Factors Influencing Personal Magnetic Field Exposure: Preliminary Results for Power Utility and Office Workers

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Epidemiological studies and laboratory research suggest that exposure to extremely low frequency (< 300 Hz) magnetic fields is associated with an increase in risk of developing a number of rare diseases including leukaemia. Overall the risks to health appear to be small but a more accurate exposure assessment technique would help evaluate the true extent of any health effects. In this pilot study we aimed to identify and evaluate personal, work and environmental factors and their influence on measured exposure levels with a view to developing a method of reconstructing exposure.

Office workers and power utility workers were studied using personal dosimeters to measure magnetic field exposure, along with frequent observation or measurement of factors related to exposure. Factors such as average and closest distance to source, time at position and current flow were combined in a series of metrics to investigate simple models of personal exposure.

The results indicate that mean and peak magnetic field exposure levels are linked to current flow and the average distance of a worker from the source of the magnetic field. These factors are more accurate predictors of high exposures than they are of lower and average levels. It may be possible, with further work, to produce a model of exposure to magnetic fields for use in epidemiological studies. © 1998 British Occupational Hygiene Society. Published by Elsevier Science Ltd.

INTRODUCTION

There has recently been considerable controversy about the potential link between exposure to extremely low frequency electromagnetic radiation (< 300 Hz) and ill-health. A number of epidemiological studies have shown small excesses of cancers, particularly leukaemia and/or brain cancer amongst populations exposed to high magnetic field levels (Coleman et al., 1983; Guenel et al., 1993; Kheifets et al., 1995; Feychting et al., 1997). It has also been postulated that reproductive disorders (Juutilainen, 1991), neuroendocrine disturbances (Stevens, 1987) and haematological imbalances (Gamberale et al., 1989), may be caused by electric and magnetic field exposure. However, other studies have failed to identify any excess mortality or morbidity which could be attributed to such exposure (Harrington et al., 1997; Tornqvist et al., 1986). These equivocal results may in part be due to unreliable assessments of exposure. With improved exposure assessments, based on an understanding of the factors which influence exposure levels, it may be possible to discern whether there is a causal association with ill-health.

The available evidence points to exposure to magnetic, rather than electric fields, as the most likely candidate for a causal exposure (Savitz and Calle, 1987; Broadbent et al., 1985). Magnetic field exposures in both the domestic and occupational setting are likely to be highly variable and dependent on changing work practices, tools used, current flow and positioning of sources. As the biological mechanism through which magnetic fields may induce adverse health effects has yet to be elucidated, it is difficult to identify a single 'exposure metric' that may equate to the harmful 'dose'. It is unclear whether time-weighted-average (TWA) exposure, the percentage of time spent above a certain threshold level, the peak exposure level or some other measure is the most appropriate metric for epidemiological investigations.

As direct measurement of magnetic fields is both impractical for large epidemiological studies and impossible as a means of collecting retrospective data on personal exposure, a suitable surrogate is necessary to help determine exposure levels. Measurement of present day exposure levels is often used to estimate lifetime cumulative exposure (Harrington et al., 1997).
but clearly such exposure assessment strategies fail to take account of long term changes due to changes in working practices, equipment etc. Job title and occupation have also been used extensively as exposure surrogates (Lindh et al., 1997; London et al., 1994; McDowall, 1983) but these studies have often produced equivocal results due to the inherent problem of intra-group variations.

The present pilot study aims to investigate the feasibility of using techniques first proposed for the assessment of exposure to hazardous substances (Cherrie et al., 1996) to predict personal magnetic field exposure levels from secondary personal, workplace and environmental information.

**METHODS**

*Identification of factors likely to influence exposure*

Factors involved in generating power frequency magnetic fields and the variables that were likely to influence a given individual's personal exposure were identified from previous studies (Gamberale et al., 1989; Lindh et al., 1997).

The magnetic field generated by a conductor is induced by the current flow through that conductor and the intensity is directly proportional to the magnitude of current flow. Different types of conductor configuration also produce different peripheral field patterns. Clearly, therefore, the number of sources, the current flow through these sources and the nature of the sources will all have a bearing on the generated magnetic field strength at any given point.

The factor having greatest effect on a given individual's cumulative personal exposure is likely to be the amount of time spent at a particular position in relation to the source. Full working shifts spent close to medium current sources may produce greater exposures than occupations spending short periods working close to high current sources and the remainder of the working day in low exposure situations. Other factors may influence the magnitude of peak magnetic fields. Switching and sudden changes in load on a given device may cause high transient fields to develop while movement by the worker into positions very close to current flow can also produce high peak exposures.

From our review it was decided to analyse the effect of time, distance and current flows on personal exposure levels. From theory it was anticipated that personal exposure would increase linearly with time while decreasing with the distance between worker and magnetic field source. In addition, field strength and hence exposure, would be expected to increase with current flow.

*Monitoring strategy*

Magnetic field measurements were obtained using a SPECLITE root mean square magnetic field meter. The monitor records the magnetic field strength at each of 42 frequency points ranging from 3000 to 40 Hertz every minute, with a total of 16.6 hours of continuous measurement. It has a full scale accuracy of ±5%.

In developing the monitoring strategy two occupational groups were identified: A team of electricity linesmen involved in a new type of live power line maintenance work termed 'hot gloving' and, secondly, a group of office workers undertaking a variety of administrative and desk based activities who were deemed likely to have lower magnetic field exposure levels.

Personal exposure and the explanatory variables were measured for a full working day on each worker. Four exposure metrics were employed: the 8-hour TWA exposure, the percentage of time that the individual spent exposed above two threshold values (0.1 μT and 0.2 μT), and the peak instantaneous exposure measured. All magnetic field strengths were measured at 50 Hz.

Information on the variables that may influence exposure was collected by observing the activities of the employee wearing the measuring device and recorded. Details of tasks, distances to sources and current loads were collected every 15 minutes. Line currents were measured and recorded using 'Load Loggers' attached to the line while information on current flow in office sources was obtained from equipment power ratings.

Where the operator was estimated to be on average greater than 5 metres from the primary source, or if the closest observed distance between worker and source exceeded 5 metres, then the data was excluded. Magnetic fields at this distance from any source would typically be very low and tend towards background levels.

*Data analysis*

Exposure measurements were divided into 15 minute time periods where mean exposure, standard deviation, peak exposure and percentage of sampling time spent over each of the two threshold levels were calculated. Additionally, for each 15 minute time period, the primary magnetic field source was identified and both the average distance between the worker and source and the closest recorded distance of the worker to the source were noted. The time fraction of the 15 minute period spent at the closest recorded position was also recorded. From these data each of the four exposure metrics was plotted against (a) average distance between worker and primary source, (b) the 'closest distance metric' calculated by multiplying the closest observed distance in metres by the inverse of the fraction of the 15 min period that the employee was noted to be at this position and dividing by a constant (7.5) to produce values on a scale between 0 and 10, (c) a composite metric of (a) multiplied by (b). Current flow was incorporated in each analysis by symbol coding each plot into 'high' (>10 Amps), 'medium' (3 to 10 Amps) and 'low' (<3 Amps) current values.
Factors influencing personal magnetic field exposure

Table 1. Summary of results from personal exposure measurements

<table>
<thead>
<tr>
<th>Worker</th>
<th>8 hour TWA ($\mu$T)</th>
<th>Peak exposure ($\mu$T)</th>
<th>% time $&gt;0.1\mu$T</th>
<th>% time $&gt;0.2\mu$T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linesman 1</td>
<td>0.1</td>
<td>0.4</td>
<td>62</td>
<td>24</td>
</tr>
<tr>
<td>Linesman 2</td>
<td>0.5</td>
<td>18.0</td>
<td>70</td>
<td>42</td>
</tr>
<tr>
<td>Linesman 3</td>
<td>0.2</td>
<td>4.0</td>
<td>61</td>
<td>31</td>
</tr>
<tr>
<td>Office worker 1</td>
<td>0.2</td>
<td>0.5</td>
<td>67</td>
<td>34</td>
</tr>
<tr>
<td>Office worker 2</td>
<td>0.1</td>
<td>0.4</td>
<td>48</td>
<td>21</td>
</tr>
<tr>
<td>Office worker 3</td>
<td>0.2</td>
<td>0.5</td>
<td>67</td>
<td>36</td>
</tr>
<tr>
<td>Office worker 4</td>
<td>0.2</td>
<td>0.6</td>
<td>65</td>
<td>31</td>
</tr>
</tbody>
</table>

RESULTS

Sampling of electricity linesmen took place over a three day period. The 'hot-gloving' team of three men were sampled while undertaking normal working operations during this time. The nature of the work was such that the majority of the day was spent travelling to, and preparing for, the on-line procedure which, typically, only occupied 2–3 hours per day. A summary of exposure results is presented in Table 1.

Much of the linesmen’s working day (61 to 70%) was spent in conditions above 0.1 $\mu$T with about half of this above 0.2 $\mu$T (24 to 42% of the working day). Clearly this indicates the different types of working environments that the linesmen experience; <0.1 $\mu$T when in transit and in preparation, and >0.2 $\mu$T when undertaking live line work.

The office workers were sampled on four separate days and a summary of their results is also presented in the table. None of them experienced high peak magnetic field exposure levels with the maximum below 0.6 $\mu$T. The 8 hour TWA value ranged from 0.1 $\mu$T to 0.2 $\mu$T.

The office workers spend from half to two thirds of their working day in conditions where magnetic field levels exceed 0.1 $\mu$T and 21 to 36% of their time above 0.2 $\mu$T. These data are similar to the hot gloving linesmen.

Figures 1 and 2 present scatter plots of the linesmen’s mean or peak exposure against average distance with details of current flow. The highest mean and peak exposures were recorded at low average distance from the source and at high current values. Low mean exposure levels are found in conditions of low current flow and high average distances between worker and line. No associations were identifiable in the case of the office workers or for the other exposure metrics.

DISCUSSION

In this pilot study, both linesmen and office workers have broadly similar exposure profiles. Although there is little difference in 8-hour TWA levels between the office workers (0.1–0.2 $\mu$T) and linesmen (0.1–0.5 $\mu$T) the linesmen were more likely to experience high peak exposures (up to 18 $\mu$T) compared with the office workers (up to 0.6 $\mu$T). Our measured exposure levels are in broad agreement with a recent investigation of exposure to power frequency electromagnetic fields in Denmark (Skotte, 1994) where office workers had mean 24-hour TWA exposure...
levels of 0.09 \mu T while electricity utility workers had mean exposure values of 0.15 \mu T (distribution workers) and 0.36 \mu T (transmission workers).

In our study there was an association between mean exposure and the average distance from the primary source, although the relationship was obvious only with high currents. As linesmen moved further from these high current lines their measured exposures were seen to rapidly decrease and then level off. The difficulty in identifying an association at low currents may be due to the magnetic field exposure levels being within the region of 'background noise' making it impossible to detect the element of exposure from the primary source (i.e. the electricity line).

Peak exposure appeared similarly associated with the average distance from the primary source. It was originally anticipated that the instantaneous peak magnetic field level would be more likely to be determined by the closest distance of the worker to the source but this was not the case in our study. Once again measured peak levels were found to be highest in conditions of high currents and when working close to the line.

There are a variety of methodological problems with this type of study. For example, the estimation of distance while sampling the electricity linesmen was difficult when the observer was located some metres away on the ground. And yet it is likely that the greatest rate of change in measured exposure level occurs close to the source. Similarly the subjective assessment of 'average distance' to source is fraught with difficulty. Nevertheless, it has been possible to identify fairly clear associations between exposure and distance from the line for these workers.

There were also difficulties in obtaining information on current flow through sources. The load loggers used to measure electricity line currents recorded only once every 15 minutes. This could again have lead to momentary surges or troughs in current flow going unrecorded. In the office environment it was often difficult to obtain information on the power use/current flow through various appliances. Also, devices such as printers and photocopiers clearly draw much less current when on stand-by mode rather than on full operation. Finally there may be other unidentified sources of magnetic fields which influenced personal exposure measurements. Underfloor wiring or devices located in neighbouring rooms or even buildings may have contributed to exposure. However, it is again encouraging that where there was a clearly identifiable single source there were observable associations between exposure and current.

The observed associations between the explanatory variables and magnetic field exposure suggest that reconstructing past exposures from historical information about work practices and equipment may be practicable, at least from situations where there are a small number of well characterised sources. Relevant information about past conditions, for example the type of electrical equipment used, current rating, proximity of workers to sources etc., could be obtained from interviews of long-service employees and these could then be used to estimate exposure. There are, however, many details of such a reconstruction strategy that remain to be resolved. In particular there are difficulties in dealing with multiple sources, some of which may be hidden behind walls or floors. Nevertheless we feel that using the approach outlined here it should be possible to improve magnetic field exposure assessments for epidemiological studies and this may help identify whether there are truly risks to health from such exposures.
Acknowledgements—We are grateful to Prof. Malcolm Harrington who first stimulated our interest in extending the techniques we have previously developed for hazardous substances to magnetic field exposure assessment. We also wish to thank Dr Monika Watt for her assistance in setting up this study. We would like to thank Mr Grant Roy of Hydro-Electric plc for his help both in providing access to the live-line team and for a great deal of information on electricity work and magnetic fields. We are also grateful to Mr Terry Slater of Innovatum Incorporated who provided the SPECLITE monitor.

REFERENCES


