Overview of Occupational Exposure to Electric and Magnetic Fields and Cancer: Advancements in Exposure Assessment

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For over ten years, there has been concern with the potential for increased risk of cancer among "electrical workers." In contrast to studies of residential exposure to magnetic fields, occupational studies include electric and magnetic field exposures and have much greater variability in field intensity, frequency, and temporal patterns. Studies of leukemia in electrical workers show a moderate consistency, with elevated risk ratios of 1.2 to 2.0 commonly observed. Brain tumors are similarly elevated with some consistency, and three recent studies have suggested increased risk of male breast cancer. Retrospective exposure assessment methods were advanced in recent studies of diverse occupations in a study in central Sweden, which yielded evidence of increased risk of chronic lymphocytic leukemia among men in more highly exposed occupations. A study of telephone workers in New York State incorporated measurements and found some indication of increased leukemia risk only when exposures were based on historical technology. Utility workers in southern California were studied and found not to have increased risks of leukemia and brain cancer based on exposures estimated with measurements. An ongoing study of electric utility workers at five companies in the United States incorporates an extensive measurement protocol. Randomly selected workers within occupational categories wore a time-integrating magnetic-field meter to provide estimates of exposure for the occupational category. We were able to estimate and partition the variance into between-day (the largest contributor), within occupational categories, and between occupational categories. Principal research needs concern optimal levels of worker aggregation for exposure assignment, historical extrapolation, study of diverse work environments, and integration of residential and occupational exposure in the same study. — Environ Health Perspect 103(Suppl 2):69–74 (1995)

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Introduction

Concerns with occupational exposure to electric and magnetic fields (EMF) as a potential cause of cancer were first noted in Wertheimer and Leeper's (1) report on childhood cancer and became more widely appreciated with the publication of Milham's (2) letter to the editor of the *New England Journal of Medicine*. His documentation of increased leukemia mortality among electrical workers has been followed by dozens of similar reports evaluating risk of leukemia and brain cancer in relation to electrical occupations.

The adequacy of the job title as an exposure surrogate was and remains a principal methodologic concern with this approach, along with the inability to isolate any role of EMF from workplace exposure to potentially carcinogenic chemicals.

However, until very recently, all reports of EMF and occupation continued to rely on intuitive notions of which men were likely to be exposed, supplemented at best with a formal judgment by expert panels to assign "definite," "probable," and "possible" EMF exposure (3,4). Three recent studies have adopted a more sophisticated strategy in which an extensive series of workplace measurements was used to classify occupational EMF exposure of workers employed in diverse settings throughout the community (5), telephone workers (6), and electric utility workers (7). The focus of this discussion is on the methodologic and substantive contributions of those studies and a description of assessment methods and exposures from a study of American electric utility workers being conducted at the University of North Carolina.

Occupational EMF Exposure

The contrast between residential and occupational EMF exposure is complex, and in contrast to many workplace hazards, not simply a higher level of the same agent. In fact, measured as a time-weighted average, the relative contribution of workplace and home is of approximately equal magnitude (8,9). Residential studies of childhood cancer have all been explicitly or implicitly focused on magnetic fields, since outside power lines are only predictive of magnetic fields and no known long-term electric field indicators are available (10). Occupational studies are less clear in terms of which field types are present; for many electrical occupations, both electric and magnetic fields are likely to be elevated. In the electric utility industry, the most extensively studied sector, both field types are elevated (8,9).

Occupational settings can be expected to show more diversity than residences in several other dimensions of exposure. There is more opportunity for intermittent very high exposures to electric and magnetic fields rarely encountered in the home. The diversity of field frequencies can be much greater, not limited to relatively pure 50 or 60 Hz fields. Varying work practices can give rise to markedly different exposure patterns over the workday. Among electric utility workers, for example, linemen would often spend several hours at zero exposure while driving to the work site and then spend an hour in a magnetic field of 2 or 3 uT, then drive back to the base with zero exposure again. In contrast, power station operators are more likely to be exposed to a steady magnetic field of perhaps 0.5 to 1.0 uT for the entire work shift. Most work occurs during the daytime, but a sizable proportion of the workforce is engaged in shiftwork and

receives exposures at night. The biological significance, if any, of these differing patterns of exposure is presently unknown, but the workplace offers more diversity to study than the residential environment.

The notion of "electrical worker" has probably been too narrowly conceived to adequately reflect the diversity of settings in which elevated EMF is encountered. Milham's (2) original list was based on intuitive perceptions of who electrical workers are, with real questions about whether such occupations as "electrical engineer" are truly exposed to elevated field levels and omitting the broad array of workers who spend extensive periods of time near electrical equipment such as photocopiers, video display terminals, or sewing machines.

Surveys of additional groups of potentially exposed workers are needed, initially including all whose jobs involve close proximity to electrical equipment for extended periods. Advances in meters for assessing EMF allow for surveys of workplaces and personal monitoring with relatively modest expense and inconvenience. By broadening the research to include workers in more diverse settings, there is a greater opportunity to evaluate the biological significance of varying patterns. Perhaps lurking among the candidate populations is one that is exposed to the true "magnetotoxin" that will show dramatic elevations in cancer.

Overview of Current Evidence

Although many epidemiologic study designs have been applied to EMF and cancer, until recently there has been one unifying methodologic feature: all were based on job title as the sole method of exposure classification. Studies include evaluations of proportionate mortality and morbidity, case–control studies, and cohort studies, with certain design features slightly favoring one approach or another. Proportionate mortality or morbidity studies are vulnerable to distortion due to differing overall mortality or morbidity among electrical workers, but marked differences are unlikely (11). Case–control studies have the potential for more detailed exposure assessment (which has not been exploited until recently) and a clear advantage in study size over cohort studies. The pervasive limitation is in exposure classification, with complete reliance on the job title obtained from the death certificate, cancer registry, or interview.

Evidence from those studies has been reviewed in several publications (10, 12–14). [A recently published book chapter

(10) serves as the primary basis for this review.] Leukemia has been the most extensively studied cancer. Of the 11 risk estimates considering electrical workers in the aggregate, 5 were very close to the null and the other 6 ranged between 1.2 and 1.5. Consistent with an earlier review (12), the point estimate for total leukemias is very close to the value of 1.2. However, in the earlier review, acute myeloid leukemia was notably more strongly and consistently related to work in electrical occupations. In the updated review, seven studies provided risk estimates for acute myeloid leukemia, with the first three (chronologically) showing elevated risks and the later four close to the null. Averaged across studies, the overall risk estimate is now close to that for total leukemias.

Focusing on specific groups of electrical workers conveys a somewhat different pattern. Of 13 reports including electricians, 6 showed elevated risks of 1.2 to 2.0, whereas 4 of 5 studies of acute myeloid leukemia in electricians were indicative of increased risks of that magnitude. Linemen show still more consistent evidence of increased risk of leukemia, with 7 of 9 studies of total leukemia supporting such an association. Perhaps no other group of electrical workers is as certain to have elevated exposure. However, electrical engineers, among those groups most questionable in regard to having elevated exposure, also show consistently elevated risks, with 7 of 9 studies reporting risk ratios of 1.2 or greater.

Brain and central nervous system tumors follow a similar pattern as leukemia, with 8 of 11 studies previously reviewed (10) demonstrating clear elevations in risk, of somewhat greater magnitude than those found for leukemia. Particularly, two studies found risk ratios above 2.0 (3,4). Electricians have a similar pattern to electrical workers in the aggregate: of 10 risk estimates, 4 are close to the null and 6 are elevated. Among linemen, a preponderance of studies (4 of 6) are close to the null.

Scattered reports appear on other types of cancer, including lymphoma (15) and melanoma (16), and recent attention has focused on male breast cancer. The principal motivation for this attention is the postulated biological pathway linking EMF to pineal melatonin production to breast cancer (17). Three epidemiologic studies have found indications of increased risk of breast cancer among male electrical workers, providing justification for an evaluation of the far more common breast cancer in women.

In summary, prior to the most recent studies, a series of reports have linked

leukemia, brain cancer, and now male breast cancer to work in electrical occupations. The magnitudes of increase observed are not generally striking, but the consistency is notable. It does not seem plausible that these observations reflect a truly random pattern of cancer occurrence in relation to occupation, yet such an interpretation has not been convincingly refuted. There has been little opportunity to evaluate any potential dose–response gradients, with largely intuitive notions of which groups are more or less likely to be exposed. Limited opportunity to adjust for other occupational exposures leaves open the possibility of confounding. The recent series of studies make the next logical advancement in the literature, focusing on improvements in exposure assessment and consideration of workplace chemical exposures.

Innovations in Exposure Assessment

Given the rarity of the principal health outcomes of interest, leukemia and brain cancer, true prospective studies in which exposure is monitored on all individuals of interest prior to the development of disease are infeasible. Instead, some variant of retrospective exposure classification is required. The key issue is how to make such assignments of exposure as accurate as possible.

Several recent studies (5–7) have incorporated measurements in combination with job titles in an effort to improve the accuracy of assignment. Historical measurements of EMF simply do not exist over the extensive time periods of interest. Job titles remain the only available index to the past, but instead of basing the assignment of exposure on some form of expert judgment alone, present-day measurements are taken to better interpret those job titles held in the past. This approach offers several advantages: a) the classification is more objective and even replicable than expert judgment alone; b) multiple indices of exposure can be considered, including peaks, variability, and measures of central tendency such as means and medians; and c) dose–response relationships can be evaluated.

The challenges inherent in this approach should also be noted. The measurements are not the "gold standard" of exposure, but possibly a better surrogate for historical exposure than a job title alone. Judgments must be made about what level of aggregation to apply to the jobs, i.e., to whom a set of measurements

can be extrapolated. For validity purposes alone, disaggregation is optimal with each job considered separately. On the other hand, feasibility constraints and the desire for adequate precision require aggregation of the jobs into "meaningful" groups. Judgments are therefore required regarding what constitutes sufficient homogeneity to be measured as a group and assigned identical exposure scores.

In addition to the extrapolation from the measured individuals to all persons whose job titles fall in the group, there is extrapolation from the present, when measurements are taken, to the past, when the etiologically relevant exposure was occurring. In principal, consideration of changes in the environment and work practices can help in judging whether adjustments are needed for historical application, yet in practice such refinements are difficult to make. Given limited interest until recently in EMF, the consequences of changes in work practices or changing technology for exposure have not received much evaluation (relative to such established health concerns as noise or dust exposure).

Measurements in a Community-based Study

Floderus et al. (5) recently conducted the first community-based study of cancer that incorporated an extensive measurement protocol to assign magnetic field exposures. In this case–control study of leukemia and brain cancer in central Sweden, men diagnosed during the period 1983 to 1987 were selected from the cancer registry (850 cases) and compared to 1700 controls selected from the 1980 Census. Questionnaires completed by study subjects (or surrogates) were combined with workplace measurements to make magnetic field exposure assignments.

The investigators chose to focus on the longest-held job in the 10 years prior to diagnosis. Once the job and work location of interest were defined for an individual case or control, a person was chosen to wear a personal dosimeter that monitored real-time exposure to estimate the exposure level of interest. If the case or control was alive and in the same work setting, he was sought for measurement. If the individual was deceased or performing another job, a surrogate person was sought who performed the job of interest. When the workplace itself was unavailable, a surrogate setting thought to be similar to the original workplace was identified and measured. Remarkably, access was denied very rarely, an experience not necessarily applicable to other settings.

Because of constraints on resources, not all of the work settings of interest could be measured, so that some aggregation of jobs was required. Thus, the rows of the job-exposure matrix are not individual work settings but aggregations of work settings. Job categories showing sufficient consistency based on four or more measurements were not measured further in favor of additional measurements of categories showing more variability. Homogeneity is an appropriate criterion for determining whether more measurements would enhance the estimated exposure for a group. Analyses considered several parameters of magnetic field exposure, including the mean, median, standard deviation, and proportion of time above 0.2 uT, each evaluated in quartiles and by isolating those above the 90th percentile.

A modest increase in risk of total leukemia was associated with jobs in the highest quartile based on mean magnetic field (odds ratio = 1.6, 95% CI: 1.1–2.4). No relationship was found for acute myeloid leukemia whereas chronic lymphocytic leukemia showed a notable dose–response gradient across quartiles, the odds ratios rising from 1.1 (95% CI: 0.5–2.3) in the second quartile to 2.2 (95% CI: 1.1–4.3) and 3.0 (95% CI: 1.6–5.8) in the third and fourth. Brain tumors showed a modest increase in risk in the upper two quartiles of mean exposure, with odds ratios of 1.4 (95% CI: 1.0–2.2) and 1.5 (95% CI: 0.9–2.1). Similar, but slightly weaker, associations were found based on other exposure indices. No confounding was found related to exposure to benzene, other solvents, or ionizing radiation. The key contribution of the measurements would appear to be more accurate assignment of jobs into categories which allowed assessment of dose–response gradients and revealed a notable pattern of association for chronic lymphocytic leukemia.

Measurements in Industry-based Studies

Analogous strategies for refining job classification are applicable to studies restricted to workers within a particular industry. This approach of measurement-based job classification has now been applied to telephone workers (6) and electric utility workers (7). There are several advantages to studies restricted to single industries, including a greater opportunity to evaluate work activities in detail, improved workplace access, and larger numbers of workers engaged in similar activities.

In the study of telephone workers (6), men who had died of leukemia while active

in or retired from the American Telephone and Telegraph Company were compared to controls selected in a three-to-one ratio to cases from the cohort. Jobs were divided into six categories for measurement and analysis. Fifteen to 61 measurements were taken per category, obtaining complete magnetic field profiles during the workday and outside of work for a subset of men. Although present-day measurements were used to estimate past exposures, in the case of central switching operations, an attempt was made to account for known changes in technology by preferentially using measurements in the offices that employed older methods that were widespread in the past. A wide array of magnetic field indices were calculated and considered for study, but only the time-weighted average and the average peak exposure were analyzed in detail. Exposure scores were calculated as the product of the exposure index times the number of years in the job over the known work history. Odds ratios were calculated comparing specific job categories but also using exposure scores divided into quartiles and divided at the mean.

Some suggestions of an increased risk were found for central office workers and engineers, but loss of subjects due to incomplete work histories resulted in very imprecise estimates. Measurements yielded stronger suggestions of increased risk: divided at the mean score of time-weighted averages, higher exposure was associated with an odds ratio of 2.5 (95% CI: 0.7–8.6). When measurements based on the older technology for switching were applied to the exposure score, a dose–response gradient across quartiles defined by peak exposure was found, with odds ratios of 1.0, 2.3, 4.5, and 5.7 across the levels. It is notable that the combination of using measurements, focusing on peaks, and incorporating technological changes yielded the strongest indication of an association. Whether these results reflect spurious or causal associations is unclear, but the opportunity for a more thorough and flexible analysis of exposure that includes alternative indices and time periods is a clear strength over most earlier work.

Sahl et al. (7) studied electric utility workers, including a complete cohort evaluation and nested case–control studies of leukemia and brain cancer mortality. Approximately 36,000 male workers employed one year or longer at Southern California Edison Company were followed for mortality from 1960 to 1988. Based on job titles from work histories, workers were classified as "electrical workers" (linemen,

electricians, etc.) and contrasted with non-management, nonelectrical worker occupations. Case–control studies were conducted for men who died of leukemia, brain cancer, or lymphoma by selecting 10 controls from each case's risk set.

Measurements were taken for 14 job groups used to construct exposure indices in the case–control studies. Magnetic field profiles for 776 workdays distributed among the job categories were used to derive indices of the mean, median, 99th percentile, fraction exceeding 1.0 uT, and fraction exceeding 5.0 uT. The product of the job-specific exposure scores and time worked on the job was summed across the work history to yield a summary exposure score.

Cohort analyses yielded rate ratios for leukemia and brain cancer for electrical workers very similar to the reference population of nonelectrical workers, with lymphomas showing a modest increase of around 25 to 30%. Case–control analyses incorporated exposure information by contrasting men with scores above specific cutpoints of cumulative exposure on each index. Across all five indices, leukemia odds ratios ranged from 1.0 to 1.3, brain cancer odds ratios from 0.8 to 1.0, and lymphoma odds ratios form 1.0 to 1.1. Varying assumptions about relevant exposure windows and latency resulted in fluctuations in risk estimates but no discernible pattern.

In this study, the risk estimates were consistently at or near the null value in spite of varying many parameters related to the study design, constitution of exposed and referent groups, magnetic field exposure index, and time period of exposure. It would be erroneous, however, to argue that the measurements were therefore not of benefit. In fact, in evaluating null results in the absence of measurements, the first question that arises concerns whether persons holding supposedly exposed job titles really had elevated exposure. To the extent that some work setting or agent was exonerated by the study, it is important to know what that agent was. All of the analyses that could have yielded evidence of a causal association and did not do so are informative.

Exposure Assessment in Ongoing Utility Worker Study

In a study of five large electric utility companies in the United States in progress at the University of North Carolina and supported by the Electric Power Research Institute, a job-exposure matrix has been constructed to link job titles to measured magnetic field levels. The study is designed to advance knowledge of potential cancer risks associated with

EMF through: a) ensuring adequate size and precision, including approximately 130,000 workers and 2,500,000 person-years of observation; b) using workplace measurements of magnetic fields to improve accuracy of classification; and c) considering the possibility of confounding related to workplace chemical exposures. A key challenge has been developing an approach to assessing EMF exposure.

Given the need to classify workers at five companies, representing nearly 10,000 individual job titles, the first task was to organize those jobs into meaningful groups for measurement. Occupational categories were defined based on a synthesis of job responsibilities, work settings, and indirectly the potential for exposure to EMF and chemicals. The occupational categories included: managers and executives, relay technicians, engineers and other professionals, telecommunications technicians, technical workers, cable splicers, field/craft/trade supervisors, power plant operators, administrative supervisors, substation operators, clerical workers, riggers, sales and marketing, auto and truck mechanics, services, painters, mechanics, pipe coverers, machinists, welders, boilermakers/steam fitters, heavy vehicle operators, electricians, materials handlers, linemen, laborers, instrument and control technicians, and other crafts and trades.

Jobs were assigned using computer searches of text strings complemented by extensive, repeated discussions with experts at the individual companies. Not surprisingly, companies use different terminology to refer to the same task and sometimes have workers holding the same job title engaged in very different activities.

Once the assignment to occupational categories was made, we developed a method for randomly selecting worker-days for measurement. Asking supervisors or workers to select "representative days" for measurements is likely to result in biases towards high or low exposure depending on the predilections of the person choosing the sampling day. We obtained rosters of all presently employed male workers and organized them into the same occupational categories for sampling purposes. An initial judgment was also made about the likely level of exposure as high, medium, or low. Then, the allocation of the number of samples was made with a total of 4000 worker-days thought to be feasible. Assignment of the samples was based on the estimated person-years of work experience in the specific occupational category in the specific company,

weighted in a 5:3:1 ratio across presumed high, medium, and low exposure groups. Within the company by occupational category cell, the targeted number of workers were randomly selected and randomly sequenced within the list given to the company representatives for measurement. Since measurements were to cover a full calendar year, the potential effects of seasonality or day-of-week on measurement were assumed to be randomly distributed and therefore unlikely to introduce bias. A subset of workers in occupational categories initially assigned as high or medium were chosen for a repeat measurement at a specified interval following the initial measurement. This repeat assessment was essential for estimating the components of variance in exposure, particularly for within-worker variability.

Data collection was coordinated by the study staff but implemented at each of the participating companies. A designated representative took responsibility for receiving assignments of which workers to monitor, distributing meters to the designated workers, collecting the meters, reading and recording the measurement results, and returning the meters for periodic calibration checks. Perhaps the greatest challenge faced by the representatives was developing a workable system within the constraints and challenges at the individual company, but the institutional and individual commitment was ultimately successful in attempting over 4000 workday measurements by the end of the data collection period.

The principal sacrifice in conducting a large, randomized measurement protocol was the type of instrumentation and resulting restriction of field characteristics. We needed to use an instrument that could be sent through company mail to individual workers (often distributed over a several-hundred-mile radius), used by a nontechnically trained worker with minimal instruction, and read by the company representative. The AMEX 3-D was chosen, which uses only one switch to turn the meter on and off and accrues charge proportional to the time-weighted average magnetic field. The time to discharge is then converted into uT-hours of exposure. With notation of the duration of use (recorded by the worker), the time-weighted average exposure during the workshift was derived. The loss of information pertains to the alternative indices of exposure that could not be examined. Fortunately, we and others have observed high correlations between measures of central tendency

(mean, median), higher-end exposures (90th percentile, peak), and measures of variability (*18*). What is not well reflected in the time-weighted average is the lower percentiles or time above some low threshold (e.g., 0.2 or 0.3 µT). None-theless, in our judgment, the advantages of obtaining a large number of randomly chosen work-day measurements outweighed the restriction of exposure information.

Starting with the 4094 attempted measurements, losses were incurred due to worker absence (446), worker refusal (121), procedural errors (346), instrument failure (296), and reported duration of use < 4 hr or > 12 hr (43), leaving 2842 (69%) in the final analysis. Analysis of these data continues, but several observations can be noted. The arithmetic means for occupational categories range from 0.05 to 1.96 µT. In the original three sampling strata, presumed low, medium, and high, the arithmetic means clearly differ, with time-weighted averages of 0.26, 0.53, and 1.02 µT across the three levels.

Examples of measured magnetic fields by occupational category are presented in Table 1. These illustrate two more general points regarding the data: First, the jobs intuitively thought most likely to have high and low exposures generally do, but several large occupational categories, such as engineers, are in an ambiguous middle range. Second, across the five companies, there is notable variation in specific occupational categories (e.g., linemen, mechanics), in part due to differing constitution of the groups and in part due to characteristics of the company itself. Analysis of geometric means of the occupational categories yield similar results to those seen for arithmetic means, but within a narrower range.

One of the virtues of our measurement data is the ability to apportion the variance in magnetic fields to different sources. The proportion of total variance in measured fields due to day to day variation within a worker is estimated at 68%. Variation among workers within the occupational categories contributes an additional 14% of the variance, leaving only 18% of the total variation across occupational categories. The magnitude of day to day variation is larger than in many industries that have a more predictable set of work activities. Although some jobs have exposure that are more predictable on a day to day basis, many of the dominant groups in the electric utility industry do not, such as linemen or electricians. Such variation poses a challenge to exposure classification,

requiring more measurements to characterize the group average with a given level of precision.

The measurements that characterize each occupational category are being used to classify exposures of work performed by all members of the category. In spite of the known uncertainties in assuming homogeneity within the occupational category across workers and over time, the measurements provide an extremely valuable addition to the study. They allow us to estimate quantitatively the uncertainty inherent in classification into groups as well as the variation due to day-to-day activities. The interpretation of results for major groups of electrical workers such as linemen and electricians is much more easily interpretable with the measurements. Finally, under a set of assumptions about the validity of the measurements, we can assess the presence of dose–response functions relating inferred magnetic fields to cancer mortality. The analyses to do so are under way.

Conclusions

In spite of considerable progress, the challenge of retrospective estimation of EMF exposure remains central in studies of occupational risks. Historical information on job titles and tasks will continue to be the principal mechanism for assessing the past and our challenge is to identify improvements in our ability to do so accurately. None of the strategies so far are so persuasively effective that they should be adopted as the model, but some variation of a measurement-based job-exposure matrix seems to be essential.

Job titles alone have been studied quite extensively, and further study of job titles in relation to leukemia and brain cancer is of limited value unless there is some opportunity to have more detailed information for imputing exposure. More studies of equal quality can only enhance the precision of the aggregate estimate, not assess its validity. Cancers other than leukemia and brain cancer and diseases other than cancer may be studied productively through

examination of job titles since relatively few studies of other diseases have been conducted.

The key challenges are in refining the strategy for assessing workplace exposure. Decisions have to be made on how to aggregate workers for assignment, ranging from measurement of a workplace for each individual, as intended by Floderus et al. (*5*), to aggregation into broad groups for measurement and assignment, as described by Bowman et al. (*19*). Even component tasks or microenvironments could be measured as the basis for assigning exposure, linking each worker to the tasks or location in which he or she spends time. Further statistical consideration is needed to define the optimal level of aggregation.

Historical extrapolation is a major source of uncertainty which can ultimately only be resolved by the passage of time and accrual of a historical set of measurements. In the interim, models of historical work settings and practices might be developed to estimate the impact of changes on exposure. Studies of occupational EMF exposure should be expanded beyond electric utilities and even perhaps beyond the traditional "electrical" occupations to include workers with occupational exposure in other industrial environments or offices. Not only would such studies offer the opportunity to examine a sociologically different population, but each one has a particular pattern of exposure. The differences in temporal pattern, field characteristics, and accompanying environmental agents might well lead to a difference in the impact, if any, of EMF.

Finally, it seems essential to integrate workplace and residential EMF exposure in a single study. There are major logistic challenges to doing so, but the known contributions from each source to the time-weighted average, nearly half from each, dictate this direction for research. The ability to separate groups with more notably distinct magnetic field exposure would constitute a much stronger test of the postulated link between EMF and cancer than has been conducted so far.

Table 1. Time-weighted average magnetic field exposures (uT) in selected occupational categories by company: U.S. utility worker mortality study.

Occupational category	Company				
	1	2	3	4	5
Clerical workers	0.10	0.21	0.22	0.26	0.35
Engineers	0.09	0.11	0.68	0.15	0.16
Linemen	0.94	1.12	0.38	0.57	0.72
Electricians	0.60	1.59	0.97	1.00	1.38

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