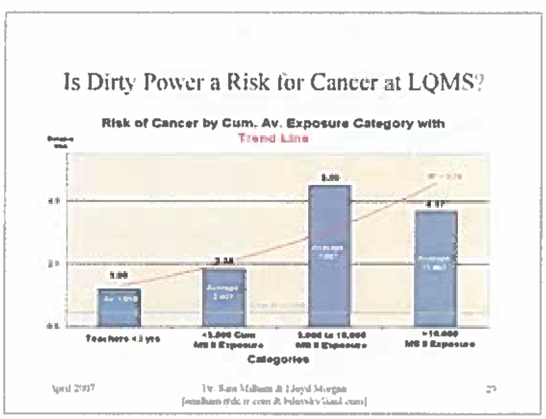

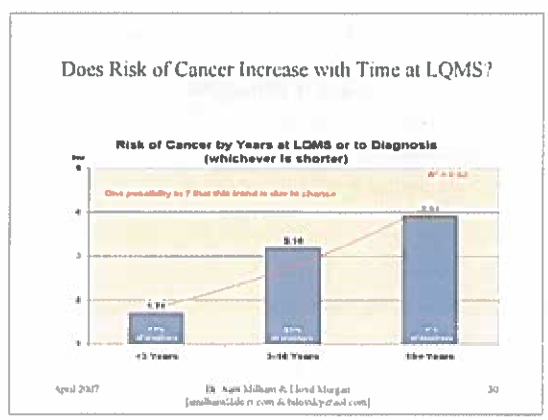

Part 2 of 8, Additional information found TheBrainCan.com , SolomonSeries.com, and https://www.youtube.com/solomonseries

There Is a Problem at LQMS

- US Government and World Health Organization
  - EMFs are a "possible human carcinogen"
- The electrical system is "unusual"
  - Employees and students have an expectation of a safe and healthy environment
- Suggested actions per Cal-DHS
  - Find and eliminate high dirty power levels
    - Fix the problem!
- Is there a cancer risk for LQMS students?
  - We do not know. Students attend LQMS for 3 years
    - For <3 years the teachers' risk of cancer is 1.7-fold above expected
    - This question could be answered
      - Investigate the cancer incidence among all LQMS students, past and present

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Others Maladies Associated with Dirty Power

- Asthma
- Elevated blood glucose
- Fibromyalgia
- Chronic fatigue syndrome
- We have no knowledge of these problems at LQMS, but
  - If and when the dirty power problem is mitigated at LQMS, or after leaving LQMS
    - Notify us if you see any changes in these or other health issues

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Teachers, Staff, Parents and Students Should Be Informed per Recommendation of Cal-DHS

- District to inform all present and former teachers, staff and students of cancer cluster findings and advise them to get melanoma screening
- District to notify local media of the truth of the cancer cluster and advise as to melanoma screening for all present and former teachers and students

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Acknowledgments

- To all the teachers who REFUSED to let this problem be ignored
- To the LQMS teachers and staff who sadly lost their lives before remedies were found
  - David Loveless, deceased June 17, 1998
  - Cal Sarver, deceased November 30, 2003
  - Van Vantress deceased 2003
  - Tomijean Doeberiner deceased, 2006
    - Attendance clerk, not included in risk calculations

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Last Thoughts

- Questions and Answers
- Next Steps (What is to be done)

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Attention Deficit Hyperactivity Disorder and Dirty Electricity

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Abbreviations: RF = radio frequency

ADHD = attention deficit hyperactivity disorder

Proprietary information: Stetzerizer Microsurge meter

Stetzerizer filters

Available from www.stetzerelectric.com

Keywords: attention deficit hyperactivity disorder, electrical pollution, dirty electricity, fluorescent lights, cell phone towers.

I have no financial interest or conflict of interest.

In February 2010, while studying a cancer cluster in teachers at a California elementary school, a fourth grade teacher complained that her students were hyper-active and un-teachable. The classroom levels of high frequency voltage transients (dirty electricity) in the radio frequencies (RF) between 4 and 100 kHz, measured in the outlets of her classroom with a Graham/Stetzer Microsurge meter were very high. Dirty electricity is a term coined by the electrical utilities to describe electrical pollution contaminating the 60 Hz electricity on the electrical grid. A cell phone tower on campus a few feet from this classroom and unshielded fluorescent lights both contributed to the electrical pollution in this room. Cell tower transmitters, like most modern electrical equipment, operate on direct current. The electrical current brought to the tower is alternating current which needs to be changed to direct current. This is done by a switching power supply. These devices interrupt the AC current and are the likely source of the dirty electricity

On a Friday afternoon after school, I filtered the five outlets in this room with Graham/Stetzer plug-in capacitive filters, reducing the measured dirty electricity in the room wiring from over 5,000 Graham/Stetzer units to less than 50 units. With no change in either the lighting or the cell tower radiation, the teacher reported an immediate dramatic improvement in the behavior of her students in the following week. They were calmer, paid more attention, and were teachable all week except for Wednesday when they spent part of the day in the library.

In his 1973 book, Health and Light [1], John N. Ott described a 1973 study of four first grade classrooms in a windowless Sarasota, Florida school. Two of the rooms had standard white fluorescent lighting, and the other two had full spectrum fluorescent lighting with a grounded aluminum wire screen to remove the RF produced by fluorescent bulbs and ballasts. Concealed time-lapse cameras recorded student behavior in classrooms for four months. In the unshielded rooms the first graders developed, "...nervous fatigue, irritability, lapses of attention, and hyperactive behavior." "...students could be observed fidgeting to an extreme degree, leaping from their seats, flailing their arms, and paying little attention to their teachers." In the RF-shielded rooms, "Behavior was entirely different. Youngsters were calmer and far more interested in their work."

The Old Order Amish live without electricity. A pediatric group practice in Jasper, Indiana which cares for more than 800 Amish families has not diagnosed a single child with ADHD[2]. Dozens of cases of childhood ADHD have been "cured" with no further need for drugs by simply changing their electrical environments [3].

Before children are treated with drugs for ADHD, the dirty electricity levels in their homes and school environments should first be examined and reduced if needed.

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Historical evidence that electrification caused the 20th century epidemic of "diseases of civilization" ☆

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SUMMARY

The slow spread of residential electrification in the US in the first half of the 20th century from urban to rural areas resulted by 1940 in two large populations; urban populations, with nearly complete electrification and rural populations exposed to varying levels of electrification depending on the progress of electrification in their state. It took until 1956 for US farms to reach urban and rural non-farm electrification levels. Both populations were covered by the US vital registration system. US vital statistics tabulations and census records for 1920–1960, and historical US vital statistics documents were examined. Residential electrification data was available in the US census of population for 1930, 1940 and 1950. Crude urban and rural death rates were calculated, and death rates by state were correlated with electrification rates by state for urban and rural areas for 1940 white resident deaths. Urban death rates were much higher than rural rates for cardiovascular diseases, malignant diseases, diabetes and suicide in 1940. Rural death rates were significantly correlated with level of residential electric service by state for most causes examined. I hypothesize that the 20th century epidemic of the so called diseases of civilization including cardiovascular disease, cancer and diabetes and suicide was caused by electrification not by lifestyle. A large proportion of these diseases may therefore be preventable.

Background

In 2001, Ossiander and I [1] presented evidence that the childhood leukemia mortality peak at ages 2–4 which emerged in the US in the 1930s was correlated with the spread of residential electrification in the first half of the 20th century in the US. While doing the childhood leukemia study, I noticed a strong positive correlation between level of residential electrification and the death rate by state due to some adult cancers in 1930 and 1940 vital statistics. At the time, a plausible electrical exposure agent and a method for its delivery within residences was lacking. However, in 2008 I coauthored a study of a cancer cluster in school teachers at a California middle school [2] which indicated that high frequency voltage transients (also known as dirty electricity), were a potent universal carcinogen with cancer risks over 10.0 and significant dose–response for a number of cancers. They have frequencies between 2 and 100 kHz. These findings are supported by a large cancer incidence study in 200,000 California school employees which showed that the same cancers and others were in excess in California teachers statewide [3]. Power frequency magnetic fields (60 Hz) measured at the school were low and not related to cancer incidence, while classroom levels of high frequency voltage transients measured at the electrical outlets in the classrooms accurately predicted a teacher's cancer risk. These fields are potentially present in all wires carrying electricity and are an important component of ground currents returning to substations especially in rural areas. This helped explain the fact that professional and office workers, like the school teachers, have high cancer incidence rates. It also explained why indoor workers had higher malignant melanoma rates, why melanoma occurred on part of the body which never are exposed to sunlight, and why melanoma rates are increasing while the amount of sunshine reaching earth is stable or decreasing due to air pollution. A number of very different types of cancer had elevated risk in the La Quinta school study, in the California school employees study, and in other teacher studies. The only other carcinogenic agent which acts like this is ionizing radiation.

Among the many devices which generate the dirty electricity are compact fluorescent light bulbs, halogen lamps, wireless routers, dimmer switches, and other devices using switching power supplies. Any device which interrupts current flow generates dirty electricity. Arcing, sparking and bad electrical connections can also generate the high frequency voltage transients. Except for the dimmer switches, most of these devices did not exist in the first half of the 20th century. However, early electric generating equipment

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and electric motors used commutators, carbon brushes, and split rings, which would inject high frequency voltage transients into the 60 Hz electricity being generated and distributed.

With a newly recognized electrical exposure agent and a means for its delivery, I decided to examine whether residential electrification in the US in the first half of the last century was related to any other causes of death. Most cancers showed increasing mortality in this period, and many are still increasing in incidence in the developed world.

Thomas Edison began electrifying New York City in 1880, but by 1920, only 34.7% of all US dwelling units and 1.6% of farms had electric service (Table 1). By 1940, 78% of all dwelling units and 32% of farms had electric service [4]. This means that in 1940 about three quarters of the US population lived in electrified residences and one quarter did not. By 1940, the US vital registration system was essentially complete, in that all the 48 contiguous United States were included. Most large US cities were electrified by the turn of the century, and by 1940, over 90% of all the residences in the northeastern states and California were electrified. In 1940 almost all urban residents in the US were exposed to electromagnetic fields (EMFs) in their residences and at work, while rural residents were exposed to varying levels of EMFs, depending on the progress of rural electrification in their states. In 1940, only 28% of residences in Mississippi were electrified, and five other southern states had less than 50% of residences electrified (Table 2). Eleven states, mostly in the northeast had residential electrification rates above 90%. In the highly electrified northeastern states and in California, urban and rural residents could have similar levels of EMF exposure, while in states with low levels of residential electrification, there were potentially great differences in EMF exposure between urban and rural residents. It took the first half of the 20th century for these differences to disappear. I examined US mortality records by urban and rural residence by percent of residences with electric service by state.

Hypothesis

The diseases of civilization or lifestyle diseases include cardiovascular disease, cancer and diabetes and are thought to be caused by changes in diet, exercise habits, and lifestyle which occur as countries industrialize. I think the critical variable which causes the radical changes in mortality accompanying industrialization is electrification. Beginning in 1979, with the work of Wertheimer and Leeper [5], there has been increasing evidence that some facet of electromagnetic field exposure is associated epidemiologically with an increased incidence of leukemia, certain other cancers and non-cancers like Alzheimer's disease, amyotrophic lateral sclerosis, and suicide. With the exception of a small part of the electromagnetic spectrum from infra red through visible light, ultraviolet light and cosmic rays, the rest of the spectrum is man-made and foreign to human evolutionary experience. I suggest that from the time that Thomas Edison started his direct current electrical distribution system in the 1880s in New York City until now, when most of the world is electrified, the electricity carried high frequency voltage transients which caused and continue to cause what are considered to be the normal diseases of civilization. Even today, many of these diseases are absent or have very low incidence in places without electricity.

Table 1
Growth of residential electric service US 1920–1956 percent of dwelling units with electric service.

Year	All		Urban and rural non-farm
	Dwellings	Farm	
1920	34.7	1.6	47.4
1925	53.2	3.9	69.4
1930	68.2	10.4	84.8
1935	68.0	12.6	83.9
1940	78.7	32.6	90.8
1945	85.0	48.0	93.0
1950	94.0	77.7	96.6
1956	98.8	95.9	99.2

Table 2
Percent of residences with electric lighting 1930 and 1940 by state.

Code	State	1930	1940
AL	Alabama	33.9	43.3
AZ	Arizona	68.8	70.5
AR	Arkansas	25.3	32.8
CA	California	93.9	96
CO	Colorado	69.6	77.6
CT	Connecticut	95.3	96.5
DE	Delaware	78.4	81.8
FL	Florida	60.9	66.5
GA	Georgia	35.5	46.6
ID	Idaho	64.5	79.1
IL	Illinois	86.1	89.9
IN	Indiana	74.8	84
IA	Iowa	65.6	76.7
KS	Kansas	62	71.5
KY	Kentucky	44.2	54.2
LA	Louisiana	42.2	48.9
ME	Maine	76.1	80.4
MD	Maryland	81.8	85.9
MA	Massachusetts	97.1	97.6
MI	Michigan	84.8	92.1
MN	Minnesota	65.9	75.8
MS	Mississippi	19.4	28.3
MO	Missouri	65.5	70.6
MT	Montana	58.2	70.7
NE	Nebraska	61	70.5
NV	Nevada	76.2	80.8
NH	New Hampshire	84.9	87
NJ	New Jersey	95.8	96.6
NM	New Mexico	39.8	49.2
NY	New York	94.5	96.4
NC	North Carolina	40.8	54.4
ND	North Dakota	41.6	53.8
OH	Ohio	85.2	90.6
OK	Oklahoma	45.3	55.1
OR	Oregon	79.5	85.8
PA	Pennsylvania	89.5	92.3
RI	Rhode Island	97.3	97.7
SC	South Carolina	34.3	46.2
SD	South Dakota	44.4	56.6
TN	Tennessee	42	50.9
TX	Texas	*	59
UT	Utah	88.4	93.9
T	Vermont	71.9	80.2
VA	Virginia	50.5	60.6
WA	Washington	86.3	90.9
WV	West Virginia	63.4	69.1
WI	Wisconsin	74.5	83.9
WY	Wyoming	60	70.9

*No data.

Evaluation of the hypothesis

To evaluate the hypothesis, I examined mortality in US populations with and without residential electrification. Vital statistics tabulations of deaths [6], US census records for 1920–1970 [7], and historical US documents [8,9] were examined in hard copy or downloaded from the internet. The same state residential electrification data used in the childhood leukemia study [1] was used in this study. Crude death rates were calculated by dividing number of deaths by population at risk, and death rates by state were then correlated with electrification rates by state using downloaded software [10]. Time trends of death rates for selected causes

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of death by state were examined. Most rates were calculated by state for urban and rural residence for whites only in 1940 deaths, since complete racial data was available by urban/rural residence by state for only 13 of 48 states. Data was available for 48 states in the 1940 mortality tabulations. District of Columbia was excluded because it was primarily an urban population. Excel graphing software [11] and "Create a Graph" [12] software was used.

I had hoped to further test this hypothesis by studying mortality in individual US farms with and without electrification, when the 1930 US census 70 year quarantine expired in 2000. Unfortunately, the 1930 US farm census schedules had been destroyed.

Findings

Rural residential electrification did not reach urban levels until 1956 (Table 1). Table 2 shows the level of residential electrification for each state for 1930 and 1940. In 1930 and 1940 only 9.5% and 13%, respectively, of all generated electricity was used in residences. Most electricity was used in commercial and industrial applications.

Figs. 1–4 were copied and scanned from "Vital statistics rates in the United States 1940–1960", by Robert Grove Ph.D. and Alice M. Henzel. This volume was published in 1968. Fig. 1 shows a gradual decline in the all causes death rate from 1900 to 1960 except for a spike caused by the 1918 influenza pandemic. Death rates due to tuberculosis, typhoid fever, diphtheria, dysentery, influenza and pneumonia and measles all fell sharply in this period, and account for most of the decline in the all causes death rate. Figs. 2–4 show that in the same time period when the all causes death rate was declining, all malignant neoplasms (Fig. 2), cardiovascular diseases (Fig. 3), and diabetes (Fig. 4) all had gradually increasing death rates. In 1900, heart disease and cancer were 4th and 8th in a list of 10 leading causes of death. By 1940 heart disease had risen to first and cancer to second place, and have maintained that position ever since. Table 3 shows that for all major causes of death examined, except motor vehicle accidents, there was a sizable urban excess in 1940 deaths. The authors of the extensive 69 page introduction to the 1930 mortality statistics volume noted that the cancer rates for cities were 58.2% higher than those for rural areas. They speculated that some of this excess might have been due to rural residents dying in urban hospitals. In 1940, deaths by place of residence and occurrence are presented in separate volumes. In 1940 only 2.1% of all deaths occurred to residents of one state dying in another state. Most non-resident deaths were residents of other areas of the same state. Table 4 presents correlation coefficients for the relationship between death rates by urban rural areas of each state and the percent of residences in each state with

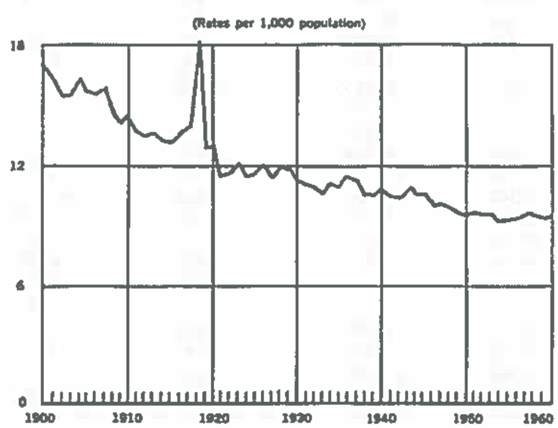

Fig. 1. Death rates: death registration states, 1900–32, and United States, 1933–60.

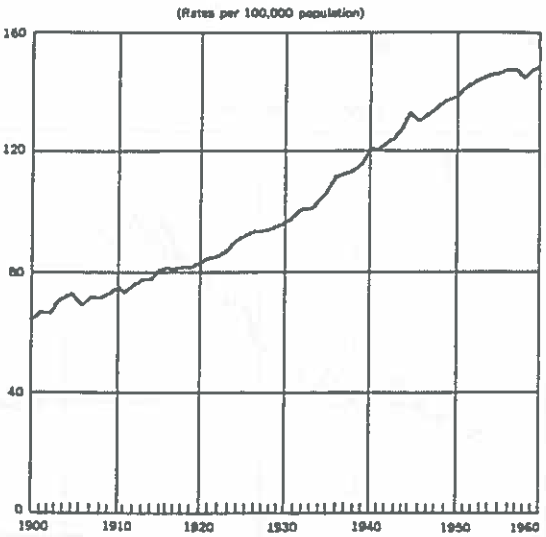

Fig. 2. Death rates for malignant neoplasms: death registration states, 1900–32, and United States, 1933–60.

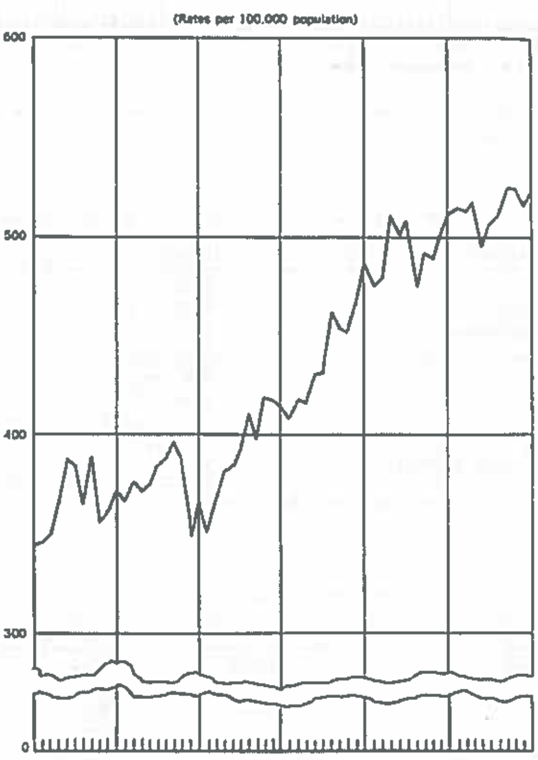

Fig. 3. Death rates for major cardiovascular renal diseases: death registration states, 1900–32, and United States, 1933–60.

electric service. In 1940 urban and rural residence information was not available for individual cancers as it was in 1930, but death rates for each cancer were available by state. They were used to calculate correlations between electric service by state and respiratory cancer, breast cancer and leukemia mortality.

All causes of death

There was no correlation between residential electrification and total death rate for urban areas, but there was a significant

Part 2 of 8, Additional information found TheBrainCan.com , SolomonSeries.com, and https://www.youtube.com/solomonseries

correlation for rural areas ($r = 0.659$, $p = <0.0001$). Fig. 5 shows the 1940 resident white death rates for urban and rural areas of states

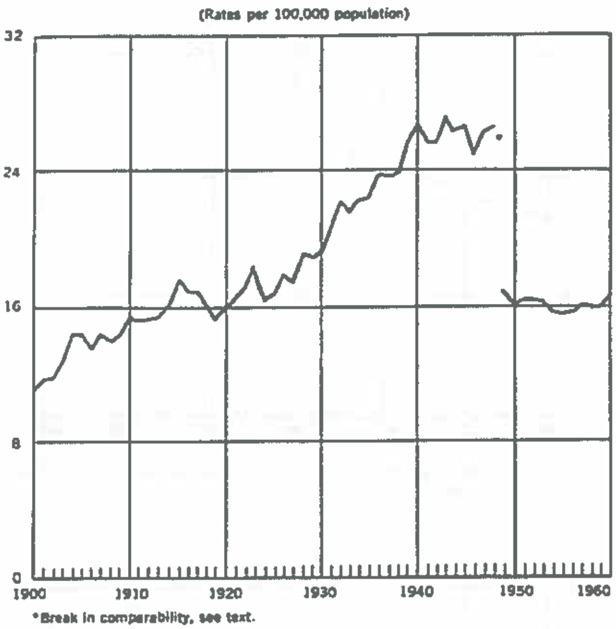

Fig. 4. Death rates for diabetes mellitus: death registration states, 1900–32, and United States, 1933–60.

having greater than 96% of residences electrified and states having less than 50% of residences electrified. In the highly electrified states, urban and rural death rates were similar, but in low electrification states, the urban death rates were systematically higher than the rural death rates. The urban death rates were similar in both high and low electrification states.

All malignant neoplasms

In 1940, the urban total cancer rate was 49.2% higher than the rural rate. Both urban and rural cancer deaths rates were significantly correlated with residential electrification. Fig. 6 shows the 1940 resident white total cancer rates for urban and rural areas of states having greater than 96% of residences electrified and states having less than 50% of residences electrified. Four of the five high electrification states had similar urban and rural total cancer rates, while all the low electrification states had urban rates about twice as high as rural rates. Both urban and rural total cancer rates were lower in low electrification states than in high electrification states. Fig. 7 shows the time trend of the total cancer rate between 1920 and 1960 for Massachusetts (1940 electrification rate = 97.6%) and Louisiana (1940 electrification rate = 48.9%). The Massachusetts cancer rate was about twice that of Louisiana between 1920 and 1945. The Massachusetts rate leveled off in 1945, but the Louisiana rate increased steadily between 1920 and 1960. A declining urban–rural gradient for cancer is still evident in 1980–1990 US cancer incidence data [13]. Swedish investigators [14] have reported increasing cancer mortality and incidence time trend breaks in the latter half of the 20th century.

Table 3
1940 US white resident crude death rates per 100,000 by urban/rural residence.

Cause of death	ICD No.[a]	Urban rate	Rural rate	(%) Urban excess
All	1-200	1124.1	929.5	20.9
All cancers	47-55	145.8	97.7	49.2
Coronary disease	94	92.4	69.1	33.7
Other diseases of heart	90b,91,92a,d,e 93a,b,d,e 95a,c	217.0	162.8	33.3
Diabetes	61	33.2	20.0	66.0
Suicide	163-164	17.1	13.2	29.5
Motor vehicle accidents	170	26.6	26.3	1.1

[a] 1938 Revision International classification of disease.

Table 4
Correlation coefficients (r) 1940 crude US death rates by state by electrification for white resident deaths.

Cause	ICD No.[A]	Residence	r	r^2	p One tailed	Slope	Y intercept
All causes	1-200	Urban	0.083	0.007	0.285	0.007	11.114
		Rural	0.659	0.434	<0.0001	0.070	4.185
All cancers	45-55	Urban	0.667	0.445	<0.0001	0.883	75.970
		Rural	0.758	0.575	<0.0001	1.502	−10.040
Respiratory cancer[B]	47	State	0.611	0.374	<0.0001	0.071	1.020
Breast cancer female	50	State	0.794	0.630	<0.0001	0.170	−1.506
Diabetes	61	Urban	0.666	0.444	<0.0001	0.278	8.168
		Rural	0.693	0.480	<0.0001	0.366	−6.184
Leukemia[B]	72a	State	0.375	0.140	0.0042	0.021	1.980
Coronary artery	94	Urban	0.400	0.160	0.0024	0.494	61.570
Disease		Rural	0.781	0.610	<0.0001	1.252	25.319
Other diseases of the heart	90b, 91	Urban	0.449	0.202	0.0006	1.236	100.35
	92a,d,e	Rural	0.799	0.639	0.0001	2.887	−48.989
	93a,b,d,e						
	95a,c						
Suicide	163-4	Urban	0.077	0.006	0.2993	0.028	16.235
		Rural	0.729	0.532	<0.0001	0.181	0.299
Motor vehicle	170	Urban	−0.254	0.064	0.0408	−0.171	44.572
Accidents		Rural	0.451	0.203	0.0006	0.195	12.230

[A] International classification of diseases 1938 revision.
[B] Age adjusted death rate both sexes.

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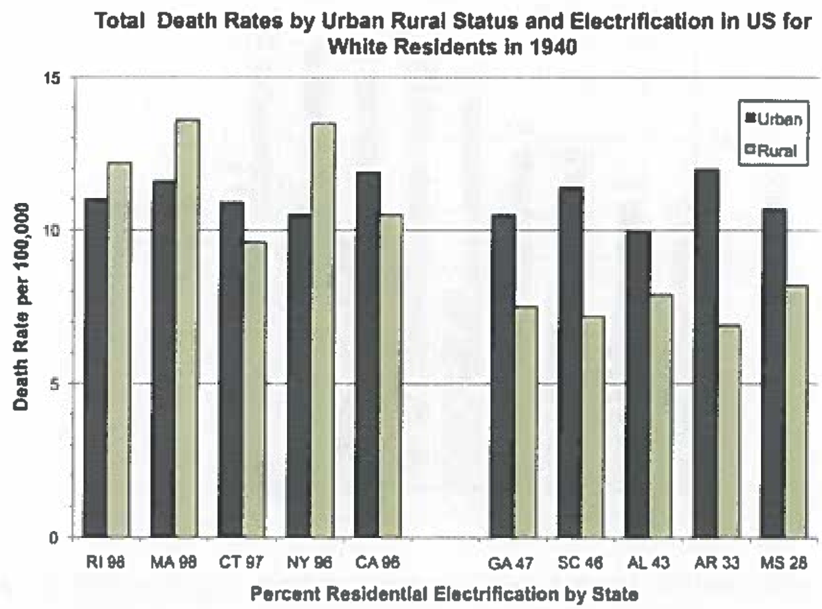

Fig. 5. All causes death rates by urban rural status and electrification in the US for white residents in 1940.

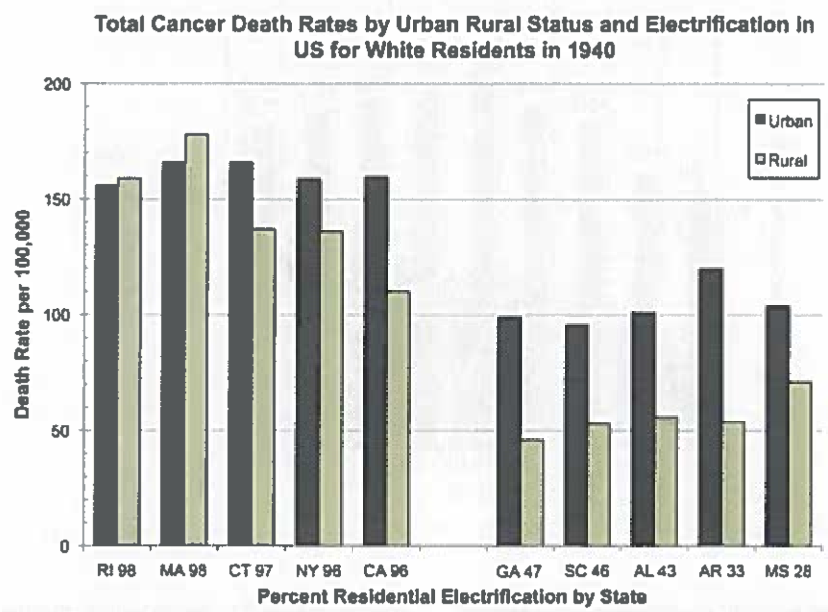

Fig. 6. Total cancer death rates by urban rural status and electrification in the US for white residents in 1940.

Respiratory cancer

No urban rural information was available for respiratory cancer, but the correlation between residential electrification and state death rates was $r = 0.611$; $p = <0.0001$. This cancer is etiologically strongly related to cigarette smoking, so the correlation with electrification is surprising. A large electrical utility worker cohort study found a high respiratory cancer incidence related to high frequency EMF transient exposure independent of cigarette smoking with a significant dose–response relationship [15].

Breast cancer

Although urban/rural information was not available for breast cancer, the 1940 state breast cancer death rates have a correlation of $r = 0.794$; $p = <0.0001$ with residential electrification. Fig. 8 shows the typical time trend of breast cancer death rates for a state with a high level of electrification (96%) and one with a low level of electrification (<50) in 1940. The California breast cancer death rate increased from 1920 to 1940, and then gradually decreased until 1960. The Tennessee breast cancer death rate is less than half of the California rate in 1920 and continues a steady increase until 1960.

Diabetes

This cause has a 66% urban excess. In spite of this, the correlation coefficients for urban and rural areas are similar at $r = 0.66$; $p = <0.0001$. There is some animal and human evidence that EMFs can effect insulin production and blood glucose levels [16]. Fig. 9

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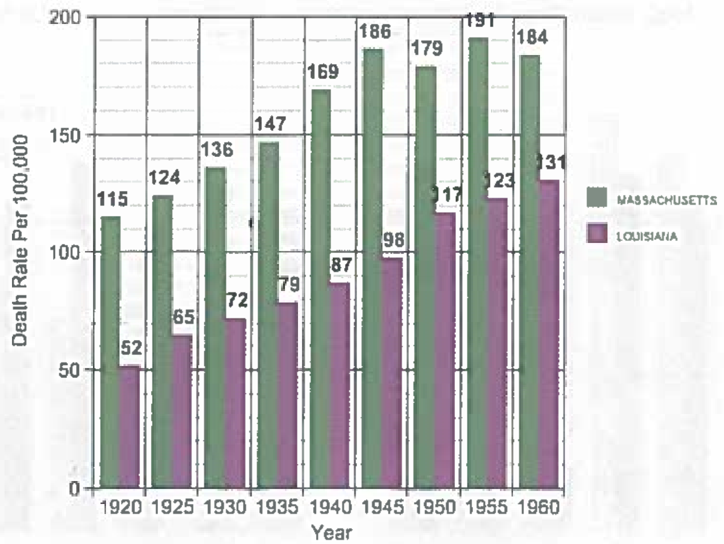

Fig. 7. US white resident total cancer death rates for Massachusetts (97.6% elect.) and Louisiana (48.9% elect.) by year.

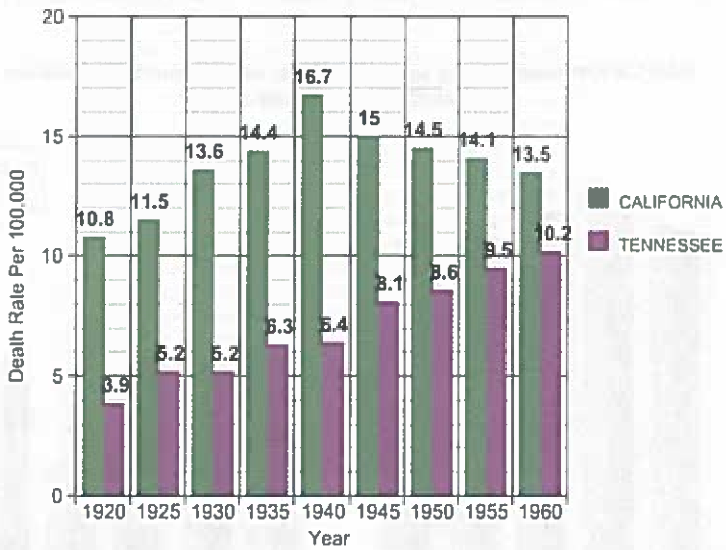

Fig. 8. US white resident breast cancer death rates for California (96% elect.) and Tennessee (50% elect.) by year.

shows that in states with low levels of electrification in 1940, the urban diabetes death rates are consistently higher than the rural rates, but are always lower than the urban and rural rates in the high electrification states.

Leukemia

Since the childhood leukemia age peak is strongly associated with residential electrification, it was interesting that the all leukemia death rate correlation was $r = 0.375$; $p = 0.0042$. Most of these deaths are in adults and are of different types of leukemia. A study of amateur radio operators showed a selective excess only of acute myelogenous leukemia [17].

Coronary artery disease and other heart disease

These two cause groups had the same percentage urban excess (33%), and very similar patterns of urban and rural correlation coefficients with residential electrification. The urban correlations were about $r = 0.4$ and rural deaths had correlations of 0.78 and 0.79, respectively. Fig. 10 shows the 1940 resident white coronary artery disease death rates for urban and rural areas of states having greater than 96% of residences electrified and states having less than 50% of residences electrified. Four of the five high electrification states had similar urban and rural total cancer rates, while all the low electrification states had urban rates about twice as high as rural rates. Urban and rural coronary artery death rates were lower in low electrification states than in high electrification states.

Suicide

The urban suicide death rate is about 30% higher than the rural rate. The urban suicide rate is not correlated with residential electrification ($r = 0.077$; $p = 0.299$), but the rural death rate is correlated with 1940 state residential electrification levels ($r = 0.729$; $p = <0.0001$). Fig. 11 shows the 1940 resident white suicide for

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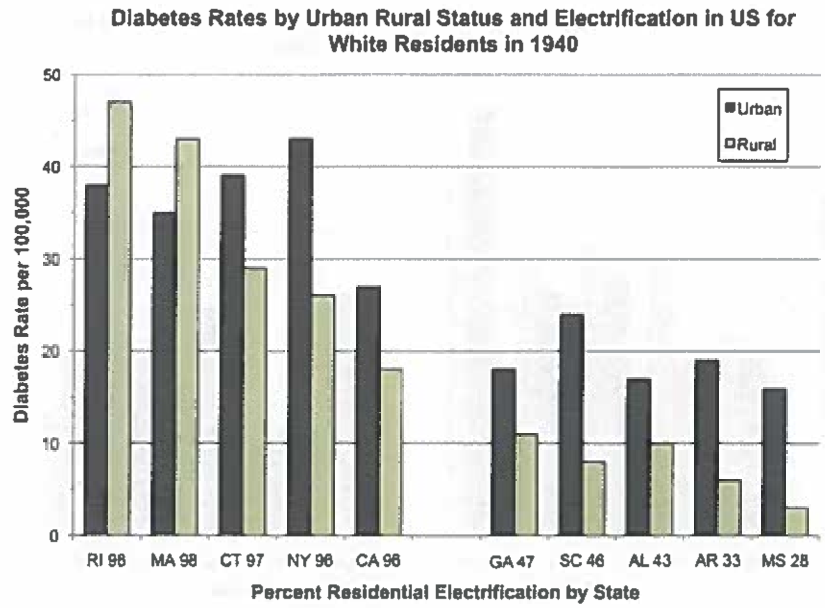

Fig. 9. Total diabetes rates by urban rural status and electrification in the US for white residents in 1940.

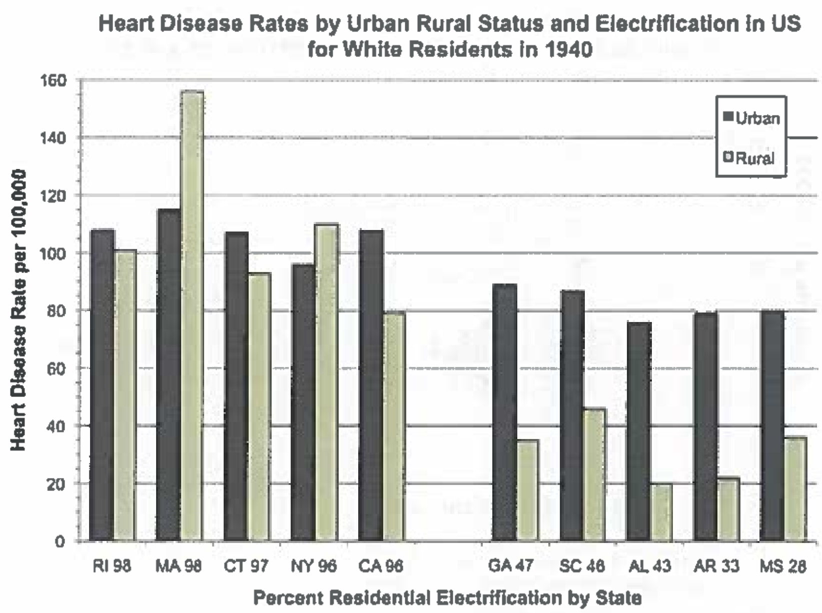

Fig. 10. Total heart disease rates by urban rural status and electrification in the US for white residents in 1940.

urban and rural areas of states having greater than 96% of residences electrified and states having less than 50% of residences electrified. In four of five high electrification states, rural suicide rates are higher than the urban rates. In all of the low electrification states, the urban rate is higher. The rural rates in the high electrification states are higher than the rural rates in the low electrification states. Fig. 12 shows X Y scatter plots for urban and rural suicide by electrification for 48 states. Suicide has been associated with both residential [18] and occupational [19] EMF exposure. Suicide is probably the visible peak of the clinical depression iceberg.

Motor vehicle accidents

Although the mortality rates are similar in urban and rural areas, the correlations with residential electrification levels are different. There is a slight negative correlation ($r = -0.254$) in urban areas and a positive correlation ($r = 0.451$) in rural areas. Since motor vehicle fatality is related to access to a vehicle and to speed. It may be that in the larger cities it was difficult to go fast enough for a fatal accident, and in rural areas especially on farms, a farmer who could afford electrification could also afford a car.

Discussion

When Edison and Tesla opened the Pandora's box of electrification in the 1880s, the US vital registration system was primitive at best, and infectious disease death rates were falling rapidly. City residents had higher mortality rates and shorter life expectancy than rural residents [8]. Rural white males in 1900 had an expectation of life at birth of over 10 years longer than urban residents.

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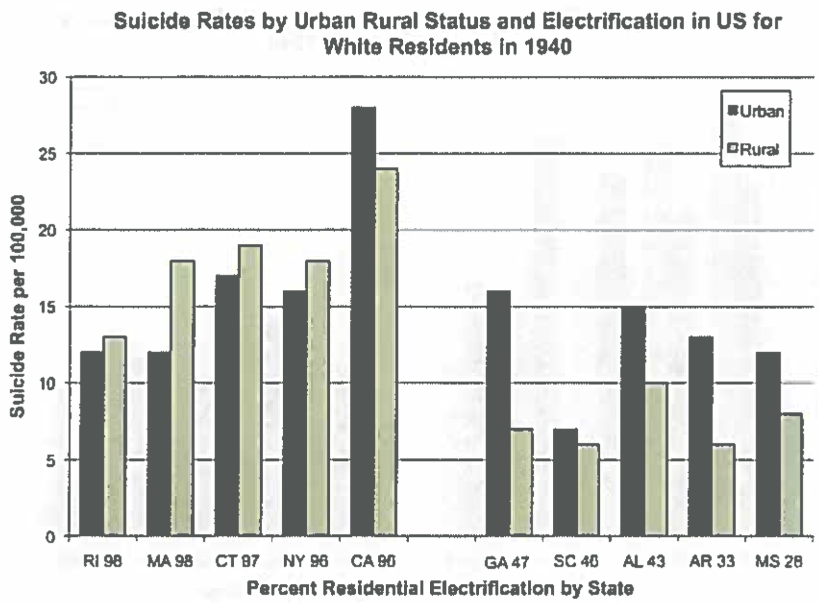

Fig. 11. Total suicide death rates by urban rural status and electrification in the US for white residents in 1940.

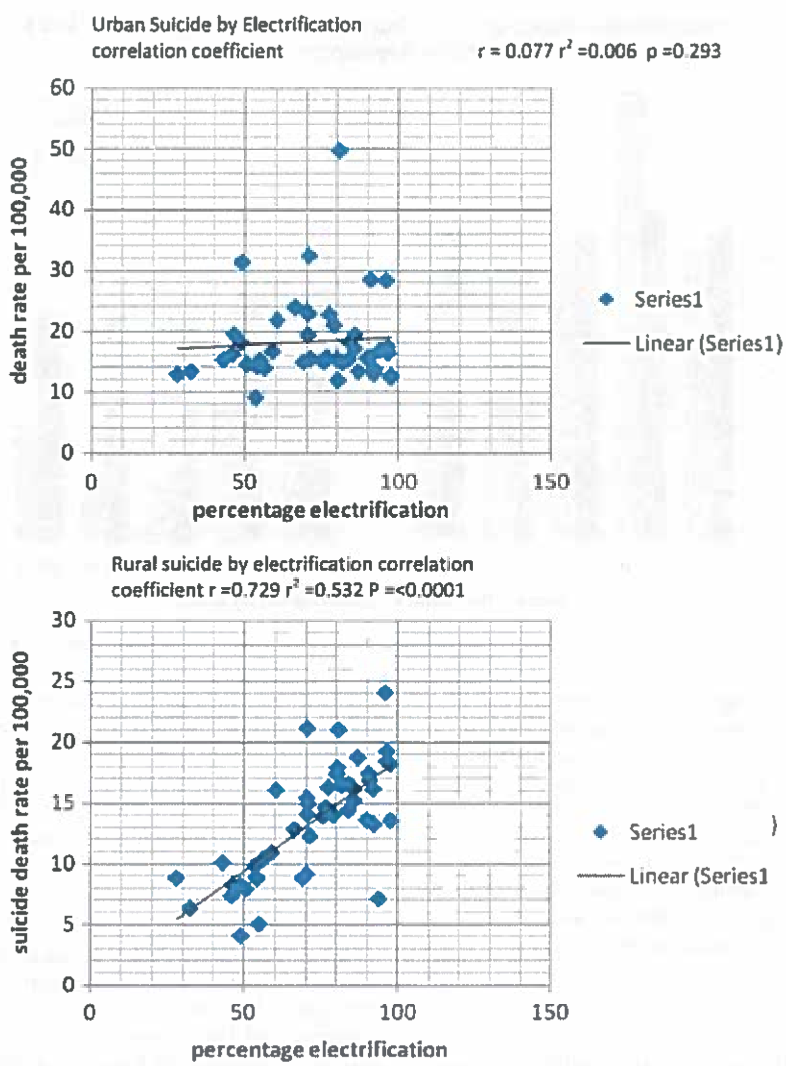

Fig. 12. 1940 US white resident urban rural suicide death rates by state and electrification.

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Although the authors of the 1930 US vital statistics report noted a 58.2% cancer mortality excess in urban areas, it raised no red flags. The census bureau residential electrification data was obviously not linked to the mortality data. Epidemiologists in that era were still concerned with the communicable diseases.

Court Brown and Doll reported [20] the appearance of the childhood leukemia age peak in 1961, forty years after the US vital statistics mortality data on which it was based was available. I reported a cluster of childhood leukemia [21] a decade after it occurred, only because I looked for it. Real time or periodic analysis of national or regional vital statistics data is still only rarely done in the US.

The real surprise in this data set is that cardiovascular disease, diabetes and suicide, as well as cancer seem to be strongly related to level of residential electrification. A community-based epidemiologic study of urban rural differences in coronary heart disease and its risk factors was carried out in the mid 1980s in New Delhi, India and in a rural area 50 km away [22]. The prevalence of coronary heart disease was three times higher in the urban residents, despite the fact that the rural residents smoked more and had higher total caloric and saturated fat intakes. Most cardiovascular disease risk factors were two to three times more common in the urban residents. Rural electrification projects are still being carried out in parts of the rural area which was studied.

It seems unbelievable that mortality differences of this magnitude could go unexplained for over 70 years after they were first reported and 40 years after they were noticed. I think that in the early part of the 20th century nobody was looking for answers. By the time EMF epidemiology got started in 1979 the entire population was exposed to EMFs. Cohort studies were therefore using EMF-exposed population statistics to compute expected values, and case-control studies were comparing more exposed cases to less exposed controls. The mortality from lung cancer in two pack a day smokers is over 20 times that of non-smokers but only three times that of one pack a day smokers. After 1956, the EMF equivalent of a non-smoker ceased to exist in the US. An exception to this is the Amish who live without electricity. Like rural US residents in the 1940s, Amish males in the 1970s had very low cancer and cardiovascular disease mortality rates [23].

If this hypothesis and findings outlined here are even partially true, the explosive recent increase in radiofrequency radiation, and high frequency voltage transients sources, especially in urban areas from cell phones and towers, terrestrial antennas, wi-fi and wi-max systems, broadband internet over power lines, and personal electronic equipment, suggests that like the 20th century EMF epidemic, we may already have a 21st century epidemic of morbidity and mortality underway caused by electromagnetic fields. The good news is that many of these diseases may be preventable by environmental manipulation, if society chooses to.

Conflicts of interest statement

None declared.

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Correspondence

Amyotrophic lateral sclerosis (Lou Gehrig's disease) is caused by electric currents applied to or induced in the body: It is an iatrogenic disease of athletes caused by use of electrotherapy devices

Amyotrophic lateral sclerosis (ALS), also known as Lou Gehrig's disease after the famous New York Yankee baseball player, is a rare condition, characterized by deterioration of both upper and lower motor neurons. It has in incidence of about 2.4 per 100,000 population per year with peak onset between 55 and 75 years of age and an average survivorship of 3 years after onset [1]. Over 90% of ALS cases are sporadic, with familial cases making up the balance. An ALS variant which is clinically different from sporadic ALS is present in the Western Pacific and is associated with symptoms and pathological characteristics of both Parkinson's disease and Alzheimer's disease.

Since the reports of an increased incidence of ALS in Italian soccer players [2], and US professional football players [3], I had been suspicious about their exposure to TENS devices and electrical diathermy devices, because of the repeated reports [4–8] of the connection of ALS with electrical shocks and electrical environments. Three of 55 members of the 1964 San Francisco Forty-niners US professional football club died of ALS [9]. The expected cases of ALS in 55 people followed for 30 years is $55 \times 30 \times 2.4/100{,}000 = 0.04$, so the relative risk of ALS in this cluster was 3.0/0.04 or 75 times expected.

In August 2007 the Seattle, Washington USA media carried information about Melissa Jo Ericson, a young woman who at age 28, had been recently diagnosed with amyotrophic lateral sclerosis. She had been a basketball player at the University of Washington, followed by a professional basketball career in Europe. She was much younger than expected for this diagnosis. In Washington State 0.5% of ALS deaths occur in individuals under age 30. I contacted her and inquired about her use of trans-cutaneous electric stimulation devices (TENS) for pain management. She reported that she and her high school, college, and professional teammates had made extensive use of TENS with devices provided by the schools and the professional teams [10].

Trans-cutaneous electrical nerve stimulation, commonly referred to as TENS, is application of electrical current through the skin for pain control. The unit is usually connected to the skin using two or more electrodes. Most battery-operated TENS units are able to modulate frequency, intensity and pulse width of the applied current. Electrical diathermy devices use short wave radio frequency radiation and microwaves for deep tissue heating. All these devices generate electric currents in tissue. Short wave diathermy units have been used in the US since around 1930 and TENS units since 1974 [11].

There is some circumstantial evidence that Lou Gehrig, the famous New York Yankee baseball player who died of ALS and whose name is synonymous with the disease might have been treated with diathermy. In 1933, Boston Red Sox player Dale Alexander had his baseball career cut short by a serious leg burn and gangrene following a diathermy treatment by Red Sox trainer Doc Woods, so diathermy was in use by major league baseball teams in the early 1930s [12]. A long-term New York Yankee trainer, Earle V. "Doc" Painter, burned Joe Di Maggio's foot during a diathermy treatment during spring training 1936, DiMaggio's first year with the Yankees [13]. Babe Ruth, Lou Gehrig and Joe DiMaggio were all reported to be patients of "Doc" Painter [14]. Lou Gehrig suffered an attack of "lumbago" on July 13, 1934 which required him to be helped from the field by his teammates. It is quite possible that he received diathermy treatments for the "cold in his back" or other musculoskeletal problems. His baseball performance declined in mid-1938, he had ALS symptoms in 1939 and died in 1941 [15].

Bob Waters, one of the three members of the 1964 San Francisco Forty-niners professional football team who died of ALS, reported being treated for many hours with diathermy in the team's training room [16]. A least a dozen US and Canadian professional football players have or have died of ALS [3].

I hypothesize that sporadic ALS is caused by exogenous electrical currents induced in or applied to the body. Since most cases of ALS have no obvious connection to electrical shock or electrical therapy, most non-familial cases must have had currents induced in their bodies by working or living in environments with strong EMFs. In addition to TENS and diathermy exposure, electro-convulsive shock therapy (ECT), and electro-surgery also generate electric currents in patients.

Electro-convulsive shock therapy causes clinic convulsions by passing electricity through the brain between electrodes placed on the temples or fore and aft on the same side of the head. Typically, the electrical stimulus used in ECT is about 800 mA has up to several hundred watts, and the current flows for between 1 and 6 s. Usually 12 treatments are given, 2–3 per week [17].

Electro-surgery is the application of a high-frequency electric current to biological tissue during surgery. Instead of a scalpel, an electrode known as an RF (radio frequency) knife is used. Various wave forms, duty cycles and modulations are used for cutting, burning, coagulation, desication, etc. Open circuit voltage in electrosurgical waveforms is typically in the range of 300–10,000 V peak-to-peak [18]. It would be interesting to examine the incidence of ALS in operating room personnel and in patients who have had electro-surgery.

This hypothesis could be tested by questioning ALS cases and a suitable comparison group like patients with multiple sclerosis about their electrical exposures. Questions should include: history of lightning strike, electric shock, TENS use, shortwave or microwave diathermy treatment, electro-convulsive shock therapy, electro-surgery, and residential, occupational or hobby exposure to EMFs, including use of electrical devices like cell phones, laptop computers, electric power tools, and electric hair dryers. All new

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patients with ALS should have their residential and work environments measured for EMFs, including as much of the non-ionizing electromagnetic spectrum as possible. The higher frequencies are more likely to induce currents in the body, since the induced currents are proportional to frequency. The residential and work environments of ALS cases should have higher levels of EMFs than the comparison cases.

If this hypothesis is correct, iatrogenic cases of ALS could be prevented.

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Review

Electromagnetic hypersensitivity: Fact or fiction? ☆

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ABSTRACT

As the prevalence of wireless telecommunication escalates throughout the world, health professionals are faced with the challenge of patients who report symptoms they claim are connected with exposure to some frequencies of electromagnetic radiation (EMR). Some scientists and clinicians acknowledge the phenomenon of hypersensitivity to EMR resulting from common exposures such as wireless systems and electrical devices in the home or workplace; others suggest that electromagnetic hypersensitivity (EHS) is psychosomatic or fictitious. Various organizations including the World Health Organization as well as some nation states are carefully exploring this clinical phenomenon in order to better explain the rising prevalence of non-specific, multi-system, often debilitating symptoms associated with non-ionizing EMR exposure. As well as an assortment of physiological complaints, patients diagnosed with EHS also report profound social and personal challenges, impairing their ability to function normally in society. This paper offers a review of the sparse literature on this perplexing condition and a discussion of the controversy surrounding the legitimacy of the EHS diagnosis. Recommendations are provided to assist health professionals in caring for individuals complaining of EHS.

Contents

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Not everything that is faced can be changed. But nothing can be changed until it is faced.

James Baldwin

1. Introduction

In the early years of the 21st century, there are increasing reports throughout the world of individuals and clusters of people complaining of various clinical symptoms in response to minimal exposure to everyday levels of electromagnetic radiation (EMR). Some individuals experience difficulty around wireless systems, when using cordless or cell phones, when exposed to some types of artificial light, or in response to various other common electromagnetic exposures. Once exposed, such vulnerable individuals often develop a variety of symptoms involving various organ systems. Although originally thought to be psychogenic in origin, such symptoms are being reported by ever-increasing numbers of previously healthy individuals (Hallberg and Oberfeld, 2006) — a phenomenon which has generated a closer assessment of the origins of electromagnetic hypersensitivity (EHS) complaints.

In this paper, a review of the emerging literature related to the perplexing EHS condition will be presented along with a case history detailing the development of EHS and subsequent recovery in an otherwise healthy individual. Consideration of physical, psychological and social aspects of this disorder will be presented. As well as an exploration of the polarizing debate that surrounds the EHS issue, recommendations are provided as to how clinicians might empower patients with EHS to regain their health and improve their wellbeing.

2. Background

The surge of wireless telecommunication throughout the world is provoking many people to question whether various EMR frequencies can have adverse effects on human health. It is widely accepted that ionizing high-frequency radiation from X-rays or emissions from radioactive materials are hazardous, with high energy levels capable of harming humans; (Ramirez et al., 2005; Brenner et al., 2003) the detrimental impact of non-ionizing radiation on humans, however, is not widely accepted.

A variety of sources emit anthropogenic EMR including high voltage power lines, cell phones, wireless internet, hair dryers, CT scanners, and radioactive nuclei (Fig. 1). While the wavelengths and frequencies emitted by these sources vary, they all have the capacity to emit energy in the form of electromagnetic radiation. The question for many scientists and patient advocacy groups, however, is twofold: 1) do some frequencies of non-ionizing radiation have the potential to cause adverse physiological effects?; and 2) do some individuals become hypersensitive to otherwise non-perceptible everyday exposure levels of electromagnetic radiation (EMR)?

These quandaries prompted the World Health Organization (WHO) to form an international coalition in 1996 to research the impact of EMR on human health (World Health Organization, 2011a). The coalition continues to the present time and conducts research studies that are underway around the globe. While there is ongoing debate about the potential adverse effect of non-ionizing EMR, there appears to be an intriguing divide. Thus far, most research carried out by independent non-government or non-industry affiliated researchers suggests potentially serious effects from many non-ionizing EMR exposures; (Sage, 2007) research funded by industry and some governments seems to cast doubt on the potential for harm (Genuis, 2008). Emerging research, however, continues to uncover an assortment of potential sequelae resulting from exposure to anthropogenic EMR (Genuis, 2008; Dode et al., 2011; Dode, 2011; Li et al., 2011; Marino et al., 1977; Kabuto et al., 2006) including the finding – recently reported in the *Journal of the American Medical Association* (JAMA) – of alterations in brain glucose metabolism in response to cell phone radio frequencies (Volkow et al., 2011).

The issue of EHS legitimacy remains equally contentious with strong voices advocating on both sides. As widespread exposure to anthropogenic EMR with reports of consequent hypersensitivity is a recent phenomenon unprecedented in human history, it is interesting to trace a few major milestones in the unfolding EHS story.

2.1. Historical milestones related to electromagnetic hypersensitivity

In the 1950s, various centers in Eastern Europe began to describe and treat thousands of workers presenting with recent onset of clusters of multi-system complaints. These individuals were generally employed in i) the manufacture, inspection, operation, or repair of equipment involved in microwave transmission, and/or ii) the operation of radio frequency devices. The constellation of health complaints was initially given the name 'Radio Wave Sickness' and afflicted individuals often presented with symptoms such as headaches, weakness, sleep disturbance, emotional instability, dizziness, memory impairment, fatigue, and heart palpitations (Sadchikova, 1960).

This emerging public health issue persisted through the 1960s and 70s and early reports from various parts of the world began to detail

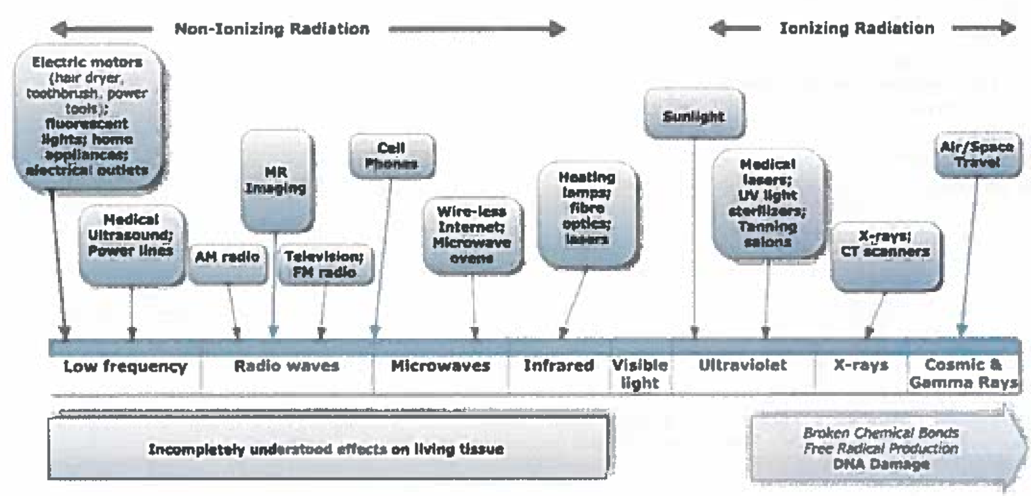

Fig. 1. The electromagnetic spectrum.

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research findings on the health effects of exposure to microwave and radiofrequency radiation (Klimková-Deutschová, 1973; Glaser, 1971; Zaret, 1973; Frey and Seifert, 1968; Frey, 1970). Increasing attention also began to mount in the public arena with books such as 'The Zapping of America' in 1977 (Brodeur, 2000) and 'Terminal Shock' in 1985 (DeMatteo, 1985) fuelling escalating concern about adverse EMR exposure. Although scientific discussion of this health issue was sparse in the medical literature, a neuroscientist from Sweden, Dr. Olle Johansson began to document a constellation of symptoms, including CNS complaints, cardiac symptoms, and skin changes in individuals exposed to various sources of non-ionizing radiation. In response, a Swedish Association for the Electrosensitive ('FEB Föreningen för el-och bildskärmsskadade') was formed and established a mandate to support those with this condition they called 'Electrical Hypersensitivity'. To engender further recognition and support, this group in 1994 disseminated a press release exhorting individuals throughout the globe "to join hands" in addressing this mounting health challenge (The Swedish Association for the Electrosensitive, 1994) — an affliction that has since been referred to as electrical hypersensitivity, electromagnetic hypersensitivity, electrical sensitivity or simply electro-sensitivity.

Clinical research to verify the physiological nature of this condition began in the 1990s. Rea et al. in 1991 reported abnormal responses to certain EMR frequencies (in comparison to blank challenges) by some hypersensitive individuals (Rea et al., 1991). As well as various clinical symptoms, a double blind assessment in this study of various physiological parameters confirmed pulmonary and cardiac changes in some EHS patients (Rea et al., 1991). Ongoing work by Johansson and colleagues confirmed evidence of physiological dermal changes in response to certain EMR exposures in sensitive individuals (Johansson et al., 2001; Johansson and Liu, 1995) With this latter observation, a hypothesis on the pathophysiological mechanism of EHS was introduced based on theorized degranulation of mast cells in various tissues – with release of a spectrum of mediators such as histamine – in response to EMR exposure (Gangi and Johansson, 2000).

In the early 2000s, estimates of the occurrence of EHS began to swell with studies estimating the prevalence of this condition to be about 1.5% of the population of Sweden, (Hillert et al., 2002) 3.2% in California, (Levallois et al., 2002) and 8% in Germany (infas Institut für angewandte Sozialwissenschaft GmbH, 2003). With the escalating prevalence of EHS and the increasing research interest in this health condition, the WHO convened a working group and an international meeting in 2004 in Prague to discuss this apparent disorder. Although not acknowledging a physiological causation for the EHS entity, the group defined EHS as "... *a phenomenon where individuals experience adverse health effects while using or being in the vicinity of devices emanating electric, magnetic, or electromagnetic fields (EMFs) ... Whatever its cause, EHS is a real and sometimes a debilitating problem for the affected persons*" (Mild et al., 2004). Ongoing debate about the veracity of the EHS affliction has erupted, however, as various researchers have found insufficient evidence to support claims about the physiological nature of this disorder. In this paper we endeavor to review the literature on EHS and to then explore apparent contradictions in evidence regarding the etiology and legitimacy of the EHS diagnosis.

2.2. Overview of electromagnetic hypersensitivity

In review, the reported phenomenon whereby vulnerable individuals experience health symptoms from being in close proximity to devices emitting some frequencies of EMR is referred to as EHS (Leitgeb and Schrottner, 2003). While the majority of the population do not perceive any health changes in response to EMR exposure, an increasing number of individuals report a variety of unpleasant symptoms (Table 1) that they attribute to the EMR exposure. The EMR appears to act as a trigger for perceived physiological disturbances in the body. The range of frequencies associated with EHS is usually within the non-ionizing range of the electromagnetic spectrum (Fig. 1).

Table 1
Common reported signs and symptoms associated with electromagnetic hypersensitivity (EHS).

Some common signs and symptoms of electromagnetic hypersensitivity (Havas, 2006; Johansson, 2006)
Headache
Thought processing difficulties
Memory impairment
Heart palpitations
Sleep disorder
General malaise
Blurred vision
Weakness
Dizziness
Chest discomfort
Muscle pain
Tinnitus
Fatigue
Nausea
Night sweats
Restless legs
Paresthesias

As a bioelectrical entity, the human organism in the 21st century is increasingly exposed to three general types of anthropogenic non-ionizing EMR:

a) Extremely low frequency EMR from power lines, electrical appliances and electronic equipment.
b) Electrical pollution: the operation of some electronic equipment (such as plasma televisions, some energy efficient appliances, variable speed motors, etc.) has the ability to manufacture frequency signals generally in the 3–150 kHz range (very low to low frequency portion of the electromagnetic spectrum) which then flows along and radiates from wiring in affected homes and other buildings. This has been referred to as electrical pollution or dirty electricity (Havas, 2006).
c) Microwave and radiofrequency emissions from wireless telecommunication devices such as wireless telephones, cell towers, antennas as well as broadcast transmission towers (Sage, 2007).

Some individuals with EHS experience symptoms when exposed to EMR in the extremely low frequency ranges; others appear to be more sensitive to frequencies emitted in the radiofrequency or microwave range. Furthermore, some people will complain of distinct symptoms in response to different frequencies — such as mood changes when exposed to one frequency range and musculoskeletal discomfort at a different frequency range. Some appear to have sensitivity responses throughout the non-ionizing range of frequencies, and a subgroup manifests sensitivity with CNS symptoms and visual disturbance in response to natural frequencies in the visible light component of the spectrum (Coyle, 1995). There is also research exploring the link between some disorders of hearing such as tinnitus and sensitivity to certain frequencies of EMF (Landgrebe et al., 2009).

As a result, unpleasant symptoms may occur when the vulnerable individual has exposure to EMR produced by common objects such as cell phones, wireless headsets, fluorescent lighting, some computers, cordless phones, appliances, and telecommunications signals (Havas, 2006). Additional sources of EMR sometimes not considered are motors such as in furnaces, various types of electronic surveillance equipment (e.g. metal detectors at airports), as well as industrial machinery such as medical diathermy (cautery tools) (Floderus et al., 2002).

Until recently, the diagnosis of EHS has not received much support from the medical community due to the lack of objective evidence to support the EHS diagnosis. In an effort to determine the legitimacy of EHS as a neurological disorder, however, a collection of scientists and physicians recently conducted a double-blinded research study on the outcome of EMR provocation which was subsequently published in the *International Journal of Neuroscience* (McCarty et al., 2011). The researchers were able to objectively demonstrate somatic reactions

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from an EHS patient in response to EMR provocation using levels typically found in the contemporary environment. They conclude that "EMF hypersensitivity can occur as a *bona fide* environmentally-inducible neurological syndrome"(McCarty et al., 2011).

Furthermore, a recent study by Havas et al. (2010) demonstrated physiological responses to low-dose EMR exposure in some individuals. Immediate and dramatic changes in both heart rate and heart rate variability were evident in affected participants with microwave exposure levels at only 0.5% of existing Canadian and American guideline limits (Havas et al., 2010). This study suggests that some individuals may experience cardiac symptoms and autonomic nervous system dysregulation as a pathophysiological response to electromagnetic stressors.

2.3. Pathogenesis of electromagnetic hypersensitivity

As with other multi-system illnesses such as multiple chemical sensitivity (MCS), fibromyalgia, and chronic fatigue syndrome (CFS), the exact pathogenesis of EHS is not completely understood. Emerging evidence suggests, however, that the aberrant biological process for developing EHS occurs through an intriguing pathophysiological mechanism (Fig. 2) referred to as sensitivity-related illness (SRI) (Genuis, 2010a; De Luca et al., 2010). In addition, recent evidence has demonstrated a potential for disruption of catecholamine production in response to EMR that may affect the human organism in many ways.

a) Sensitivity related illness
SRI describes a pathophysiological response to bioaccumulation of foreign materials originating from various potential sources such as toxic chemicals, surgical implants, infections, dental materials, and radioactive compounds. The mechanism by which the body becomes hyper-reactive or hyper-sensitized to electromagnetic energy may start with a totally unrelated toxicant insult or multiple insults in the form of foreign exposures. This pathway to illness has been referred to as TILT (Toxicant Induced Loss of Tolerance) (Miller, 2001; Miller, 1997).
After a threshold of bioaccumulation is achieved, an individual's immune system loses the normal adaptive responses with immune tolerance and becomes sensitized to exposures from seemingly insignificant and unrelated environmental stimuli. For example, a study in Sweden found that people with EHS had significantly higher levels of accrued polybrominated diphenyl ethers (PBDEs) — very common and hormonally active persistent pollutants used as flame retardants and which bio-accumulate in adipose tissue (Hardell et al., 2008). (Until recently, these compounds have routinely been applied to mattresses, for example, to meet fire regulation standards and consequently off-gas nightly into the slumbering recipient.)
In patients with TILT, subsequent triggering of the hypersensitive immune system by chemical or electromagnetic incitants precipitates a clinical reaction resulting from a dysregulated biochemical response from various components of the immune system (Genuis, 2010a; Duramad et al., 2007; Tracey, 2007). It is unclear why some people, after developing TILT, develop sensitivity to chemical triggers, to electromagnetic stimuli, or to both. The nature of the reaction is mediated by the unique makeup of the bioaccumulated toxicant load and/or the distinctive genetic and biochemical thumbprint of the individual (Genuis, 2010a). The ensuing antibody, cytokine, interleukin, and chemokine activation by environmental stimuli may affect various organ systems and physiological functions including the endocrine system, the autonomic nervous system, genetic expression, and so on — resulting in abnormal multi-system signs and symptoms (Genuis, 2010a; Ashford and Miller, 1998). (This activation phenomenon has been referred to as MATES: Minute Assorted Triggers Evoke Symptoms (Genuis, 2010a)).
Although the precise pathophysiological mechanisms of the hypersensitivity response to EMR have not been clearly delineated, emerging research confirms that some frequencies of EMR can exert immune dysregulation in vitro with increased production of selected cytokines — a common feature of SRI (Stankiewicz et al., 2010; Dabrowski et al., 2003). Furthermore, the development of the immune dysregulation associated with SRI and EHS after toxicant bioaccumulation appears to involve genomic considerations. De Luca et al. (2010) discovered that people who suffer from EHS may have various defects in genes involved in toxicant elimination within their body. These genes are responsible for producing antioxidant/detoxification enzymes such as glutathione-S-transferases, superoxide dismutase, catalase, N-acetyl transferases, cytochrome 450 enzymes and others (Wormhoudt et al., 1999). As a result these people may have impaired detoxification mechanisms resulting in a predisposition to toxicant bioaccumulation.

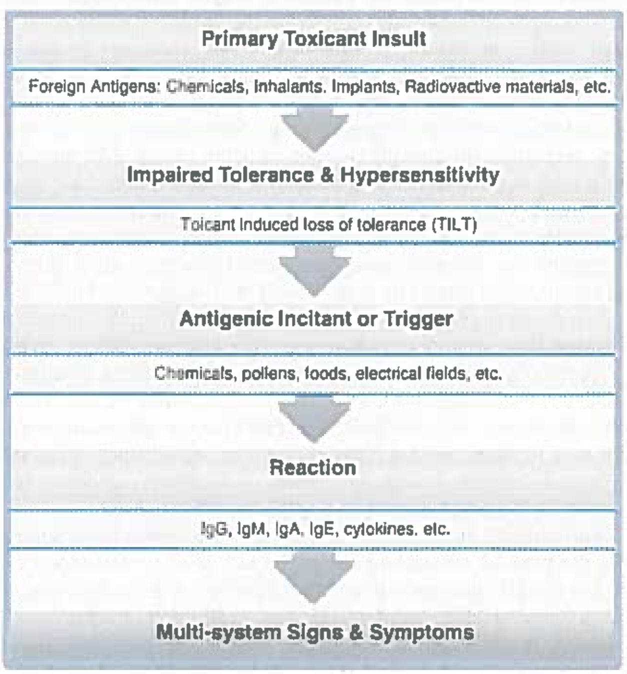

Fig. 2. Pathogenic mechanism for development of sensitivity related illness.

b) Catecholamine dysregulation
Another important mechanism that may be responsible for some of the manifestations of EHS involves disruption and dysregulation of catecholamine physiology in response to adverse EMR (Buchner and Eger, 2011). Although EMR frequencies were first reported to affect regulation of endocrine systems including adrenal gland function in 1977, (Marino et al., 1977) recent research highlights a dose–response relationship which occurs well below established limits for technical radiofrequency radiation exposure (Buchner and Eger, 2011). Furthermore, with ongoing exposure – such as living in close proximity to a cell phone base station – this pathophysiological reaction may involve a protracted alteration of norepinephrine, epinephrine, dopamine and phenylethylamine biology with yet unrecognized health implications (Buchner and Eger, 2011). As these endogenous compounds are well known to be instrumental in several fundamental biological actions including autonomic nervous system function, neurotransmission, state of alertness and response to stress, it is uncertain if dysregulation elicited by adverse EMR exposure may be involved in EHS and/or predispose vulnerable individuals to a variety of health issues associated with catecholamine and neurotransmitter dysregulation.
Other pathophysiological mechanisms for the EHS phenomenon have been proposed. Costa et al. (2010) have submitted that heavy metal poisoning has the potential to precipitate EHS — as EMR influences metals to become re-mobilized in the body possibly resulting in systemic symptoms. There has also been the suggestion that in the

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complex clinical environment of the 21st century, EHS may – in part – involve a multifaceted interplay between certain neurocognitive factors within the patient's psyche (Landgrebe et al., 2008).

In review, the exact pathophysiological mechanism of EHS has not been fully elucidated. The observation that 1) EHS patients are generally previously healthy individuals who have sustained a toxicant burden; and 2) EHS often subsides when elimination of toxicants is achieved, suggests that the TILT mechanism may feature prominently in the ethology of this complex clinical phenomenon. The precise role of prolonged catecholamine dysregulation in the manifestation of EHS remains to be elucidated.

2.4. Biochemical markers for electromagnetic hypersensitivity

It would be clinically advantageous if there was one pathognomonic marker reflecting a defined mechanism for the development of EHS. Such is not the case. Ongoing research continues to identify changes within the immune system that may be involved in the immune dysregulation associated with EHS. For example, while DNA bond breakage generally requires the high thermal energy found in ionizing radiation, Mashevich et al. (2003) found that very low frequency EMR and microwaves can lead to altered genotypes in human lymphocyte DNA via non-thermal protein stress. Furthermore, recent evidence suggests that DNA replication and mitosis can be disrupted and form altered proteins in the presence of EMR (Lin et al., 1997; Lin et al., 1998; Tsurita et al., 1999; de Pomerai et al., 2000). Accordingly, abnormalities within cellular machinery may lead to aberrant immune responses. No single biochemical marker unique to EHS that reflects such underlying changes, however, has yet been identified.

Furthermore, the immune system may become hyper-reactive in direct response to regulatory influences from other organ systems such as the CNS. A paper by D'Andrea et al. (2003) explains that microwaves and radio frequencies are capable of affecting central nervous system physiology. Through a review of numerous laboratory studies on humans and animals, microwaves were shown to affect the permeability of the blood brain barrier to drugs and to impact hormones, blood cortisol levels, memory functioning, electroencephalogram (EEG) readings, as well as neurochemistry markers (D'Andrea et al., 2003; Salford et al., 2008). Thus far, however, no consistent laboratory finding has been identified which objectively establishes a diagnosis of EHS.

3. Management of electromagnetic hypersensitivity

With appropriate care, it is possible for patients with EHS to improve considerably and be restored to normal functioning. By understanding the pathway to the development of SRI, by practicing avoidance of triggers and further toxicant exposure, and by instituting appropriate therapeutic measures when necessary, patients consistently improve. An overall environmental approach to managing exposure related illness, such as EHS, is depicted in Fig. 3 (Genuis, 2010a). Details of this management approach can be found in other papers (Genuis, 2010a; Genuis, 2011) but the general approach is summarized in the three following phases.

(a) Avoid environmental triggers
In order for symptoms to diminish, it is necessary for SRI patients to avoid inciting triggers. For patients with EHS, they must be vigilant about avoiding frequencies of EMR that ignite their symptoms. Table 2 makes suggestions on how common sources of EMF exposure might be reduced for people with EHS. As a result of the underlying toxicant burden, however, many individuals with EHS also experience symptoms in response to chemical triggers. These must be addressed as well for success to be achieved. Various jurisdictions have begun to establish safe residences and places of respite for individuals suffering from EHS.

(b) Remediate nutritional and biochemical status
Once a concerted effort is underway to avoid inciting exposures, the next step involves remediating the nutritional biochemistry of the individual. During states of chronic stress and inflammation, the body quickly depletes its store of nutrients required for the cellular machinery and normal functioning of inherent physiology. Biochemical testing is available to assess the state of nutritional biochemistry, and interventions should be tailored to address specific abnormalities. Detoxification biochemistry must be optimal in order to proceed to the final step — diminution of the total toxicant load that initiated the health problem in the first place.

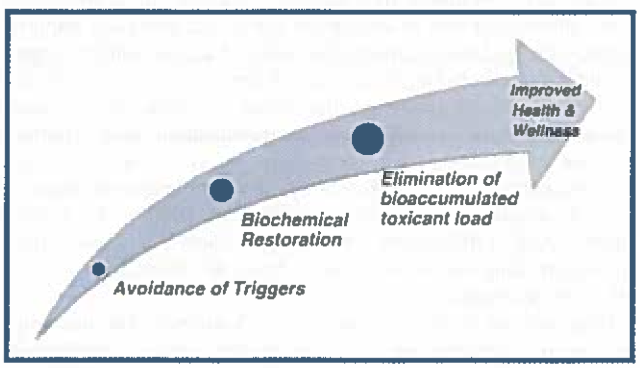

Fig. 3. Intervention approach to manage sensitivity related illness.

Table 2
Examples of strategies to reduce electromagnetic radiation.

Sources of adverse EMR	Considerations to reduce EMR exposure
Cell phones and cordless phones	• Minimize use of cell and cordless phones and use speaker phones when possible • Leave cell or cordless phone away from the body rather than in pocket or attached at the hip
Wireless internet	• Use wired internet • Turn off the internet router when not in use (e.g. night-time) • Use power line network kits to achieve internet access by using existing wiring and avoiding wireless emissions.
Computers releasing high EMR	• Limit the amount of time spent working on a computer • Avoid setting a laptop computer on the lap • Increase the distance from the transformer • Stay a reasonable distance away from the computer
Handheld electronics (electric toothbrush, hair dryer, Smart phone, electronic tablets, etc.)	• Limit the use of electronics and/or revert to using power-free devices • Turn devices off before going to sleep • Minimize electronics in bedrooms
Fluorescent lights	• Consider using alternate lighting such as incandescent. (Uncertainty exists about the safety of LED lights) • Rely on natural sunlight for reading
Household power	• Measure levels of EMR and modify exposures as possible • Avoid sleeping near sites of elevated EMR • Filters can be used to mitigate dirty power
High voltage power lines and substations	• Consider relocating to an area not in close proximity to high voltage power lines
Transmission towers and emitters (cell phone tower, radar, etc.)	• Maintain considerable distance from emitters • Consider forms of shielding (shielding paints; grounded metal sheets)
Utility neutral-to-ground bonded to water pipes	Increase size of neutral-wire to substation and install dielectric coupling in water pipe.

(c) Reduce the toxicant burden
The total burden of toxicants encumbering the immune system must be reduced to diminish the hyperactive immune response and to achieve optimal health. Some recent research is beginning to make the link between specific toxicants such as heavy metals and EHS, (Costa et al., 2010) but it is imperative to explore the total load that encompasses the range of potential toxicants including various adverse chemical agents, implants, some dental materials, mold exposures and other toxins (Genuis, 2012). For some toxicants, the avoidance of further exposure will allow the body to detoxify spontaneously and eliminate these compounds; for some persistent toxicants such as cadmium, lead, perfluorinated compounds, and others, active intervention may be required to reduce the accrued toxicant burden (Genuis, 2011; Genuis, 2010b). When detoxification is undertaken effectively and further exposure is avoided, patients consistently begin to recover from their hypersensitivity problems.

3.1. Explore associated health challenges

Management of all EHS patients should include a thorough health assessment as well as investigations and interventions to identify and address all determinants of illness. Both Dahmen and Hillert, for example, found that people with EHS had an elevated prevalence of thyroid dysfunction and liver disease (Hillert et al., 2002; Dahmen et al., 2009). The mental health symptoms that sometimes accompany or result from EHS may be responsive to cognitive behavioral therapy with amelioration of depression, anxiety, phobias, and other related symptoms (Hillert et al., 1998; Rubin and Das, 2006).

One of the major health challenges with EHS is sleep quality. As adverse EMR is frequently encountered inadvertently in the bedroom from sources such as electronics, wireless systems, and possibly metal bed materials (Hallberg and Johansson, 2010), restful sleep is often interrupted. Sleep interference and disturbed day/night rhythms often ensue resulting in delayed waking, daytime napping, impaired concentration, and other issues. Any EHS treatment program needs to check for and address factors that may incite sleep disturbance (Hobbs, 2011).

3.2. Neural re-training

There is ongoing discussion in the scientific literature about neuroplasticity and the innate ability of the brain to be retrained with resultant modification of established brain responses (Berlucchi, 2011; Cioni et al., 2011). As a result, there has been the emergence of training interventions endeavoring to modify hypersensitivity reactions in patients with various sensitivity related conditions including EHS (Hooper, 2011). Limited scientific study is available to date on the efficacy of such neural retraining approaches, but some patients anecdotally report that reducing the toxicant burden combined with intense retraining of pathological brain responses yields preferred outcomes.

3.3. EMF shielding

Recognizing that the initiating trigger of EHS is exposure to EMR, some EHS patients endeavor to block exposure to offending frequencies within their home or workplace via shielding modalities (Less EMF Inc., 2011). While some frequencies of EMR can be readily blocked by various materials, other anthropogenic sources of EMR such as low frequency magnetic waves are more difficult to block. No scientific study of the impact of such shielding techniques on EHS patients is available thus far, but anecdotally some individuals claim benefit. The issue of shielding, however, can be complex as exposure can also be affected by reflection within a shielded environment so that adverse EMR can backfire into the allegedly protected domain (Torrens, 2008).

3.4. Grounding technique

A simple technique with uncertain efficacy involves the discharge of accumulated electrical charge into the earth by intermittently 'grounding' the EHS patient (Chevalier et al., in press). This unassuming practice involves placing bare feet on the earth, or on another conductive surface (e.g. metal sheet) which is in direct contact with the earth. Although more science is required to determine the credibility of this approach, some patients with disabling EHS report clinical benefit and provisional relief from symptoms using this modality. Caution is required, however, as grounding in the area of buried power lines or in the vicinity of current from other electrical sources diverted into the earth may aggravate symptoms.

A case history is presented for consideration to illustrate the challenges and potential successful outcomes associated with clinical management of this condition.

4. Case history of electromagnetic hypersensitivity

A 35 year-old previously healthy, well-educated and highly functioning married mother of two children noticed an abrupt decline in her health and ability to function within three weeks of moving into a newly renovated house. She developed progressive fatigue, muscle pain, cognitive decline, anxiety, and uncharacteristic memory impairment — to the point where she forgot to pick up her children from elementary school on multiple occasions. Despite seeing multiple physicians and undergoing extensive testing (including MRIs and CTs) her symptoms worsened to the point where she experienced ongoing night sweats, nausea, severe headaches, muscle weakness, myalgias and weight loss of near 20 lb. No explanation was found and she was given assorted diagnoses including allergic disease, psychosomatic illness, early multiple sclerosis and chronic fatigue syndrome.

It was notable, however, that when she went on trips away from the newly renovated house, her symptoms conspicuously improved, only to return in full force when she came home. Concerned that she may be experiencing an adverse reaction within her home environment, she thoroughly cleaned the premises and instituted air and water purification as well as making every effort to eat a well-balanced diet. Despite her efforts, the symptoms continued to worsen. In desperation she sought help from additional health professionals and was introduced to the idea of possibly being sensitive to EMR within her home.

With vigilant observation, she made a clear connection between her symptoms and exposure to the numerous electrical items in her environment. Her symptoms were worse when near fluorescent lights, microwaves, and kitchen appliances. Despite limiting her exposure to these appliances, however, her night time symptoms of nausea, fevers, chills, tremors, and vomiting persisted; whenever she spent a night at a motel, these symptoms would abate.

In addition to her own health issues, she noted increasing illness in other family members. Her children developed unremitting respiratory ailments as well as several ear and throat infections requiring repeated medical interventions; her husband also developed respiratory difficulties including pneumonia. When looking for the initiating cause of the health problems, she noted a number of off-gassing chemical exposures related to the recent renovations and, in particular, discovered a floor stain that had been improperly finished and was off-gassing heavily. With concern about the potential impact of ongoing off-gassing from the renovation in addition to a 200 A power supply to their home and close proximity to a power generation station, they decided to move to an environment with less EMF and chemical exposure.

Upon moving to an older home near a nature reserve, her symptoms began to improve but did not completely resolve until she took measures to reduce the quantity of EMR in her new environment — measures such as converting to wired internet connections and turning off power to non-essential appliances during the night. Her health subsequently improved markedly and she was able to return to normal activities including cycling with her family, rollerblading, and going for long walks. Thirteen years later, her health remains stable and she is able to live an active normal life, but takes ongoing measures to avoid chemical and pronounced EMF exposures.

It is hypothesized that this previously healthy individual experienced a toxicant burden and consequent TILT after moving into a newly renovated home with various chemical exposures. A hypersensitivity to EMR ensued resulting in myriad symptoms — that settled when she avoided EMR. After relocation and avoidance of further exposure, her body burden diminished as she spontaneously eliminated toxicants by endogenous mechanisms. As a result of the diminished total toxicant load, her SRI slowly diminished as her TILT abated, and her hypersensitivity to electromagnetic triggers settled.

5. Quality of life considerations

For individuals suffering from EHS, there are a number of issues that consistently arise. A major challenge of EHS is the imperceptible nature of EMR to otherwise healthy people. The absence of perceptible stimuli inclines physicians, family members, friends, employers, and insurance companies to classify the symptoms of EHS as psychogenic or psychiatric in origin (Rubin et al., 2010; Kanaan et al., 2007; Das-Munshi et al., 2006; Rubin et al., 2011). As a result, patients with EHS frequently experience ridicule and eventual rejection or dismissal by their usual systems of support. This common outcome has a profound impact on many aspects of life including employment, accommodation, healthcare, finances as well as having a profound bearing on social, emotional and psychological dimensions of life (Parsons, 2011).

5.1. Social impact

EHS has been described by patients as a 'loner's disease'. Due to the prevalence of ubiquitous EMR in the contemporary urban environment, EHS causes patients to experience extreme social isolation. The serious symptoms confine them to their home. Venturing out to shopping malls, libraries, theaters, hospitals, and doctors' offices is often precarious because of the prevalence of wireless routers, cell phones, antennas, and other sources of EMR. Furthermore many patients are often no longer able to spend time in the homes of family members due to EMR issues. As a result, huge stresses are placed on marriages and families — especially if family members are not willing to reduce EMR in the home environment.

The pronounced physical and psychological symptoms often prompt EHS patients to take medical leaves from their employment and many eventually leave work all together. The inability to participate in previously enjoyed leisure activities and meaningful occupations is worsened by the lack of empathy and fractured relationships with family, colleagues and health care providers.

5.2. Physical and psychological impact

People with EHS frequently experience debilitating symptoms which can affect any body system including the central nervous system, musculoskeletal system, gastrointestinal tract, and endocrine system. Symptoms often lead to ongoing psychological stress and intense fear of being 'hit' by EMR wherever they go. Many patients become incapacitated by such fear — knowing that an invisible wireless signal may incite major symptoms in their body at any time and any place. This unremitting fear and preoccupation with health issues can have a major impact on well-being, to the point where EHS individuals develop a phobia and disdain of electricity, with some desiring to escape civilization.

Cross-sectional surveys conducted in Sweden found that people with EHS expressed increased tendencies to anxiety and states of hyper-vigilance and stress (Johansson et al., 2010). These psychological factors may be further mediators of illness in people with EHS and place them at increased risk for other psychologically-related disorders (De Luca et al., 2010; Johansson et al., 2010). Furthermore, the lack of support and acceptance by loved ones often leads EHS individuals to question their own sanity and to states of diminished self-esteem. Finally, the underlying toxicant burden associated with EHS makes patients vulnerable to other sensitivity related conditions such as fibromyalgia, chronic fatigue syndrome, and multiple chemical sensitivity (Genuis, 2010a).

6. Debate about the legitimacy of electromagnetic hypersensitivity

Despite increasing reports in the world literature recognizing EHS as a legitimate clinical entity, (World Health Organization, 2011a; McCarty et al., 2011; Havas et al., 2010; Havas, 2000; World Health Organization, 2011b; Chemical Sensitivity Network, 2011) many people remain skeptical about the veracity of the idea that a subsection of the population experiences illness and disability as a result of intolerance of ordinary everyday levels of EMR (Levallois, 2002). Some consider the EHS condition to be purely psychosomatic (Rubin et al., 2010; Das-Munshi et al., 2006) — a "made-up term used by hypochondriacs and alternative-medicine practitioners to explain away unrelated medical problems" (National Post, 2011).

This stance is buttressed by the failure of numerous studies to prove a connection between people's reported EHS and their actual exposure to EMR (Nam et al., 2009; Mortazavi et al., 2007). In fact, many of the studies show that people with self-reported EHS were more sensitive to devices emitting no EMR than true EMR (Frick et al., 2005). In contrast to the more recent double-blind work confirming measurable physiological change in response to EMR exposure (McCarty et al., 2011), Rubin et al. (2011) found that participants with self-reported EHS did not have any abnormal physiological responses to acute EMR exposure. Looking at twenty-nine single or double-blind studies that exposed people to real and sham EMR, they report that most of the studies did not show any significant association between EMR and consistent symptoms in the self-reported EHS participant (Rubin et al., 2011).

Secondly, many EHS patients with EMR-induced brain dysfunction have CNS symptoms involving mood, cognitive ability, perception, and behavior. Because of the labile nature of this condition depending on incitant exposures, EHS patients are often perceived as inconsistent and unreliable, which makes it tempting for skeptics to label their condition as psychogenic. As a result of these various factors, many clinicians, politicians, and industry groups have chosen to label EHS as a fictitious malady.

After reviewing all available evidence, however, the WHO in 2004 released a factsheet identifying non-specific multi-system illness resulting from EMR exposure as 'electromagnetic hypersensitivity' (EHS) (World Health Organization, 2011b). In May of 2011 a coalition of physician scientists met with officials in the WHO responsible for developing the International Classification of Diseases (ICD). The WHO expressed a willingness to consider professional and public input on evidence supporting the inclusion of EHS into the 11th version of ICD to be released in 2015 (Chemical Sensitivity Network, 2011).

Various national governments have also recognized EHS as an emerging medical problem. Sweden (with about a quarter of a million people with EHS reported in 2004 (Johansson, 2006)) classifies EHS as a functional impairment (Johansson, 2006). Taking steps to diminish the risk of toxicant exposures – the source etiology of SRI and EHS – the Swedish Chemicals Agency has introduced recommendations in the form of a 'Substitution Principle'. This report recommends: "*If risks to the environment and human health and safety can be reduced by replacing a chemical substance or product either by another substance or by some non-chemical technology, then this replacement should take place*"

(Swedish Chemicals Agency, 2007). Other nations have also begun to introduce guidelines and legislation in relation to EHS. Spain, for example, recognizes EHS as a permanent disability (Grupo Medico Juridico, 2011) while the Canadian Human Rights Commission includes EHS among environmental sensitivities as a disability to be accommodated under Canadian federal legislation (Sears, 2007a). With conflicting outcomes in EHS research to date, however, legislative and public health action has been slow in many jurisdictions.

What considerations might potentially explain the apparent inconsistencies and contradictions in study outcomes and conclusions about the legitimacy of the EHS diagnosis?

6.1. Response to challenges relating to the EHS diagnosis

- ***Lack of Clinical Response to EMR in some Research:*** Individuals with EHS may be sensitive to different frequencies; not all electromagnetic frequencies are the same. Just as people with food intolerances are not sensitive to all foods and chemically sensitive patients are not sensitive to all chemical exposures, EHS patients are not necessarily sensitive to all frequencies in the electromagnetic spectrum. Testing EHS patients for identifiable physiological changes by exposing them to one frequency may miss frequencies that they are sensitive to — it is equivalent to testing people for food intolerances by exposing them to only one food or testing for all atopic illness in a patient by testing with only one antigen.
- ***Fluctuating Clinical Response to EMR in some Research:*** For those individuals with SRI, levels and intensity of intolerance can change over the short and long term (Genuis, 2010a; Ashford and Miller, 1998; Miller and Ashford, 2000). The intensity of response can fluctuate depending on changing levels of the total body burden, incitant dose, overall inflammatory status of the body, concomitant associated triggers, medication or natural health product use, general health, emotional state, and various other determinants.
- ***Delayed Clinical Response to EMR in some Research:*** Clinical change following incitant exposure is not necessarily immediate and can be delayed in onset. As some inflammatory responses can take time to manifest, immediate clinical testing for the purposes of research may not be reliable.
- ***Differing Clinical Outcomes in Different Individuals:*** Some of the studies claiming to disprove EHS utilize a reductionist approach to assessing patient suffering. Each person with EHS is a unique individual functioning in a complex environment, not a machine in a laboratory. Many of the studies attempt to create a controlled environment, and then draw conclusions — which are not generalizable to the complex environment where biochemically unique individuals with distinct genomes exist, and where a multiplicity of interconnected determinants may impact susceptible persons.
- ***Psychogenic Etiology:*** Many patients with EHS have been able to recover and have achieved sustained health using physiological interventions, without psychological therapies. In other words, correction of patho-physiology rather than patho-psychology has been successful in ameliorating this condition. This suggests that there may be a physiological basis for at least some portion of EHS.
- ***Lack of Objective Evidence:*** Unlike hypertension or diabetes, where isolated predetermined clinical markers determine diagnosis, EHS is not easily measured with quantifiable criteria. Without objective markers, some health professionals tend to dismiss the EHS diagnosis. EHS generally does not occur in isolation — it is often one component of complex multi-system health problems resulting from SRI (Genuis, 2010a; Dahmen et al., 2009; Sears, 2007b). EHS is a person-specific syndrome based on a person's total environmental burden, on their overall health, and how their unique bioelectric cellular chemistry responds to external EMR. Individuals with EHS may have associated biochemical deficiencies, toxicant bioaccumulation, and individual genetic polymorphisms that affect cellular detoxification processes, neurocognitive biology, and other determinants of health and illness (Landgrebe et al., 2008).
- ***EHS Defies Experience and Doesn't Make Sense:*** As most healthy people do not perceive EMR in their environment, it may be counter-intuitive to accept that some individuals experience physically disabling symptoms as a result of seemingly incidental exposure. As a result, many scientists and clinicians are not willing to entertain the possibility that such sensitivity exists, and automatically default to the psychogenic attribution of disease. It is instructive to consider, however, that just as some vulnerable individuals with peanut allergy can experience life-threatening anaphylaxis from exposure to miniscule amounts of everyday peanuts, some EHS persons can develop debilitating responses to everyday levels of EMR.
- ***Conflict of Interest Issues:*** Sensitivity to environmental factors has huge implications for issues relating to insurance, employment, human rights, liability, policy initiatives, legislation, industrial policies, lifestyle and so on — issues with profound economic implications. In science and medicine as in other disciplines, there are those so closely allied to vested interests that they have seemingly been inoculated against truth, against credible research, and against observed fact (Michaels, 2008; Moynihan, 2003). Regardless of how compelling the evidence to the contrary, some unscrupulous or uninformed scientists continue to serve and represent the vested interests that fund them or the entrenched ideas and ideologies that propel them (Michaels, 2008; Angell, 2000). It has been suggested that perhaps some of the facts about EHS are being obfuscated and that 'evidence' has been manipulated to instill doubt and to impede public health regulation in exposure related matters (Genuis, 2008; Michaels, 2008).
- ***Historical Precedent:*** History repeatedly demonstrates that a disorder failing to fit the existing scientific paradigm of a specific era does not automatically translate into the condition being a psychosomatic or metaphysical nonentity. Many afflictions from Parkinson's to peptic ulcer disease were initially thought to be psychological rather than physiological in origin (Pall, 2007; Marshall, 2002).
- ***Knowledge Translation:*** Medical history consistently demonstrates that the adoption of new knowledge in clinical medicine is notoriously slow (Genuis, 2012; Genuis and Genuis, 2006; Doherty, 2005; Grol and Grimshaw, 2003). Currently, EHS is generally ignored, ridiculed or denied in much the same way that many other conditions such as ulcerative colitis, migraine headaches, multiple sclerosis and post-traumatic stress disorder were summarily dismissed in the past (Pall, 2007).

7. Conclusion

Over the last 50 years, there has been an anthropogenic electromagnetic revolution with the widespread release of electronic equipment, wireless systems, electrical machines as well as pervasive high voltage power lines and telecommunication emitters; in the next 50 years we will begin to witness the consequences of these developments. We have an ethical responsibility to define the impact of such technology on the human organism and to develop methodologies to investigate and manage adverse sequelae.

When exposed to certain frequencies of EMR, patients with EHS experience non-specific signs and symptoms affecting multiple body systems; many are rendered disabled and unable to function effectively in society. Evidence is accumulating, however, that many EHS patients can be successfully managed clinically and can experience substantial recovery. General recommendations for treating people with SRI, including EHS, involve reducing and avoiding environmental triggers, remediating biochemical and nutritional status, and diminishing bioaccumulated toxicant loads (Genuis, 2010a). In addition, some patients find cognitive behavior therapy and neural re-training to be

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helpful adjuncts in addressing psychological stress and acquiring skills to overcome EHS.

Further research is required to fully understand the detailed pathophysiology of EHS and to enhance current therapies to ameliorate the suffering experienced by afflicted individuals. Public health measures including community education and appropriate governmental regulation relating to environmental chemical toxicant exposure and EMR are urgently required to preserve public health and to stem the increasing incidence of this preventable medical disorder. The 'Substitution Principle' invoked by Sweden, requiring adoption of least-risk and most sustainable strategies, is a logical approach to promote innovative technologies to protect individual and public health.

Recent evidence in the scientific literature suggests that various objective physiological alterations are apparent in some EHS persons claiming to suffer after exposure to certain frequencies of EMR (McCarty et al., 2011; Havas et al., 2010). As a result, many scientists now recognize that hypersensitivity to EMR can be a debilitating medical condition that is affecting increasing numbers of people throughout the world. While EHS patients can initiate steps to reduce exposure to EMR once they recognize the importance of doing so, more clinicians familiar with EHS and the SRI mechanism of ill-health (Genuis, 2010a) are needed to diagnose, assist and treat the burgeoning number of suffering individuals who are at a total loss to explain their various symptoms. In the end, regardless of whether one chooses to believe that EHS is fact or fiction, every ethical health provider has an obligation to sincerely listen to his/her patients, including those with EHS, and to do everything possible to ameliorate their suffering.

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Review Article

Fielding a current idea: exploring the public health impact of electromagnetic radiation

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Ground current;
Human exposure assessment;
Non-ionizing radiation

Summary Several publications in the scientific literature have raised concern about the individual and public health impact of adverse non-ionizing radiation (a-NIR) from electromagnetic field (EMF) exposure emanating from certain power, electrical and wireless devices commonly found in the home, workplace, school and community. Despite the many challenges in establishing irrefutable scientific proof of harm and the various gaps in elucidating the precise mechanisms of harm, epidemiological analyses continue to suggest considerable potential for injury and affliction as a result of a-NIR exposure. As environmental health has not been emphasized in medical education, some clinicians are not fully aware of possible EMF-related health problems and, as a result, manifestations of a-NIR may remain misdiagnosed and ineffectually managed. It is important for physicians and public health officials to be aware of the fundamental science and clinical implications of EMF exposure. A review of the scientific literature relating to the link between electromagnetic radiation and human health, several public health recommendations, and four case histories are presented for consideration.

'A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it.' Max Planck (Nobel Prize Winner—Physics).

It was only a few decades ago when individuals queued up in shoe shops and malls to view their metatarsals under fluoroscopy machines; with expert reassurance that such a novelty was perfectly safe, the increased cancer rates in participants came as a surprise. While there is recognition of the potential cellular and tissue damage associated with exposure to ionizing radiation from X-rays, electromagnetic radiation (EMR) emanating from power lines, mobile phones, common electrical devices and some types of machinery has also begun to attract recent attention as a potential health hazard. Conflicting

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information is found in the medical literature; while some reports dismiss the alleged risk associated with EMR, various international bodies including the World Health Organization[1] and the International Agency for Research on Cancer[2] (IARC) have called for intense investigation of the impact of non-ionizing radiation (NIR) on human health in response to mounting research suggesting a link between adverse EMR and various afflictions including reproductive dysfunction, cancer and central nervous system (CNS) disorders.

Overview of electromagnetic spectrum and NIR

Radiation refers to a type of energy that is given off or 'radiates' away from the source of that energy. There are different forms of energy, each with distinct physical properties that can be measured and expressed in terms of frequency and wavelengths. Some waves have a high frequency, some medium and some low. The electromagnetic spectrum is a name used to describe a group of distinct energy forms that emanate from various sources; the energies released are referred to as types of EMR (Fig. 1). Exhibiting high frequencies are gamma rays, X-rays and ultraviolet light; lower frequencies of the spectrum include microwaves and radio waves. Light wave emission, which occurs at medium frequencies, provides for normal vision and the light we perceive; infra-red energy allows for the perception of heat.

Most energy forms such as X-rays, ultraviolet energy and radio waves are invisible and imperceptible to the human. Without specialized instrumentation, most frequencies cannot be detected and, as a result, people generally do not appreciate their exposure to energy fields in these ranges. Despite the lack of perception, exposure to high-frequency energy including X-rays is termed 'ionizing radiation' and is potentially damaging to human cells. By altering the atomic composition of cell structures, by breaking chemical bonds and by inducing free radical formation, sufficient exposure to ionizing radiation may inflict DNA damage or mutation, thus increasing the risk of malignancy or cell death.

Non-ionizing radiation

'Non-ionizing' radiation (NIR), generally referring to energy forms with lower frequencies, has been considered safe by many scientists and without adverse effects at common exposure levels. Recently, however, increasing evidence suggests that some frequencies of NIR may have potential to cause biological harm. Most of the research on the health effects of adverse NIR (a-NIR) has been done at: (1) extremely low-frequency (ELF) energy waves produced and emitted by power stations, power lines and some electrical equipment; and (2) radio and microwave frequencies given off by wireless communication technologies, cordless and cellular phones, and some electrical materials. Current study is also investigating the potential sequelae of intense exposure to a-NIR as a result of voltage originating from 'dirty electricity' and 'ground current'.

Just as clean water can become polluted when it travels through a contaminated environment, electricity becomes increasingly polluted when it comes into contact with assorted types of electronic equipment. Regular or 'clean' electricity enters buildings at a frequency of 50/60 Hz; power becomes 'dirty' or polluted when it develops scattered higher-frequency signals as a result of contact with equipment such as computers, plasma televisions and some appliances. NIR generated by dirty power may radiate to contaminate the adjacent environment and is alleged to be

Non–Ionizing Radiation						Ionizing Radiation	
Extremely Low Frequency	Radio frequency	Microwave	Infra-red	Visible Light	Ultraviolet	X-Rays	Gamma Rays
Non Perceptible				Perceptible	Non Perceptible		
Possible Biological Damage at Some Frequencies					Destructive to Living Tissue		

Figure 1 Electromagnetic spectrum—types of radiation.

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potentially harmful.[3] Ground current, sometimes referred to as 'stray current,' is electricity that is not confined to electrical wiring. Electrical current follows the path of least resistance and can flow through any and all available paths including earth, wires and various objects. Accordingly, electrical voltage can transmit through the ground and into building structures through such devices as metal pipes or rods in plumbing equipment, resulting in a-NIR scattering into the adjacent environment.[4–6] All forms of a-NIR, however, only inflict harm within their fields of influence.

A field is 'something' that exists in space around an object or device; the area over which the object exerts some form of physical influence. The inherent properties of the object or device produce the surrounding field. A magnet, for example, creates an invisible field that can attract or repel other objects within a certain distance. When power is generated, transmitted or used, electrical materials and devices produce fields around them called 'electric fields' and the combination of certain elements in various devices results in the production of both an electric and a magnetic component, called an 'electromagnetic field' (EMF). Another way of expressing this phenomenon is to consider that waves or rays of energy are released outward from some electrical materials, radio emitters and power devices, but the intensity of the field of exposure rapidly drops off with increasing distance from the source. Shielding against some energy frequencies, such as blocking X-rays with lead plates, is efficacious; it is difficult, however, to effectively shield against some energy wavelengths including ELF EMFs.

Nearly everyone in our society is exposed to some degree of EMF pollution, yet few are cognizant of the debate about health risks associated with a-NIR. As subatomic matter in human cells entails the movement of electrons, and various biological activities including brain function and cardiac conduction involve measurable electrical activity, it is not surprising that intense electrical fields can exert influence on the human electrical system. Although this evolving area of science provokes many unanswered questions, considerable research suggests that exposure to certain frequencies of EMR may affect physiological processes, with potential long-term sequelae.[7,8]

EMFs and human health

While medical studies correlating EMF with adverse health outcomes have sometimes yielded apparently contradictory results, recent research reported in respected medical journals has uncovered evidence about potential risk. Studies looking at reproductive dysfunction, cancer potential and CNS disorders appear to support previous suspicions that EMF exposure may present a health risk.

EMFs and reproductive dysfunction

Adverse pregnancy outcomes including miscarriage, stillbirth, preterm delivery, altered gender ratio and congenital anomalies have all been linked to maternal EMF exposure.[9–13] A large prospective study published in *Epidemiology*, for example, reported on peak EMF exposure in 1063 pregnant women around the San Francisco area. After participants wore a magnetic field detector, the researchers found that rates of pregnancy loss grew significantly with increasing levels of maximum magnetic field exposure in routine day-to-day life.[12]

Paternal EMF exposure has also been correlated with serious potential sequelae. The development of testicular abnormalities, atypical sperm, chromosomal aberrations and offspring congenital defects have all been linked to male EMF exposure.[14–18] Switchyard workers exposed to electrical current, for example, were compared with salesmen and clerks for evidence of chromosomal anomalies. With a significant increase in the number of chromosomal aberrations in switchyard workers,[18] and an increased tendency towards malformations among their children,[15] researchers have surmised that EMF exposure may be a factor in adverse outcome. Fathers employed in industries with higher than average EMF exposure have also been noted to have offspring with higher rates of brain and spinal cord tumours.[16,17]

EMFs and cancer

Numerous studies have investigated the allegation that intense exposure to some frequencies of EMR may be carcinogenic. For example, *International Journal of Cancer* recently published an important population-based case–control study on the link between childhood leukaemia and magnetic fields in Japan. By assessing magnetic field levels in children's bedrooms, the researchers confirmed that high EMF exposure was associated with a significantly higher risk of childhood leukaemia.[19] Furthermore, recent studies reported in major journals such as *The Lancet and International Journal of Oncology* discuss the apparent link between cordless and cellular phone use with conditions such as lymphoma,[20] malignant and

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benign brain tumours,[21–23] as well as other problems including alterations in blood pressure.[24]

An important case–control study reported in the *British Medical Journal* found a link between childhood leukaemia and prenatal proximity to high-voltage power lines.[25] Compared with children whose birth address exceeded 600 m from a high-voltage power line, those with birth addresses within 200 m had a relative risk of leukaemia of 1.69, and those between 200 and 600 m had a relative risk of 1.23.[25] In addition, extensive research by Johansson and others in Sweden recently confirmed that adverse EMR has the potential to induce various dermatological abnormalities[26] and is a determinant in the development of malignant melanoma,[27,28] an increasingly prevalent cancer that was uncommon until about 50 years ago. As a result of considerable EMF research undertaken in Sweden, it is interesting to note that Swedish authorities have officially acknowledged adverse EMR as a problem and have categorized electrohypersensitivity as a functional impairment.[26]

Although several reports suggest a possible link between certain types of EMF exposure and assorted malignancies,[29–37] including breast cancer[38–41] and childhood cancer,[42–45] some studies have reported differing results. A recent study published in *Cancer Causes Control*, for example, dismissed suspicions of an association between EMF exposure and female breast cancer,[46] and the UK Childhood Cancer Study published in 1999 failed to support a link between EMF exposure and childhood cancer.[47] After reviewing the available information in relation to cancer, however, the International Agency for Research on Cancer (IARC) has advised that EMF exposure should be classified as a possible carcinogen.[2]

EMFs and CNS dysfunction

The CNS appears to be a potential target organ system for adverse EMR. In addition to reports of specific EMF-related health problems, such as amyotrophic lateral sclerosis,[48] Alzheimer's disease,[49] insomnia,[50] headaches,[51] sexual dysfunction,[52] chronic fatigue,[50] learning and memory problems,[53–55] and assorted other maladies,[33,56] there is increasing evidence to suggest that neuropsychiatric problems may also result from EMR. Higher rates of depressive symptoms and suicide have been found to result from EMF exposure.[48,57–59]

In a recent epidemiological study, for example, researchers found that those living near power lines were more than twice as likely to report symptoms of depression compared with controls.[58] Preliminary evidence has also suggested a potential correlation between exposure to EMFs from dirty electricity with common medical conditions including attention-deficit disorder/attention-deficit hyperactivity disorder, asthma, diabetes and multiple sclerosis.[3,60] In review, many independent research projects have uncovered a link between adverse EMF exposure and a variety of afflictions in various organ systems, particularly the CNS.

Proposed mechanisms of EMF impact

Basic scientific study of the human body has demonstrated that most physiological functions in living organisms are electrochemical in nature. Living cells are made up of molecules and atoms, which in turn are made up of electrons, neutrons and protons. The intrinsic functioning of these atoms and molecules with homeostasis of cells, tissues and organs is entirely dependent on ordered chemical and electrical activity. Disturbance of intrinsic electrical or chemical processes within cell structures has the potential to disrupt cell functioning, leading to malfunction of organ systems and ultimately to clinical illness.

Extensive research has attempted to elucidate definitively the precise mechanisms whereby EMF exposure may disrupt normal physiology. For example, a wide-ranging research project entitled EMFRAPID (Electric and magnetic fields research and public information dissemination) was a 5-year US Federally organized effort co-ordinated by the National Institutes of Health to assess the effects of adverse EMR on biological systems.[61] The results of this and many other initiatives have revealed significant information.

Biological systems including the human organism intrinsically use some frequencies of EMR for cellular as well as hormonal function and regulation.[62] For example, imperceptible ultraviolet energy waves from sunlight are used in the production of human vitamin D,[63] an essential nutrient involved in myriad physiological functions. Just as external electrical signals can cause interference with radio and television signals resulting in static and distortion, exposure to adverse electrical frequencies can disrupt human metabolism and homeostasis by interfering with normal physiology of required energy frequencies.[62]

Cellular pathogenesis of adverse EMR

Although the cellular pathogenesis of damage from EMR is not completely understood, various

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hypotheses have been proposed based on preliminary evidence. It was previously thought that thermal alteration of cells and tissue heating may be the predominant mechanism of harm. More recently, however, increasing evidence has indicated the potential of EMR to induce cell stress[64] and to inflict specific damage on various intracellular components and mechanisms at non-thermal levels of EMF exposure.[62] For example, molecular vibrations from EMR may induce free radical formation and alter the conformation of protein molecules.[65] Adverse EMR has been found to affect DNA synthesis, to impair cell division and to potentially alter the electrical charge of ions and molecules within cells.[14,62] By affecting electrical charge, EMFs may also modify ionic structures of elements within cell membranes, potentially disturbing the influx and efflux of various elements including calcium ions.[66]

Just as certain chemical toxicants may induce expression of abnormal genes,[67] recent research is exploring potential epigenetic influences of EMR. By its impact on genetic expression,[68] adverse EMFs may serve as a trigger for the expression of pathological and disease-causing genes. Furthermore, direct damage to the DNA of human lymphocytes[69] and alteration of phagocytic activity in animal macrophages[70] has been confirmed recently, and may account for changes in immunological parameters and for immune system dysfunction attributed to EMR. With alteration of cell structures and impairment of cellular functions by these various mechanisms, it is not surprising that tissue disorders, organ dysfunction and clinical illness may ensue. Attenuation of insulin secretion characteristically found in diabetes, for example, can be induced or accentuated by exposure to adverse EMF through distortion of calcium influx in cells.[71]

EMFs and melatonin metabolism

Some investigators have explored potential EMF disturbance of blood–brain barrier permeability with resulting increased susceptibility to CNS toxicants.[56] Particular attention, however, has recently been devoted to researching the impact of EMR on pineal gland physiology.[72] The pineal gland secretes the neuroendocrine hormone melatonin that is synthesized from the neurotransmitter serotonin. Melatonin is involved with regulation of myriad physiological processes including sleep patterns,[73] free radical metabolism,[74] blood pressure control,[75] nitric oxide physiology,[76] lipid metabolism,[62] immune system functioning,[77] and activity of sex hormones such as oestrogen.[78] The potential link between disordered melatonin physiology and the development of malignancy has emerged as a priority area of investigation,[79] particularly in breast and prostate cancer, melanoma, colon cancer, lung cancer and leukaemia.[72]

Adverse EMF exposure has the potential to impact directly on pineal gland function by interfering with melatonin production and metabolism.[80,81] As well as in cancer, reduced melatonin levels have been observed in assorted non-malignant conditions including coronary artery disease,[82] chronic pain[83] and various psychiatric conditions including Alzheimer's disease[84] and schizophrenia.[85] Although EMR exposure reduces melatonin production,[62,80,86] conclusive evidence of the direct clinical sequelae of specific EMR-related pineal dysfunction remains to be established.

Limitations and research challenges

Although preliminary evidence on disease pathogenesis such as melatonin dysregulation, epigenetic modification, DNA disruption and cell stress is important for continuing study, research designed to establish a definitive link between EMR and clinical health sequelae faces several obstacles. Within the scientific community, experimental studies such as randomized controlled trials where subjects are manipulated according to study protocol remain the gold standard to establish disease cause-and-effect, as well as efficacy of interventions. Such experimental study, however, is contraindicated in exposure research.

Limitations of exposure research

Just as it would be ludicrous to perform clinical trials on parachute efficacy by dividing skydivers into randomized groups with some using parachutes and some not,[87] it is not ethically possible to perform efficient randomized controlled trials with environmental issues by exposing some study participants to potentially dangerous exposures and comparing outcomes with an unexposed control group. As a result, more cumbersome and lengthy observational studies including epidemiological cohort studies and less definitive case-control research are employed to explore aetiology of harm. This presents difficulties, however, as epidemiological and case–control assessments of environmental exposure are sometimes plagued by confounders such as unfolding awareness of previously unrecognized exposures as well as multi-exposure interactions. For example, in complete contradiction to some other reports, a recent study

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funded by the telecommunications industry on cellular phone use in Denmark concluded there is no link with the development of brain tumours.[88] The comparison general population cohort in this study, however, included widespread users of cordless phones which have recently been implicated with potential EMF risk;[20–23] a determinant that was not fully realized at the outset of the epidemiological study and a confounder which potentially negates the reported outcomes. Numerous concerns relating to methodology and bias have also plagued this Danish study.[89]

Multiple concomitant exposures are another major confounder in some environmental research. Synergism and interaction of multiple exposures from various chemical, electrical or infectious sources may confound research outcomes. For example, some clinicians have observed that compromised patients with accumulated chemical toxicants may be more susceptible to EMR influence because of toxicant-induced loss of tolerance or 'spreading';[90] a phenomenon where individuals affected by one type of adverse environmental exposure become more sensitive to other exposures.[91,92] Other difficulties plague observational exposure research. With long lags between exposure and illness, for example, studies that have short follow-up periods do not provide opportunity for illness to manifest and conclusions may be erroneous. In addition, unique individual host sensitivity to exposure based on distinctive health status and genomic make-up presents a challenge when interpreting quantitative data. The result is that EMR studies have a high probability of significantly underestimating the risks of adverse health effects.[93]

In review, epidemiological study of adverse exposures does not generally establish indisputable evidence for or against a cause-and-effect hypothesis. In observational environmental research, a weight of evidence linking health sequelae to an exposure is produced and increased risks must be interpreted in context. Credible interpretation of findings is established when unbiased and qualified scientists examine the evidence with an open mind. A conclusion is then calculated based on the fundamental question: 'Is there another way of explaining the findings; is there another answer more likely than cause-and-effect?' When a conclusion is reached, the impact on public health is considered and protection strategies are amended as necessary. This imprecise approach, however, routinely renders the science of human exposure assessment and environmental medicine vulnerable to criticism and controversy; a vulnerability that has consistently been exploited by interest groups.

Exposure research and vested interests

With incomplete understanding of pathogenetic mechanisms and intransigent disbelief by some vocal researchers, many scientists have been quick to dismiss any alleged health hazard related to EMF exposure. Medical history has confirmed, however, that controversy is customary when environmental issues involve sizeable economic and health implications. Havas, a pioneer in EMR research, noted that despite considerable evidence, 'asbestos, lead, acid rain, tobacco smoke, DDT, and PCBs were all contentious issues and were debated for decades in scientific publications and in the popular press before their health effects and the mechanisms responsible were understood'.[14] As with previous examples, there are strong political and economic reasons for wanting no adverse sequelae to EMF exposure.[94] Vested interests have been effective in delaying restrictive EMF legislation by injecting confusion and doubt into scientific debate, by focusing on uncertainties, and by deflecting attention from harm potential.[95,96]

Numerous examples have been discussed in the scientific literature where claims of environmental harm have been challenged by researchers who fail to disclose covert ties to industry.[96] The influence of economic interests on medical journals has also been discussed extensively in recent publications,[97,98] along with examples where some editors and journal staff have suppressed publication of scientific results that are adverse to the interests of industry.[96,99] In the area of adverse EMF exposure and cellular phones, for example, it has been suggested that independent study results have differed considerably from industry-funded study.[89] After reviewing the research on EMR extensively, the International Commission for Electromagnetic Safety concluded in 2006 that present sources of funding for EMF study are biasing the 'analysis and interpretation of research towards rejection of evidence of possible public health links'.[100] How does society at large respond to mixed messages and uncertainty from the scientific community?

With enormous potential to generate misinformation, publication of imprecise science has influenced academic and social thought profoundly.[96] In response to conflicting scientific allegations, legislators and the general public commonly feel uncomfortable and are unable to determine the legitimacy of scientific debate.[14] When doubt and confusion are introduced, the public are often quick to disregard data that appear disturbing or unwelcome. The typical outcome in the short term is 'paralysis by analysis'; by introduction of contrary information and

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recommendations for further study, restrictive legislation is effectively stalled for years or even decades. If the environmental exposure in question is eventually proven to be hazardous, as has often been the case historically, individual and public health is compromised in the interim.

Quo vadis

The study of environmental medicine and the relationship between human exposures and adverse health outcomes has not yet been incorporated into most medical education programmes.[101] At the same time, however, escalating news reports of concerns such as reproductive dysfunction in teachers working near power lines and neurological sequelae in people residing in close proximity to mobile phone masts have evoked public awareness of electromagnetic contamination as an emerging environmental health issue; as a result, primary care physicians are increasingly questioned about EMF-related health risks.[102] Accordingly, it behoves the medical community to consider a credible response to this up-and-coming issue.

Most would agree that the home, school, workplace and community need to be free from dangerous exposures, and that individuals need to be aware of the risk/benefit ratio of EMF exposures. Several recommendations have been suggested by environmental health groups and scientific organizations studying the EMF concern. It is the generally held scientific view that incomplete EMF knowledge beckons ongoing unbiased research, not dismissal of the issue.[103] The World Health Organization has recommended intensive research,[65] and various scientists have called for an international scientific commission to monitor this emerging hazard.[100] Further recommendations and ideas are presented for consideration.

Public health recommendations

- To ascertain effective public health policy, scientific integrity and reliability among researchers, medical publications, official guidelines and academic institutions must be established to ensure credible research and dissemination of results.[96,104]
- Easily accessible measurement methodologies for adverse EMR are required. As well as gauss meters to detect ELF/radiofrequency radiation, for example, microsurge meters purported to detect 'dirty' electricity have been introduced.[60] New technologies need to be evaluated expeditiously and incorporated if credible.
- Adverse biological impact has been described for exposure levels much below current EMR standards. Allowable levels should be amended to provide sound protection of public health.[62]
- Ongoing epidemiological research and monitoring of health effects on EMR-exposed populations should be undertaken and reported. An independent commission devoid of conflicts of interest should oversee such work.
- Regulations to minimize exposure to adverse EMR should be enforced by governments and power authorities.
- Potentially harmful radiofrequencies from telecommunications technology should be assessed and regulated by authorities. For example, in response to complaints from citizens in Brussels about sleep disruptions following the installation of mobile phone masts near their homes, Belgian authorities recently approved a bill to regulate such masts to minimize EMR exposure.[105]
- Emerging protective equipment should be assessed independently and implemented if useful. Graham–Stetzer filters, for example, allegedly diminish dirty electricity and potentially result in health benefits when installed properly.[3,60] Such reports should be scrutinized scientifically and results disseminated.
- While research is ongoing, a precautionary avoidance strategy should be considered.[100,106] Incorporation of protective air-tube headsets for cellular phone use, for example, and wireless-free zones in public buildings such as patient areas in hospitals and schools[100] might be favourable.
- Training of health professionals and public health officers about the EMF-health issue is an important step in addressing this challenge.
- Clinicians should consider implementation of precautionary avoidance with individual patients.[106] Chronically ill people exposed to EMR might benefit from avoidance of high EMF smog. Four cases employing a precautionary approach are presented for consideration.

Case reports involving EMF exposure

In each of the following cases, improvement was realized when EMF exposure was diminished. As with most environmental exposure case reports, however, it is impossible to prove conclusively that neither the source of affliction nor the benefit realized were related exclusively to environmental exposure and subsequent intervention.

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Without re-exposing patients and monitoring sequelae, improved outcomes may be suggestive but absolute proof of causation and benefit are unattainable.

Case history #1

A 66-year-old woman in generally good health complained of a 9-year history of debilitating daily headaches and intermittent dizziness. Neurological assessment was unremarkable and a computer tomography scan, magnetic resonance imaging and electroencephalogram were reported normal. At a chronic pain clinic, the patient received narcotic analgesics and a diagnosis of 'primary pain disorder'. Detailed aetiological history was unremarkable other than the patient used an electric toothbrush six times a day for meticulous care of failing dentition. Gauss meter assessment revealed inordinately high levels of EMFs (>200 mGauss) emanating from the toothbrush. Within 6 weeks of discontinuing the use of an electric toothbrush, the headaches subsided and, with assistance, she was able to quickly overcome her dependence on prescription analgesics.

Case history #2

A 33-year-old woman wishing to have a large family complained of six consecutive pregnancy losses. After two uncomplicated pregnancies with vaginal deliveries, the patient changed residence and subsequently experienced three first-trimester miscarriages. After assessments by a family physician, a gynaecologist, an infertility specialist and a specialty reproductive care unit, the patient subsequently sustained three second-trimester losses despite interventions including clomiphene, human chorionic gonadotrophin injections, progesterone supplementation and counselling. From history, no potential determinants appeared to have changed from the two completed gestations other than her employment as a seamstress for 6 h/day in the basement of her new residence; an environment with low ceilings and fluorescent lights. Using a gauss meter, the patient recorded high EMF levels (>140 mGauss) in the vicinity of her head when fluorescent lighting in her workspace was turned on and high EMF levels (~180 mGauss) adjacent to her sewing machine. Following advice to minimize EMR exposure by avoiding fluorescent lights and minimizing use of her sewing machine, the patient promptly conceived and carried the pregnancy to full term.

Case history #3

A 17-year-old boy experiencing a 3-year history of intrusive thoughts relating to religious themes believed he had committed unpardonable sins and was convinced the devil was imminently taking him to hell. As well as increasing depressive symptoms, the adolescent displayed escalating aggression towards his parents. The nominally religious parents took their son for religious counsel to no avail. Psychiatric diagnosis included a thought disorder. Psychotropic medication failed to control the symptoms but caused numerous side effects. Human exposure assessment uncovered extremely high gauss measurements (>200 mGauss) at the head of the teen's bed, as electrical entry to the house was immediately adjacent to the bedroom, right beside his bed. As well as changing rooms, all other sources of EMF exposure were minimized. Within 12 weeks, the intrusive thoughts abated considerably, the mood symptomatology declined, the medication was stopped, and the parents indicated that their son was now a friendly, motivated boy. One episode of symptom aggravation subsequently occurred immediately following 4 h of online work in a high school computer laboratory; symptoms subsided within 72 h of deliberate EMF avoidance. All adverse symptoms completely cleared within 6 months and wellness was maintained over the next 2 years and at the time of writing.

Case history #4

A 51-year-old man in generally good health complained of chronic difficulty with insomnia. Although he experienced no problem falling asleep, for the last 17 years he had routinely awoken at about 2:30 a.m after 4 h of slumber and was consistently unable to return to sleep. As a result of sleep deprivation, he experienced constant fatigue, often falling asleep at various intervals during the day. While on holiday in their mobile home, however, the patient enjoyed improved sleep, causing his physician to attribute the insomnia to job stress. Numerous therapies had been unsuccessful including counselling, relaxation techniques, benzodiazepine medication, acupuncture and various nutritional supplements. Microsurge meter assessment in the patient's bedroom revealed power surges reaching 1600 GS units (safe levels reported as <30 GS units). Filtration of dirty electricity reduced levels to under 30 GS units, and the patient noticed a dramatic and consistent improvement in sleep patterns within 1 week.

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Concluding thoughts

Despite differing perspectives on the severity of impact, there is compelling research to suggest that EMR has the potential to have an adverse effect on cells and tissues. Commenting on research by himself and co-workers,[107] Trosko recently summed up the prevailing sentiment: 'until now, the weight of the theoretical and experimental evidence has suggested that [low-frequency EMFs] did not have the ability to interact with genetic material to damage it', but recent studies show that '...there is a biological effect of the energy imparted by extremely-low-frequency EMF on living systems'. Definitive conclusions on the extent of resultant harm, however, remain difficult to establish comprehensively as controlled trials with exposure of cohorts to potentially toxic influences are unethical. Furthermore, the allegation that industry-funded studies tend to produce industry-desired outcomes further complicates the ability to establish veracity on this issue.

It is thus difficult to winnow fact from fiction among the many claims relating to the impact of EMR on people as well as on the environment. While some authors have discussed adverse effects of EMR on plants and trees,[8,108] and much research suggests health disorders and behavioural abnormalities in animals exposed to adverse EMFs,[109–111] the intensity of impact on human health remains the subject of much debate. With a multiplicity of views and potentially competing priorities including comfort, convenience, financial interest, health and technological necessity, a consensus on the risk/benefit ratio of EMF exposure may be challenging to achieve in the near future. However, with a great percentage of people in the early 21st Century bathing in EMF smog resulting from living, working and playing in close proximity to electrical appliances, wireless networks, cellular phone masts, power lines, TV and radio towers, fluorescent lighting and dirty power, as well as from ubiquitous use of cordless and cellular phones, automobile seat warmers, electric toothbrushes, electric shavers, hair dryers etc., a response from the medical and public health community is indicated.

The moral and political question arises regarding whether public health policy should be based on 'proof of safety' or 'proof of harm'. In relation to environmental health issues, an 'innocent until guilty' approach has generally been adopted whereby public health initiatives commence only after 'proof of harm' is established conclusively.[112] Medical history has repeatedly demonstrated that despite strong suspicions and preliminary evidence, various toxic agents and devices routinely remain in use for years prior to the availability of definitive evidence of harm; precautionary avoidance is generally not implemented. As a result, schools and residences continue to be erected in immediate proximity to power lines emitting immense EMR, pregnant women continue unawares to be exposed to EMR in various occupations, teens spend inordinate amounts of time attached to cellular phones, and mobile phone masts continue to be placed in communities close to residences, schools, preschools, hospitals and workplaces.

Sickness is often the consequence of an interaction between a causative agent and a susceptible host, and adverse EMR appears to be one such causative agent. With increasing evidence linking significant EMF exposure to adverse health sequelae, and with the increasing intensity of electronic pollution resulting from wireless technology and dirty electricity, it may be prudent to consider erring on the side of caution. Considering the potential long-term danger, physicians and public health officials should alert individual patients and the public to this issue and provide ongoing information on precautions to diminish potential risk associated with EMF exposure.

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Bioelectromagnetics 21:538–553 (2000)

The Possible Role of Contact Current in Cancer Risk Associated With Residential Magnetic Fields

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Residential electrical wiring safety practices in the US result in the possibility of a small voltage (up to a few tenths of a volt) on appliance surfaces with respect to water pipes or other grounded surfaces. This "open circuit voltage" (V_{OC}) will cause "contact current" to flow in a person who touches the appliance and completes an electrical circuit to ground. This paper presents data suggesting that contact current due to V_{OC} is an exposure that may explain the reported associations of residential magnetic fields with childhood leukemia. Our analysis is based on a computer model of a 40 house (single-unit, detached dwelling) neighborhood with electrical service that is representative of US grounding practices. The analysis was motivated by recent research suggesting that the physical location of power lines in the backyard, in contrast to the street, may be relevant to a relationship of power lines with childhood leukemia. In the model, the highest magnetic field levels and V_{OC}s were both associated with backyard lines, and the highest V_{OC}s were also associated with long ground paths in the residence. Across the entire neighborhood, magnetic field exposure was highly correlated with V_{OC} ($r = 0.93$). Dosimetric modeling indicates that, compared to a very high residential level of a uniform horizontal magnetic field (10 μT) or a vertical electric field (100 V/m), a modest level of contact current (~18 μA) leads to considerably greater induced electric fields (> 1 mV/m) averaged across tissue, such as bone marrow and heart. The correlation of V_{OC} with magnetic fields in the model, combined with the dose estimates, lead us to conclude that V_{OC} is a potentially important exposure with respect to childhood leukemia risks associated with residential magnetic fields. These findings, nonetheless, may not apply to residential service used in several European countries or to the Scandinavian studies concerned with populations exposed to magnetic fields from overhead transmission lines. Bioelectromagnetics 21:538–553, 2000.

Key words: magnetic fields; childhood leukemia; power lines; open circuit voltage

INTRODUCTION

Background

The question of whether residential exposure to power frequency (50 and 60 Hz) magnetic fields is a risk factor for childhood leukemia remains unresolved [NIEHS Working Group, 1998; NIEHS, 1999]. Early epidemiological studies conducted in Denver and Los Angeles reported associations between electric utility line wiring configurations and childhood leukemia [Wertheimer and Leeper, 1979; London et al., 1991] or all childhood cancer [Savitz et al., 1988], with a suggestion of increased leukemia risk in the latter. As developed initially by Wertheimer and Leeper [1979, 1982] with subsequent refinements by others [Barnes et al., 1989], the wiring configurations were the basis of a categorical exposure surrogate, referred to as the "wire code". The positive relation between wire code and magnetic field [reviewed in Kheifets et al., 1997], as well as suggestive associations between measured fields and relative risk estimates [Savitz et al., 1988; London et al., 1991], appeared consistent with the hypothesis that the residential magnetic field was the causal agent in these studies.

In a recent re-analysis of the Denver and Los Angeles studies, Ebi et al. [1999] report that in both data sets, risk associated with wire code was concentrated in residences served by backyard distribution lines, as opposed to distribution lines in the street. This observation motivated the analysis presented in this paper, which is concerned with (a) the relationship

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between the physical features of residential electric service and exposures to magnetic fields and currents; (b) the correlation among specific electric and magnetic exposure parameters; and (c) the dosimetric implications of these relationships with respect to childhood leukemia risk. We introduce an exposure called the "open circuit voltage" (V_{OC}), which is a small power frequency voltage (up to a few tenths of a volt) that may appear on electrical equipment. V_{OC} can cause a "contact current" to flow directly into a person in manual contact with the appliance. The findings presented in this paper suggest that contact current due to V_{OC} may be an exposure variable that could hold the key to clarifying the reported associations of power line environments with childhood leukemia. We first review the relevant aspects of residential electrical service.

Residential Electrical Service

The major features of electrical service in US distribution systems are illustrated in Figure 1 and further elaborated in its caption. Electrical service to the residence occurs via the "service drop", which connects the distribution transformer secondary located outside on a utility pole or underground, to the "service panel", where the occupant has access to circuit breakers and/or fuses. The service drop consists of three cables: two 120 volt (V) alternating current (ac) "hot legs", which provide the load currents for lights, appliances, etc., and the neutral, through which current may return to the substation.

For safety purposes, e.g., electric shock and fire prevention, residential electrical wiring in the US provides multiple pathways for current to return to the substation [NESC, 1992]. Under normal conditions, the current returns via both the utility's service drop neutral and an alternative pathway, which in many cases is a conductive residential plumbing line connected to the municipal water main in the street. The connection to the plumbing is established with a "ground wire" bonded electrically to the utility neutral at the service panel and strung at some length to a convenient (exposed) water line. For cases in which conductive water pipes are not available, houses will have driven ground rods to establish a strong alternative ground connection. The amount of current that each pathway takes has an inverse relationship to each pathway's electrical resistance.

The "net load current" is the algebraic sum of the current in the two supply conductors. The "net current" in the utility service drop equals the net load current to the residence minus the current in the service drop neutral. Net current equals the current that flows in the alternative ground pathways, which we refer to as the "ground current" (see Figure 1). Thus, the service drop to ground wire pathway becomes a magnetic field source in the residence. The source strength depends on the current magnitude and the pathway's geometry. In residences located away from overhead utility distribution or transmission lines, Kavet et al. [1999] report that, compared to other predictor variables, the net service drop current (i.e., the ground current) correlates most strongly with magnetic fields measured in the residence. In communities with conductive water service and water mains, a fraction of ground current generated in one residence may flow to another residence's ground.

Since the ground wire has a resistance, though small, the current flowing in it produces a voltage difference between the service neutral and the plumbing connection. This voltage equals the ground wire current multiplied by the wire's resistance (assuming no additional resistance due to poor bonding at the wire's termini). To prevent shock, electrical appliances have their metallic chassis connected, either through their neutral wire or their third wire, to the utility neutral bonding point in the service panel (Figure 1). Through this connection, the chassis carries the voltage generated in the ground wire, which we refer to as the "open circuit voltage" or V_{OC}. As indicated by the open switch in Load 3 in Figure 1, V_{OC} is present on an appliance even when in the "off" position, so long as it is plugged in.

V_{OC} can serve as a source of contact current into a person who touches the chassis, and, through either the other hand or the feet, completes an electrical circuit back to the house's ground. This circuit is shown schematically in Figure 2. The resistance of the ground wire, R_{GW}, is usually very small (around 0.1 ohm (Ω) for a 30 m length) compared to the resistance in the rest of the contact current pathway, which consists of R_P, the resistance of the individual, in series with R_G, the resistance from the feet back to ground. R_P is on the order of several thousand ohms [Reilly, 1998], but varies depending on skin moisture and other factors; R_G depends on footware, floor material, and housing materials. Thus, since $R_{GW} \ll R_P+R_G$, contact current is essentially equal to V_{OC} divided by the sum of R_P and R_G. If the other hand comes in contact with a water fixture, which is usually at house ground potential, then the contact current would likely take the hand-to-hand route as the path of lower resistance.

Organizations concerned with EMF exposure guidelines [e.g., International Commission on Non-Ionizing Radiation Protection (ICNIRP)] and appliance safety [e.g., Underwriters Laboratories (UL)] have published limits for contact or "leakage"

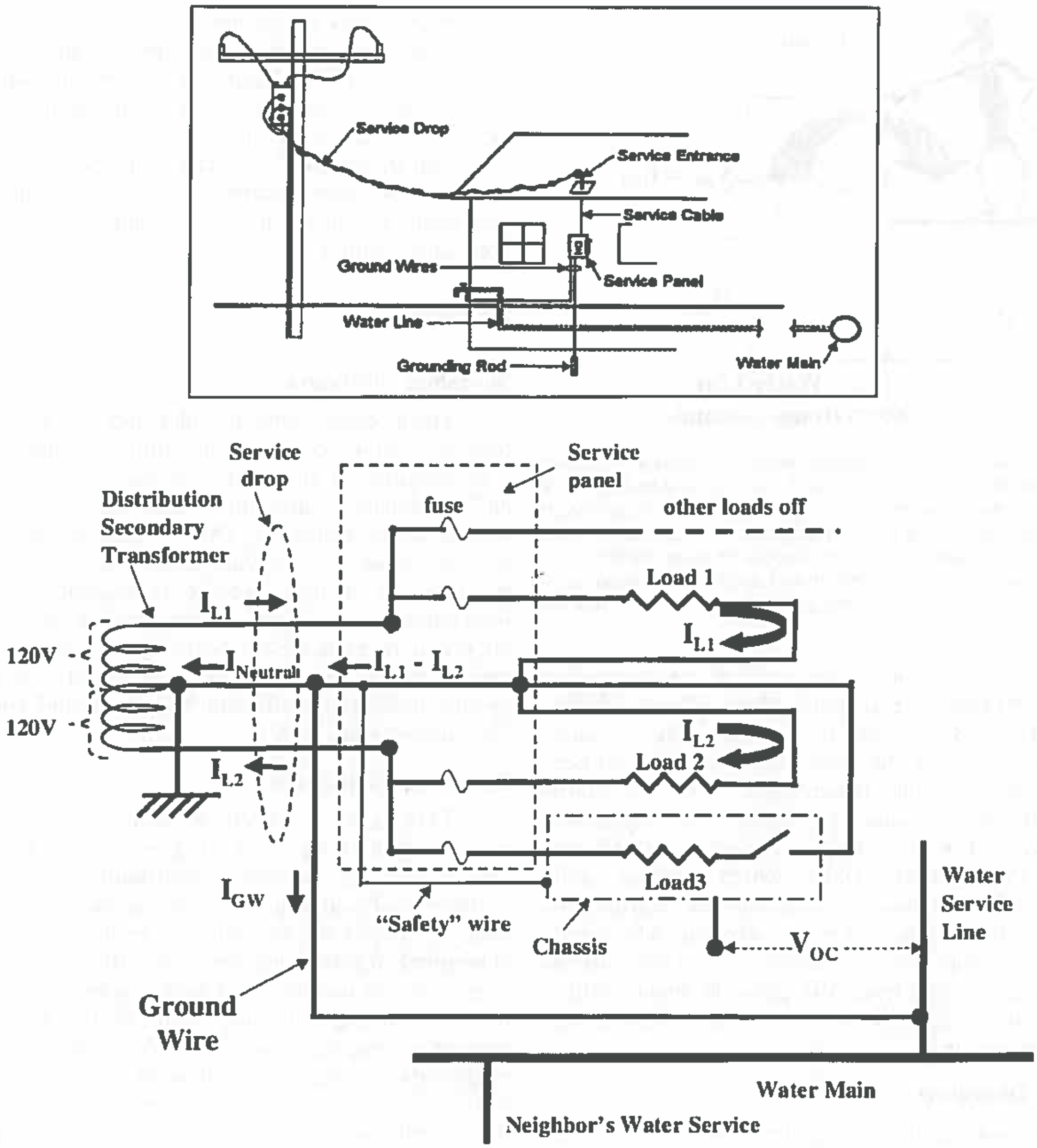

Fig. 1. Residential Electric ServiceTypical of "Multi-grounded Neutral" Systems used in the US and Origin of Open Circuit Voltage (V_{OC}). Top inset is a "real world" view of electrical service to a single-unit residence. Bottom graphic is a schematic of the electrical relationships in the service and internal wiring. Two 120-V conductors (hot legs) from the distribution secondary transformer, 180 degrees out of phase with each other, supply currents I_1 and I_2 to Load 1 and Load 2, respectively. The center tap of the transformer is grounded at the street pole or underground transformer location. The "net load current" on the service drop is the amount of current returning to the substation at any point in time and, in the figure, equals $I_{L1} - I_{L2}$. Current returns via two basic pathways: (a) the service drop neutral cable or (b) an alternate ground path, which in the figure consists of a ground wire connected to a conductive water line. The net load current equals the sum of the currents in these two pathways, $I_{Neutral} + I_{GW}$. The "net current" in the service drop equals net load current minus the current in the neutral, or $I_{Net} = (I_{L1} - I_{L2}) - I_{Neutral}$. The current in the ground wire, I_{GW}, equals I_{Net}. I_{GW} and I_{Net} are sources of magnetic field in the residence. Because the ground wire has a finite resistance, R_{GW} (not pictured), a voltage is developed across its length equal to $I_{GW} \times R_{GW}$, which we refer to as the open circuit voltage (V_{OC}). Load 3, plugged in but in the off position (open switch), has a safety wire that connects the load's chassis to the service panel neutral. The chassis is, thus, at a voltage V_{OC} with respect to the grounded water system. In this model, V_{OC} represents the largest voltage potentially present prior to contact between a person and an appliance chassis or between a person and metallic structures (e.g., hot water heaters, steam radiators) connected to residential water pipes. Ground currents may be shared among residences.

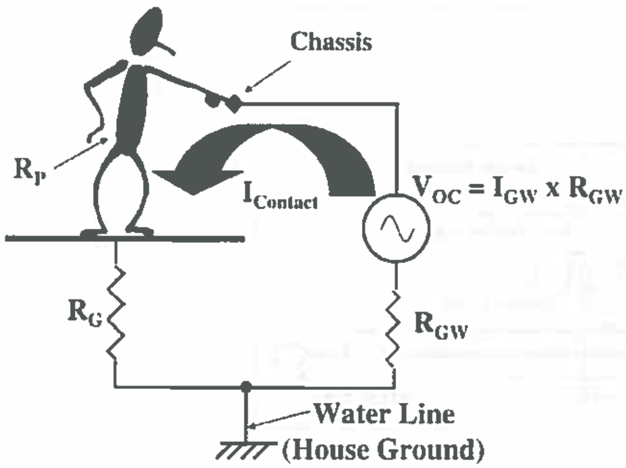

Fig. 2. Contact Current. A person contacting a chassis is exposed to V_{OC}, which can drive current into that person, depending on the nature of his/her connection to the chassis and to the ground. Moist extremities decrease a person's electrical skin resistance, while insulating footwear or poorly conductive housing materials will sharply limit current. The figure shows hand-to-feet contact, but if the second hand is in touch with a grounded object, the current will take a hand-to-hand route.

currents. These limits are designed to avert hazardous startle and adverse perceptual effects. Below 2.5 kHz, ICNIRP [1998] specifies 0.5 mA and 1.0 mA contact current limits for the general public and workers, respectively. UL lists 0.5 mA and 0.75 mA as startle limits for portable and fixed appliances, respectively [reviewed in Reilly, 1998]. The National Electric Safety Code [NESC, 1992], which specifies safety practices for overhead transmission line construction and operation, limits to 5 mA steady-state whole body current that may result from electric field induction on large objects (e.g., trucks) in physical contact with a person in the right-of-way of overhead high-voltage transmission lines.

Study Overview

We constructed a computer model of a 40 house neighborhood to address how specific physical features of residential electrical service affect magnetic field and V_{OC} exposures within the residence. The software running the model has been previously validated against measurements taken in a test residence under various grounding conditions [Zaffanella et al., 1997]. The features we examined are line location—backyard or street, relative length of the ground return pathway—short or long, and service line type—overhead or underground. The quantities modeled include the 60 Hz and 180 Hz magnetic fields at the center of each room, the time-weighted-average fields experienced by a child as a result of a day's occupancy of the residence, and the V_{OC}. The neighborhood wiring follows practices applicable to the US, although we recognize that such practices vary among countries [Rauch et al., 1992]. Despite the stochastic nature of the residential loading imposed on the neighborhood, the model itself is completely deterministic, and the statistical treatment of the data is intended to clarify relationships among exposure and source variables, rather than to achieve inferential support as occurs in population studies.

METHODS

Modeling Software

The modeling software calculates magnetic fields resulting from currents on arbitrary arrays and configurations of electric transmission lines, primary and secondary distribution lines, and ground and neutral return pathways. The program conducts network analyses of ground/neutral currents in neighborhoods based on user-specified residential loads and impedances. Local dipole sources, such as appliances, are not included in the field calculation. As mentioned above, the program has been previously validated against measured fields and known ground currents [Zaffanella et al., 1997].

Modeling Objective

This paper is concerned exclusively with magnetic fields and V_{OC}s resulting from currents in the service drop (i.e., secondary distribution current) and in the ground path (Figure 1). Wertheimer-Leeper wire code categories do not play a role in the model as configured for the analyses here. In fact, for the neighborhood loading used here, primary loads and their return currents had a negligible effect on residential magnetic fields and V_{OC}. However, the neighborhood was provided with a full range of distribution wiring configurations representative of the Wertheimer-Leeper wire code, should further development of the neighborhood (e.g., downstream connections to other load centers) be warranted. The appendices contain a detailed description of the neighborhood's electrical infrastructure.

Neighborhood Description

Briefly, the study neighborhood (Figure 3) consists of four streets containing 40 two-story houses, each 10.7 m by 7.6 m (35 × 25 ft) with the long dimension parallel to the street. Each house has eight equal-size rooms, four per floor. For each house, the service drop arrives at a corner and then goes to the electrical panel. All houses have copper-pipe water service that provides a conductive ground path to the

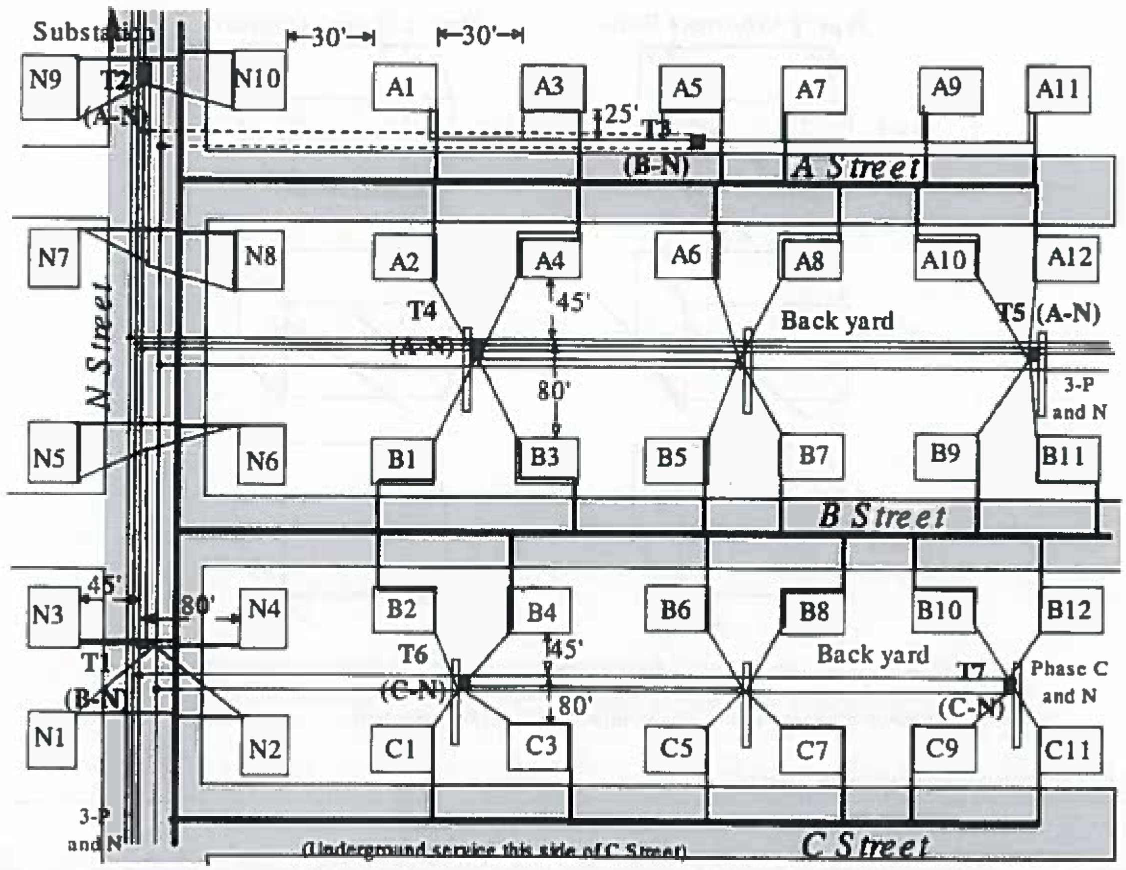

Fig. 3. Model neighborhood (see text and Appendix).

water main. All water mains were located in the middle of the street.

With the exception noted below, all combinations of the following attributes were represented: line location—backyard or street; relative length of the ground return pathway—short or long; and service line type—overhead or underground. Underground lines were not situated in the backyard, as this is a less common feature of residential electric distribution systems. Figure 4 illustrates the "length of ground path" dichotomous variable: Type 1 is the shorter possible path for overhead street lines, overhead backyard lines, and underground street lines (top to bottom in Figure 4); Type 2 is the longer possible path for overhead street lines, overhead backyard lines, and underground street lines (top to bottom in Figure 4).

Loading

As discussed above and shown in Figure 1, the net load is the parameter that defines the electrical load of the house with regard to ground current. The "1,000-home study" [Zaffanella, 1993] developed a database of electrical parameters, including the 24 h statistical distribution of the net load for each house. These data suggested using a net load for each house randomly extracted from a log-normal distribution with a median value of 4.34 ampere (A) and a geometric standard deviation of 1.87. The model was run 100 times, each time with a net load randomly allocated to each house. To account for possible ground current interactions between residences, the sign of the net load was also randomly chosen. The load currents were all at the power frequency of 60 Hz with a 15% third harmonic. The value chosen for the third harmonics corresponded to the average value recorded during the 1000 home survey [Zaffanella, 1993].

RESULTS

General Statistical Description of Sample

The parameters selected for study are listed in Table 1, and their descriptive statistics across the entire neighborhood are shown in Table 2. The variables displayed continuous, smooth distributions, although

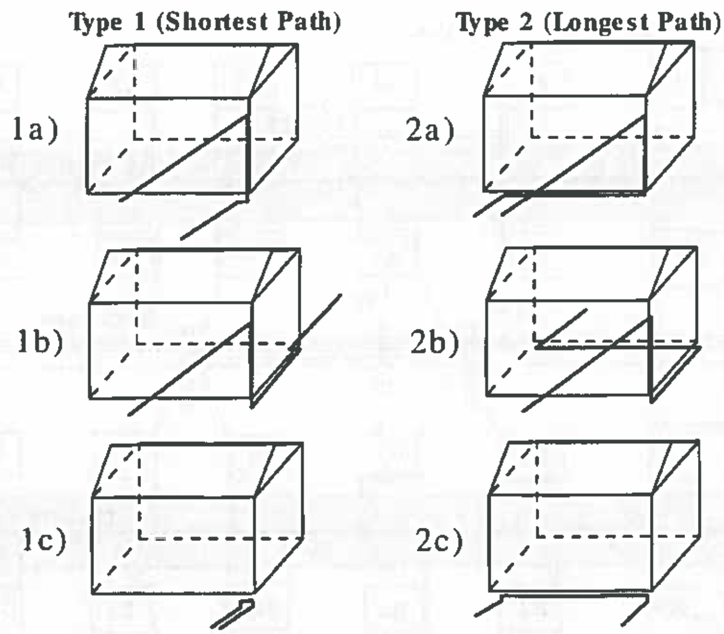

Fig. 4. Net and ground current paths: 1a) Overhead street line, short path; 1b) Overhead backyard line, short path; 1c) Underground street line, short path; 2a) Overhead street line, long path; 2b) Overhead backyard line, long path; 2c) Underground street line, long path.

TABLE 1. Parameters Reported on in Results[a]

Parameter	Description
AvgRoomB	Temporal average of the 60 Hz magnetic field in the center of each room 1 m above the floor averaged across all eight rooms
Avg180HzB	Temporal average of the 180 Hz magnetic field in the center of each room 1 m above the floor averaged across all eight rooms. Typical values of harmonic loads are assumed [Zaffanella, 1993]
AvgPerimB	Temporal average of the magnetic field sampled every 5 m around the house periphery, 1 m from the house, and 1 m off ground
AvgChildB	Temporal average of the field across the entire indoor space, from floor to four feet above the floor. The field is calculated at all points of a three-dimensional grid with one foot (0.305 m) grid size. For each floor of a 10.7 m by 7.6 m (35 × 25 ft) house, there are 4680 calculation points in the "child" space
10%ChildB	The upper 10th percentile value of child's exposure within a house
AvgGC	The temporal average of the current in the residential ground path; same as average net current in the service drop
10%GC	The upper 10th percentile value of GC within a house
AvgV_{OC}	Temporal average of the open-circuit voltage between appliance chassis and the water line at the point where it is connected to the conductor that grounds the electric service neutral
10%V_{OC}	The upper 10th percentile value of V_{OC} within a house

[a]Within each residence parameters are calculated for each of 100 loads randomly assigned. Thus, for example, AvgGC for a residence is the ground current averaged over 100 values; 10%GC for a residence is the value exceeded for 10% of the calculations.

most were not normally distributed according to the Shapiro-Wilk test.

Stratification of Sample

By design (see Methods), only the currents in the service secondaries, service neutral, and ground pathways influenced the electrical quantities computed for each residence. Thus, all one-, two-, and three-phase primary lines were collapsed into one "overhead" (OH) category, with the remainder classified as "underground" (UG). The basic geometric differences between OH and UG are evident in Figure 4.

Table 3 shows summary statistics for several key exposure variables, stratified by engineering factors. Visual inspection suggests that the highest field exposure quantities were associated with backyard, overhead lines, the highest ground currents were associated with overhead lines, and the highest V_{OC}s were associated with overhead, backyard lines with long ground paths.

TABLE 2. Descriptive Statistics for Selected Exposure Variables for the Entire Neighborhood Sample ($N = 40$ Houses)

Statistic	AvgRoom B (μT)	Avg180Hz B (μT)	AvgPerim B (μT)	AvgChild B (μT)	10%Child B (μT)	AvgGC (A)	10%GC (A)	$AvgV_{OC}$ (mV)	10%V_{OC} (mV)
Mean	0.077	0.014	0.118	0.097	0.169	1.44	2.82	54.4	107.1
SD	0.046	0.009	0.096	0.052	0.103	0.64	1.22	34.2	67.6
Median	0.088	0.016	0.085	0.095	0.169	1.23	2.47	53.2	105.2
Upper 10%	0.135	0.025	0.264	0.177	0.320	2.53	4.79	90.8	187.5
Lower 10%	0.012	0.002	0.011	0.021	0.008	0.79	1.53	10.4	20.0
Shapiro-Wilk *P*-value	<0.05	<0.01	<0.01	>0.1	>0.3	<0.01	<0.01	<0.05	<0.05

TABLE 3. Summary Statistics for Selected Exposure Measures Broken Down by System Characteristics

Line type	Location	Ground type	*N*	AvgRoomB (μT) Median	AvgRoomB (μT) Min–Max	AvgChildB (μT) Median	AvgChildB (μT) Min–Max	AvgGC (A) Median	AvgGC (A) Min–Max	$AvgV_{OC}$ (mV) Median	$AvgV_{OC}$ (mV) Min–Max
OH	Backyard	Short	12	1.12	0.12–1.64	1.05	0.61–1.83	1.49	0.88–2.60	52.0	30.7–91.0
OH	Backyard	Long	12	0.99	0.54–1.63	1.12	0.80–2.14	1.09	0.78–2.10	74.5	53.7–144.0
OH	Street	Short	6	0.72	0.41–1.09	0.73	0.34–1.01	2.13	0.98–2.80	20.9	9.6–27.6
OH	Street	Long	4	0.53	0.14–1.03	1.05	0.34–1.42	1.46	0.48–1.98	64.6	21.1–87.7
UG	Street	Short	4	0.10	0.04–0.15	0.17	0.14–0.21	1.01	0.83–1.22	10.0	8.2–12.0
UG	Street	Long	2	—	0.18–0.18	—	0.25–0.40	—	0.51–0.79	—	22.4–35.1

Regression Model

A linear regression model was used to clarify the dependencies between the three factors (line type, location, and ground type) and the nine computed exposure variables:

$$\text{Exposure} = \beta_1 * (\text{Line Type}) + \beta_2 * (\text{Location}) + \beta_3 * (\text{Ground Type}) + \varepsilon$$

The results of the regression analysis are summarized in Table 4. The computed *P*-values shown cannot be taken too literally because the residual "errors" are not random and because if the number of houses and number of temporal samples were increased, all the *P*-values would necessarily become smaller. In general, exposure values were increased for residences served by backyard OH lines. Not surprisingly with their lower resistance, short ground paths increased ground current, and the long ground path increased V_{OC}.

The results in Table 4 were generally consistent with subgroup models that included OH lines only ($N = 34$: Location and Ground Type predictors); backyard lines only ($N = 24$; Ground Type predictor only); and street lines only ($N = 16$: Line Type and Ground Type predictors).

Correlation of Exposure Variables

Table 5 shows the Pearson correlation among the six average exposure parameters under study. The nonparametric Spearman test produced essentially the same results. The nearly perfect correlation between AvgRoomB and Avg180HzB is not surprising as sources for both exposures and methods for field calculation are tightly linked.

We note a very high correlation ($r = .93$ or about 87% explained variance) between AvgChildB and $AvgV_{OC}$. The correlations between these two parameters and the other exposure variables were relatively weaker. The reasons for this difference are (1) the way AvgChildB was computed, compared to the other field quantities (see Table 1), and (2) the relation between ground current (GC) and both AvgChildB and V_{OC}, as compared to the other field quantities. First, AvgChildB was computed across the entire floor space of the residence and thus it controls for asymmetric service and ground wiring patterns among residences. AvgRoomB, which represents the average field from only the center of each house's rooms, does not completely control for asymmetry, nor does AvgPerimB taken at selected points outside the residence.

Second, linear regression allows us to observe that, within both Backyard ($N = 24$) and Street ($N = 16$) strata, the following model accounts for 100% of the variability in both $AvgV_{OC}$ and AvgChildB (of course, the value of the α coefficients are different for $AvgV_{OC}$ and AvgChildB):

$$AvgV_{OC} \text{ or AvgChildB} = \alpha_1 * (AvgGC) + \alpha_2 * (\text{Ground Type}) + \alpha_3 * (\text{Ground Type})^* (AvgGC) + \varepsilon$$

Part 2 of 8, Additional information found TheBrainCan.com , SolomonSeries.com, and https://www.youtube.com/solomonseries

TABLE 4. Summary Results of Regression Analysis of Full Sample ($N = 40$)

	Predictor variables		
Exposure variable	Line type (OH or UG)	Location (Backyard or Street)	Ground type (Short or Long)
AvgRoomB	OH, <0.01	Backyard, <0.05	>0.2
180HzAvgB	OH, <0.05	Backyard, <0.01	>0.2
AvgPerim	>0.2	Backyard, <0.01	>0.2
AvgChildB	OH, <0.01	Backyard, <0.01	>0.2
10%ChildB	OH, <0.01	Backyard, <0.01	Long, <0.05
AvgGC	OH, <0.01	>0.2	Short, =0.01
10%GC	OH, <0.01	>0.2	Short, <0.01
$AvgV_{OC}$	<0.2	Backyard, <0.001	Long, <0.001
$10\%V_{OC}$	<0.2	Backyard, <0.001	Long, <0.001

Table shows P-value associated with regression coefficients of predictor variable: $P < 0.2$ means $0.10 < P < 0.2$; $P < 0.1$ means $0.05 < P < 0.1$; $P < 0.05$ means $0.01 < P < 0.05$; $P < 0.01$ means $0.001 < P < 0.01$. In one case $P = 0.01$.
Table also shows which predictor causes exposure to rise for all cases when $P < 0.05$, e.g., AvgGC increases with Short Ground Type, compared to Long, and AvgRoomB increases with OH Line Type, compared to UG.

TABLE 5. Pearson Correlation of Average Exposure Parameters (N = 40)

	180HzAvgB	AvgPerimB	AvgChildB	AvgGC	$AvgV_{OC}$
AvgRoomB	0.99	0.84	0.78	0.54	0.68
180HzAvgB	—	0.84	0.80	0.50	0.73
AvgPerimB		—	0.74	0.47	0.66
AvgChildB			—	0.65	0.93
AvgGC				—	0.37

The Ground Type main term (the α_2 term) contributes negligibly to explaining $AvgV_{OC}$ or AvgChildB. In other words, within each Location stratum (Backyard or Street) both $AvgV_{OC}$ and AvgChildB in our model are determined solely by ground current plus ground current as modified by the length of the ground path. For AvgRoomB, the same model explains 45% of the variance for Backyard and 72% of the variance for Street; for AvgPerimB, the model explains 47% of the variance for Backyard and 46% of the variance for Street. For neither AvgRoomB nor AvgPerimB were the main Ground Type or interaction terms statistically significant. Thus, across the full population of our model neighborhood, V_{OC} and the child's magnetic field exposure classify each other better than any of the other field or ground current quantities.

Comparative Dosimetry

Finally, we compare dosimetric quantities averaged within the bone marrow and across the heart of an adult male resulting from magnetic field exposure, electric field exposure, and contact current, all 60 Hz. Although an important focus of these comparisons concern children, more precise modeling data are available for adults than for children. For this comparison, a uniform magnetic field of 10 μT, oriented perpendicular to the front of the body was chosen; the electric field chosen was 100 V/m, vertical and uniform when unperturbed; two electric field results are presented, one for a grounded subject and one for a subject in free space (off ground). These values represent extremely high residential fields that do not occur away from appliances. Contact current was estimated from the upper 10% average V_{OC} value of 90 mV (see Table 2). Assuming a total body resistance (R_P) of 2.5 kΩ (see Reilly, 1998) and the same value back to the circuit ground (R_G), for a total resistance of 5 kΩ, we calculated a contact current of 18 μA, more than ten times below the median perception threshold for adult males (0.36 mA) [IEEE, 1985]; based on limited data for children in IEEE [1985], we estimated that the perception threshold for a child would be about 35–50% of the value listed for adult males (on the order of 0.15 mA). Of course, for hand-to-feet contact, current would double in a very well-grounded person, but would be much less, or even zero, for an individual wearing well-insulated footwear or standing on an insulated floor surface.

TABLE 6. Comparative Dosimetry from Magnetic Field, Electric Field, and Contact Current Exposure[a]

			Bone marrow		Heart		
Factor	Configuration	60 Hz exposure	E (mV/m)	J (mA/m^2)	E (mV/m)	J (mA/m^2)	Reference
Magnetic field	Uniform, horizontal, perpendicular to front of body	10 μT	1.6×10^{-1}	8.0×10^{-3}	1.4×10^{-1}	1.4×10^{-2}	Dawson and Stuchly, 1998
Electric field	Uniform, vertical, grounded model	100 V/m	3.2×10^{-1}	1.6×10^{-2}	1.3×10^{-1}	1.3×10^{-2}	Stuchly et al., 1998
Electric field	Uniform, vertical, free space model	100 V/m	1.0×10^{-1}	5.0×10^{-3}	6.6×10^{-2}	6.6×10^{-3}	Stuchly et al., 1998
Contact current	Current injection into shoulders	18 μA (total)	3.5×10^{0}	1.8×10^{-1}	1.9×10^{0}	1.9×10^{-1}	Dawson et al., in press[b]

[a]The electric fields and current density values are averaged across the tissue.
[b]This reference reports dosimetry relevant to pacemaker interference only; tissue average values for this table provided by M. Stuchly (personal communication).
σ(heart) = 0.1 S/m
σ(marrow) = 0.05 S/m

The induced average electric fields and current densities (Table 6) were derived from values published by Stuchly and colleagues (references listed in table). These investigators used the scalar potential finite difference and finite-difference time-domain methods to calculate induced electric fields and current densities from fields and injected currents in anatomically correct models of adult males subdivided into cuboidal voxels 3.6 mm on a side, with tissue-specific conductivity, as estimated from published sources.

Table 6 reports that 18 μA injected current produces an electric field of 3.5 mV/m averaged across bone marrow and 1.9 mV/m averaged across heart tissue, more than an order of magnitude higher than from the field levels selected for comparison.

DISCUSSION

Our initial objective was to explore a possible engineering basis for the result of Ebi et al. (1999) that, in two previous studies of power lines and childhood cancer [Savitz et al., 1988; London et al., 1991], risk was related to the backyard location of lines, in contrast to street location. To that end, we developed a virtual neighborhood of 40 single-dwelling houses with different combinations of residential electric service attributes, including line location, line type, and ground length, as described above in detail. We report higher power-frequency and harmonic fields associated with overhead lines located in the backyard, higher ground currents associated with overhead lines and short ground paths, and higher open circuit voltage (V_{OC}) associated with backyard lines and long ground paths. Further, we find (a) V_{OC} is highly correlated with the magnetic field across the residential floor area (AvgChildB) in the neighborhood model; and (b) compared to magnetic or electric fields, V_{OC} can produce a higher electric field in target tissue. As further discussed below, these last two results suggest that V_{OC} is a potentially relevant, though overlooked, exposure in prior studies concerned with the relationship of electric power line environments to health.

Correlation of Magnetic Fields With V_{OC}

The correlation of magnetic fields with V_{OC} in our virtual neighborhood reflects their fundamental electrical relationship. Both result from electrical current, the former from any current source near or in a residence and the latter from current in the ground. The high correlation of V_{OC} with AvgChildB for the neighborhood indicates that, in locations with similar electrical characteristics, the magnetic field measured across a residential area would serve as a marker or surrogate for V_{OC}. In actual neighborhoods, a poorer correlation is likely to occur. For example, currents on primary distribution lines that do not contribute to a given residence's ground current will nonetheless contribute to the residential field. Likewise, the correlations reported here do not extend to magnetic fields calculated for residences near overhead transmission lines based on historical load data, as was done for several Scandinavian epidemiology studies [reviewed in NIEHS Working Group, 1998]. Without further investigation, however, we would not categorically dismiss the possibility of contact potentials resulting from magnetic induction on long conductive paths within and between residences abutting rights-of-way.

We designed the neighborhood according to the "multi-ground neutral" practice required in the US, in which the chassis wire, the ground wire, and the utility neutral are electrically connected with each other at the service panel. As a consequence, current in the ground will create a voltage source of magnitude V_{OC} at the chassis, which can drive a small "leakage" or contact current into an individual who contacts it (Figure 2). Several European countries, have used grounding practices that keep the chassis wire separate from the ground return pathway, leaving a much lower possibility for contact current [Rauch et al., 1992].

It is important to observe that V_{OC} is a characteristic of the residence itself, as determined by its electrical supply and grounding characteristics. Thus, all plugged-in devices with a conductive exterior surface will carry an equivalent V_{OC}, regardless of location in the residence. In contrast, high magnetic fields are often confined to "hot spots" associated with service drops, ground return pathways, or unusual wiring. Such hot spots may be away from areas that are normally occupied.

Dosimetry

As shown in Table 6, contact currents far below perception thresholds produce electric fields in tissue that exceed those due to ambient residential magnetic fields (away from appliances). We compared a contact current due to time-averaged V_{OC} within the upper tail of this parameter's distribution across the neighborhood to a uniform magnetic field (10 μT) larger by a factor of at least 10–20 than the highest space and/or time-averaged residential magnetic fields measured in many US studies [reviewed in Kavet, 1995]. Near appliances the fields may be even higher than 10 μT, but they are highly nonuniform in space falling off usually with the cube of distance from the device.

The dosimetric contrasts shown in Table 6 for adults would likely be accentuated for child-size subjects. As Kaune et al. [1997] have shown in analytical solutions of simple ellipsoidal models, induced electric fields and current densities from the same electric and magnetic fields as above would be lower due to reduced coupling to the smaller body size. With the dimensions Kaune et al. [1997] used, coupling in children was about 30% lower for both magnetic and electric fields. For contact potentials, although total body impedance is higher for children (approximately 40–50%, see Reilly [1998]), their reduced cross sectional area (roughly half or less of an adult) results in larger induced quantities. Further, the marrow dose for contact current shown in Table 6 was based on bilateral current injection into the shoulders [to analyze pacemaker interference (Dawson et al., in press)]. The tissue levels shown in the table are averaged across the body even though, for shoulder injection, the current through the arm is negligible. Thus, for hand-to-feet conduction, the current would pass through the long bones of a single arm, which has a smaller cross section than the leg, the net effect of which would be higher induced quantities in the exposed upper extremity.

In addition to these relative aspects of dose, the absolute (as well as modest) level of contact current modeled (18 μA) produces average electric fields in tissue along its path that exceed 1 mV/m. At and above this level, the NIEHS Working Group [1998] accepts that biological effects relevant to cancer have been reported in "numerous well-programmed studies". The effects the Working Group cites are "increased cell proliferation, disruption of signal transduction pathways, and inhibition of differentiation". The NIEHS endorses this conclusion in its final EMF RAPID report [1999].

Nonetheless, it remains important to compare electric fields induced in tissue due to environmental exposure to the magnitude and spectra of fields due to endogenous electrical activity. Hart and Gandhi [1998] report that the average 40–70 Hz endogenous electric field in cardiac tissue is between 8 and 25 mV/m, depending on computational method. The cardiac signal decreases with distance to neighboring tissue and is negligible in the brain. Natural electrical activity in the central nervous system (CNS), as recorded on the electroencephalogram, may be several millivolts per meter (see NIEHS, 1997), peaks below 30 Hz and has little spectral power beyond 40 Hz.

Bone marrow, target tissue for leukemia, is located directly adjacent to bone tissue, which when physically loaded, experiences "streaming potentials" of up to 0.1–1 V/m [MacGinitie, 1995; reviewed in NIEHS Working Group, 1998]. In general, the spectral power of these potentials is mainly below 10 Hz [McLeod et al., 1998]. The extent to which these fields extend to the marrow is not known precisely, although they tend to be radially oriented and would not be expected to produce marrow fields that exceed 1 mV/m. Although cartilage has streaming potentials even higher than bone, the physical and electrical relations of cartilage to bone marrow are also likely to result in only small fields in the marrow [K. McLeod, personal communication]. Finally, active skeletal muscle produces local extremely-low-frequency (ELF) electric fields due to ongoing action potential activity. However, given the relative resistance of muscle and bone, the resulting fields normal to the bone are expected to remain confined to the muscle layer itself with little effect inside the marrow; some penetration of the component parallel to bone will occur due to boundary effects, but is likely to be attenuated in the marrow. Thus, the marrow of the long bones, site of hematopoiesis and leukemogenesis in humans, is most likely electrically silent with respect to natural ELF signals in the heart and CNS (due to distance), and based on first principles, quite likely "quiet" due to bone and muscle activity nearby. However, further microdosimetric research will be required to clarify the natural electric field environment inside bone marrow.

Epidemiological Implications

In a pooled analysis of all "qualifying" worldwide studies concerned with residential magnetic fields and childhood leukemia published through 1998, Greenland et al. (submitted) report a summary relative risk of 1.8 (95% CI: 1.1–2.9) associated with fields greater than 0.3 μT, compared to <0.1 μT, with no evidence of heterogeneity across studies or across continents. In contrast, the risks associated with high wire categories (relevant to US studies only) were not consistent across studies.

Since the pooled analysis was completed, two studies of leukemia among children in Canada have been published, with neither reporting excess risk associated with wire code. McBride et al. [1999] reported little indication of an association of leukemia with personally monitored fields, while Green et al. [1999a] showed elevated odds ratios associated with fields measured within the residence and around the residence perimeter, as well as with the exposures recorded on personally-worn monitors [Green et al., 1999b]; these elevated risks were concentrated among younger children. A study across England, Wales, and Scotland [UKCCSI, 1999] reported no excess risks of childhood leukemia (or other cancers) associated with measured residential magnetic fields. How these more recent results may affect the pooled analysis has not been determined.

The immediate application of our results to specific studies in the EMF childhood leukemia literature is limited. The neighborhood was configured to represent residential electric service scenarios found in the Denver [Savitz et al., 1988] and Los Angeles [London et al., 1991] studies to address findings unique to those data sets [Ebi et al., 1999].

To that end, the neighborhood model incorporated realistic housing dimensions and realistic distances from the residence to street facilities (utility line and water main) and to backyard lines. The loads on the service drop conductors and 3rd harmonic generated from residential electricity usage were based on data acquired in a large-scale survey of nearly 1000 homes in the US [Zaffanella, 1993]. The power lines serving the neighborhood, however, were not loaded in accordance with their current-carrying capacity, nor were transformers more heavily concentrated on three-phase primaries, as compared to the other primaries in the model. Accordingly, the model neighborhood's power delivery system analyzed in this paper did not (and was not intended to) simulate the Wertheimer-Leeper wiring configurations, as they have been used in many epidemiological and exposure assessment studies.

In our simulated neighborhood, in which overhead distribution currents played no role in producing residential fields, the Spearman correlation of AvgGC with RoomAvgB was 0.52; in a sample of 333 nationwide residences whose magnetic fields were minimally affected by overhead power lines [see Kavet et al., 1999], the Spearman correlation of 24 h average ground current with spot measurements averaged across the residence was 0.41 [Kavet, unpublished observation]. Whereas the latter correlation was with respect to a field measurement taken at one point of time during the day in the real world, compared to a time averaged room measurement computed in a simulated neighborhood, the correspondence of these two correlation values is reassuring with regard to the neighborhood's representativeness of service drop/ground electrical properties.

V_{OC} is an exposure variable that we believe could explain the marginal association of measured field with leukemia in the Denver study (odds ratio (OR) of 1.93, 95% confidence interval (CI) 0.67–5.56; $\geq 0.2\,\mu T$ spot-measured field compared to $<0.2\,\mu T$), and in the Los Angeles study (OR of 1.48, 95% CI 0.66–3.29; $\geq 0.268\,\mu T$ 24 h bedroom average compared to $<0.68\,\mu T$). Both of these studies also reported positive associations between Wertheimer-Leeper wire code and leukemia risk, as well as positive associations between wire code and measured fields. As Ebi et al. [1999] reported, the wire code/leukemia associations in both studies were confined to backyard lines. Here, we report that both magnetic fields and V_{OC} are higher in residences with backyard lines.

In a separate follow-up analysis of the Savitz et al. (1988) Denver data set, Wertheimer et al. [1995] reported that increased all-cancer risks were associated with conductive plumbing, as well as with a metric they termed "elevated non-vertical" (ENV) fields, a marker of magnetic fields due to ground currents. These ENV fields may well have served as markers for V_{OC} according to the engineering relationships presented in this paper. No similar data were explicitly reanalyzed for Los Angeles, although Bowman et al. [1999] created a predictive model for residential magnetic fields in that data set which was used to confirm an association of leukemia risk with magnetic fields [Thomas et al., 1999]. These investigators conclude that the predicted fields cannot entirely account for the wire code association with leukemia reported by London et al. [1991], and that "the most likely hypothesis is that an unidentified exposure metric involving the ELF magnetic field plays a role in carcinogenesis". Although the investigators are likely alluding to alternate field metrics (perhaps transients), we believe that in a broader context, a "metric involving the ELF magnetic field" could also include contact current.

In the nine-state National Cancer Institute (NCI) childhood leukemia study [Linet et al., 1997], excess risk was reported for fields above 0.3 μT "blended" time-average field relative to < 0.065 μT (OR 1.7; 95% CI 1.0–2.9); in the 0.4–0.5 μT stratum, the OR peaked at 3.3 (95% CI 1.2–9.4). At higher fields the OR fell. We can only conjecture that the absence of a monotonic risk function in this study is due to the fact that the highest fields in the NCI data are caused by sources, such as nearby high voltage transmission lines, which do not contribute current to the residential ground path and thus to V_{OC}, whereas risk peaked among residences with high fields created by ground currents with correlated increases in V_{OC}. The NCI study reported no relationship of leukemia risk with Wertheimer-Leeper wire code category.

As mentioned above, the model here does not in any obvious way, adequately explain positive associations of cancer with overhead high voltage transmission lines, as reported in Sweden by Feychting et al. [1993]. However, we note the absence of a positive association in the study of childhood leukemia across the United Kingdom [UKCCSI, 1999], where residential wiring practices may preclude contact currents of the magnitude prevalent in residential electrical systems in the US.

Limitations

At this time there are no data that describe (a) the distribution of V_{OC} across residences, both single dwelling and multioccupancy, (b) the extent of physical contact with energized equipment or other conductive objects in the home that could produce contact current, or (c) the currents that actually result from such contacts. Factors that affect the magnitude of current from such contact include a residence's service/ground configuration and time-varying net load, alternative current paths (hand-to-hand and hand-to-feet), and variable impedance back to ground.

In addition, other situations can lead to either high V_{OC} or V_{OC} on unintended surfaces. For example, a poor connection in the service drop neutral will increase current through the ground wire, which will increase V_{OC}. Although all water pipes were assumed at ground in the model, a poorly conductive joint in a water line can produce V_{OC} on water fixtures if the ground wire is bonded upstream of that joint.

We need to address the data gaps identified above from a historical, as well as contemporary, perspective. Historical, to understand previous epidemiology studies of cases that occurred up to decades ago, when appliance construction, home wiring practices, and water service were different than they are today. More appliances today have a plastic exterior compared to metal exterior surfaces prevalent years ago; three-hole and two-hole polarized sockets are standard today as opposed to the unpolarized two-wire sockets used previously; and water service has evolved from copper pipe to plastic pipe, resulting in more alternative grounding practices. Contemporary, because if V_{OC} is an important exposure parameter with respect to health risks, then the knowledge of exposure characteristics as they now occur is critical to the design of new epidemiology studies. Obtaining reasonable estimates of the magnitude and temporal quality (likely to be highly intermittent) of residential contact current exposures, both historically and contemporarily, will also assist in designing laboratory studies to determine if appropriate cell or animal models of leukemia respond to exposures representative of the real world.

Another factor concerns exposures in apartment buildings, in which individual units are served through separate electric meters served from the same service drop. About one-quarter of all housing units in the US are apartments [US Census Bureau, 1999]. Depending on the wiring in the building, V_{OC} in one apartment may be dependent, to some extent, on net loads serving the others.

Other potentially relevant aspects of residential distribution systems have not been addressed here. These would include possible effects from loads downstream of the neighborhood in terms of fields from the primaries associated with those loads, and ground return currents that can insinuate themselves into the neighborhood's grounding system. All of the grounding in the neighborhood was through conductive water pipe through a conductive water main. The analysis here did not address redistribution of return current due to alternate grounding methods, such as driven ground rods or the effect of unintentional faults in the grounding system.

CONCLUSION

We have identified contact current due to V_{OC} as a factor potentially responsible for the association between residential magnetic fields and childhood leukemia. The studies of childhood leukemia risks in

Part 2 of 8, Additional information found TheBrainCan.com , SolomonSeries.com, and https://www.youtube.com/solomonseries

EMF environments, which were of case-control design, encompass diverse combinations of base populations, control selection methods, transmission and distribution systems, and methods for assessing historical exposure relevant to a proposed etiologic period. Although alternate environmental exposures, including local vehicular traffic density [Pearson et al., 1999], viral contact [Sahl, 1994], and water quality [Kavet, 1995] have been proposed as possible explanations, none have risen to an acceptable level of plausibility. In addition, no bias with respect to case-control selection or response has been identified that would rationalize the positive associations in any unifying way [NIEHS Working Group, 1998]. The NIEHS Working Group's report [1998] and the NIEHS EMF RAPID report [1999] both concluded that significant uncertainty remains with respect to childhood leukemia risk in magnetic field environments.

In the virtual neighborhood analyzed here, which models residential service for single dwelling homes across much of the US and Canada, V_{OC} is strongly associated with the magnetic field, and is capable of delivering biologically significant dose to target tissue. Our conclusion regarding V_{OC} is more difficult to rationalize for those studies reporting positive associations in an overhead transmission line environment, although exposed caseloads were extremely small in number and magnetic induction effects cannot be ruled out automatically. The pooled analysis by Greenland et al. (submitted) suggests increased childhood leukemia risk above 0.3 μT, indicative of large currents in and around the residence. In our model, large currents in the ground are also capable of generating high V_{OC}. Interestingly, there has been no trace of positive association of childhood leukemia with residential electric fields [Savitz et al, 1988; London et al., 1991; McBride et al., 1999], which may be present regardless of current flow.

Two-year bioassays, as well as shorter-term model-specific bioassays for magnetic field carcinogenicity, and leukemia in particular, have been almost entirely negative [McCann et al., 1997, 2000] and have created a conceptual obstacle for drawing inferences regarding magnetic fields as a possible leukemogen [NIEHS, 1999]. If a toxicologically significant dose (induced electric field) is required in the fore- and hindlimbs to promote leukemia in a rodent model, then a magnetic field, even the high fields used in the bioassays, may be ineffective because of poor coupling to those sites.

To date there is no accepted biophysical mechanism that would explain leukemogenic effects of residential-strength magnetic fields, which are < 1 μT away from appliances [Valberg et al., 1997; NIEHS Working Group, 1998]. Contact currents due to V_{OC}s of the magnitude estimated for the residences in our neighborhood model produce electric fields in tissue that do not strain the question of biological plausibility to this extent, and in fact, produce doses with the potential to trigger biological effects.

Many unknowns about contact currents resulting from V_{OC} remain with respect to biological effects in appropriate laboratory models, the extent of exposure across the population now and historically, and the relevant associations of exposure with health endpoints. Finally, contact current is an exposure that likely occurs in the workplace in association with energized equipment. Occupational exposures to contact current merit as much attention as do residential exposures.

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APPENDIX 1

Detailed Neighborhood Description

1. Four streets and 40 houses comprise the model (Figure 3). A Street, B Street, and C Street run West to East, and N Street runs South to North. A Street and C Street are cul-de-sac, with 12 houses in A Street and six in C Street included in the study. B Street and N Street are through streets. Twelve houses in B Street and 10 in N Street are included in the study. A Street, B Street, and C Street are 12.2 m (40 feet) wide. N Street is 19.8 m (65 feet) wide. Houses are set back 9.1 m (30 feet) from the street.
2. A three-phase overhead distribution line, with thick wires (the term, "thick", was used by Wertheimer and Leeper [1979] to describe lines with high potential loading), is running along N Street. Another three-phase overhead distribution line, with thick wires, is running in the backyards of houses between A and B Streets. An overhead distribution line with a single-phase primary is running in the backyards of houses between B and C Streets. An underground distribution line serves the houses on the North side of A Street. The height of the neutral above ground is 10.1 m (33 feet). The distances between houses and lines are shown in Figure 3 and are listed in Appendix 2.

3. Seven different distribution transformers (T1 to T7) serve different groups of houses as shown in Figure 3. The transformers are connected between one phase of the primary and the neutral. For instance, transformer T6 is connected between Phase C and the neutral and serves eight houses: four houses directly connected to the transformer and four houses connected at the end of a secondary line.
4. The segments of the ground current circuit are indicated with thicker lines. They include water mains, water service lines connecting houses to the main, and the conductors connecting the electrical service neutral to the water service line inside the houses ("grounding wires"). The water mains are located in the middle of the street, 1.1 m (3.6 feet) below street level. Two types of ground current paths are considered inside each house: type 1 and type 2 (Figure 4). Type 1 is the shorter possible path for overhead street lines, overhead backyard lines, and underground street lines (top to bottom in Figure 4). Type 2 is the longer possible path for overhead street lines, overhead backyard lines, and underground street lines (top to bottom in Figure 4). For each house, the service drop arrives at a corner and then goes to the electrical panel. The attachment points of overhead service drops at the houses are 5.3 m (17.4 feet) above street level. The distance between service drop and inside wall of the house is 0.5 m (20 inches). The grounding wire is 0.3 m (10 inches) below the first floor. The water service line from the main is perpendicular to the street and arrives at 0.3 m (1 foot) from a house corner at a depth of 1.1 m (3.6 feet) below street level.
5. The class (1 = thick 3-phase primary, 3 = first span secondary, 6 = end pole, 7 = underground), distance, and wire code of the residences, the type of line (street or backyard), and the type of ground current path (Type 1 or Type 2) are listed in Appendix 2. Using Wertheimer-Leeper wire code terminology, there are 11 Very High Current Configuration (VHCC) houses, 13 Ordinary High Current Configuration (OHCC) houses, two Ordinary Low Current Configuration (OLCC) houses, and 14 Very Low Current Configuration (VLCC) houses, six of which have underground service.
6. The same dimensions are assigned to all houses: two-floor houses with a rectangular floor plan 10.7 m by 7.6 m (35 × 25 ft), with the longest dimension parallel to the street. The first and second floors are at 0.5 m (1.6 feet) and 3.3 m (10.8 feet) above street level, respectively. Each house contains eight equal size rooms, four per floor.
7. The electrical parameters of the conductors of the ground current circuit are given in Appendix 3. The values of these parameters were chosen to represent values encountered in practical situations. The termination impedances (to ground) simulating the extension of water mains and primary neutrals beyond the immediate neighborhood are listed in Appendix 3. The primary loads and their return currents had a negligible effect on residential magnetic fields and ground currents, and, therefore, were not taken into account in the neighborhood analysis presented in the Results.

APPENDIX 2

Characteristics of Neighborhood Houses

House	Class	Distance m (feet)	Residence code	Line type	Line location	Ground type
A1	7	7.6 (25)	VLCC	UG	Street	1
A2	1	13.7 (45)	VHCC	3-Phase	Backyard	1
A3	7	7.6 (25)	VLCC	UG	Street	2
A4	1	13.7 (45)	VHCC	3-Phase	Backyard	2
A5	7	7.6 (25)	VLCC	UG	Street	2
A6	1	13.7 (45)	VHCC	3-Phase	Backyard	1
A7	7	7.6 (25)	VLCC	UG	Street	1
A8	1	13.7 (45)	VHCC	3-Phase	Backyard	2
A9	7	7.6 (25)	VLCC	UG	Street	1
A10	1	13.7 (45)	VHCC	3-Phase	Backyard	2
A11	7	7.6 (25)	VLCC	UG	Street	1
A12	1	13.7 (45)	VHCC	3-Phase	Backyard	1
B1	1	24.4 (80)	OHCC	3-Phase	Backyard	2
B2	6	13.7 (45)	VLCC	1-Phase	Backyard	2
B3	1	24.4 (80)	OHCC	3-Phase	Backyard	2
B4	3	13.7 (45)	OHCC	1-Phase	Backyard	1
B5	1	24.4 (80)	OHCC	3-Phase	Backyard	1
B6	3	13.7 (45)	OHCC	1-Phase	Backyard	1

House	Class	Distance m (feet)	Residence code	Line type	Line location	Ground type
B7	1	24.4 (80)	OHCC	3-Phase	Backyard	1
B8	6	13.7 (45)	VLCC	1-Phase	Backyard	2
B9	1	24.4 (80)	OHCC	3-Phase	Backyard	1
B10	6	13.7 (45)	VLCC	1-Phase	Backyard	2
B11	1	24.4 (80)	OHCC	3-Phase	Backyard	2
B12	6	13.7 (45)	VLCC	2-Phase	Backyard	1
C1	6	24.4 (80)	VLCC	2-Phase	Backyard	1
C3	3	24.4 (80)	OLCC	2-Phase	Backyard	2
C5	3	24.4 (80)	OLCC	2-Phase	Backyard	1
C7	6	24.4 (80)	VLCC	2-Phase	Backyard	2
C9	6	24.4 (80)	VLCC	2-Phase	Backyard	2
C11	6	24.4 (80)	VLCC	2-Phase	Backyard	1
N1	1	13.7 (45)	VHCC	3-Phase	Street	1
N2	1	24.4 (80)	OHCC	3-Phase	Street	1
N3	1	13.7 (45)	VHCC	3-Phase	Street	1
N4	1	24.4 (80)	OHCC	3-Phase	Street	1
N5	1	13.7 (45)	VHCC	3-Phase	Street	2
N6	1	24.4 (80)	OHCC	3-Phase	Street	1
N7	1	13.7 (45)	VHCC	3-Phase	Street	1
N8	1	24.4 (80)	OHCC	3-Phase	Street	2
N9	1	13.7 (45)	VHCC	3-Phase	Street	2
N10	1	24.4 (80)	OHCC	3-Phase	Street	2

APPENDIX 3

Electrical Parameters of the Ground Current Circuit Conductors[a]

	Resistance (mΩ/m)	Geometric mean diameter (m)
Primary neutral	0.494	0.008
Secondary neutral (overhead line)	0.494	0.008
Secondary neutral (underground line)	0.336	0.009
Service drop neutral (overhead)	0.494	0.008
Service drop neutral (underground)	0.84	0.005
Grounding wire	3.25	0.0025
Water line	0.206	0.023
Water main[b]	0.32	0.01
Ground rod at service entrance	50 Ω	
Water main terminations	0.002 Ω	
Primary neutral terminations	0.002 Ω	

[a]The values in the table are based on personal experience of one of the authors (LEZ), who managed the EPRI high voltage facility in Lenox, MA, was the principal investigator of the "1000-home study" [Zaffanella, 1993], and developed the algorithms for the ground current network analysis used in the modeling software.
[b]Geometric mean diameter (GMD) is a function of a conductor's physical dimensions and impedance characteristics. The water main has a smaller GMD than the water line, even though it is physically larger.

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