Measuring biologically-based exposure metrics for Extremely Low Frequency (ELF) magnetic fields with a personal waveform monitor

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Purpose

This study is a first effort to measure worker exposures to magnetic field metrics derived from biophysical mechanisms, using a new waveform capture monitor. The primary purpose was to test whether these biologically-based exposure metrics are significantly elevated in electrical occupations which had been associated with cancer. Secondarily, this pilot study tested the feasibility of using this new monitor in epidemiologic studies.

Background

Magnetic fields with extremely low frequencies (ELF = 3-3000 Hz) have been associated with increased risks of leukaemia and brain cancer in several well-done epidemiologic studies, but were only rated a "Possible Carcinogen" (IARC category 2B) by an U.S. government risk assessment (1).

One reason for the uncertainty has been inconsistencies in the epidemiologic associations between occupational EMF studies. Another has been that exposures have been measured with the RMS (root-mean-squared) magnitude of the ELF magnetic field vector (Figure 1). Although convenient to measure, the ELF magnitude has no direct relationship to any effects on biophysical processes.

A strategy for obtaining more consistent results from epidemiologic studies has been to measure exposure metrics derived from biophysical mechanisms (2). The mechanisms with the most empirical support are:

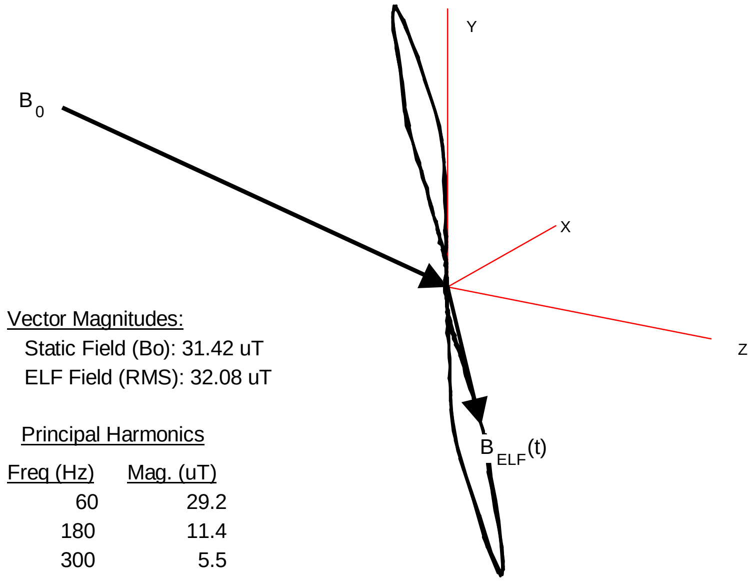
- Currents induced in the body by time-varying magnetic fields
- Changes in the free radical production rates
- Interactions with magnetosomes (biologic ferromagnetic crystals)
- Resonant interactions of excited-state ions in protein complexes

These hypothesized mechanisms lead to "biologically-based exposure metrics", such as the current density induced in the tissue where a cancer originates.

To measure exposures to these biologic metrics, this study used a new personal waveform capture monitor. By simultaneously digitizing the signals from three orthogonal magnetic field sensors with a 0-3000 Hz bandwidth, the Multiwave® System III (Electric Research and Management, State College, PA) totally captures the ELF and static field vectors over several 60 Hz cycles (Figure 1). The waveform data allows accurate biophysical modeling, and also provides all the field's physical parameters (ELF magnitude, frequency spectrum, etc.) (3).

As a first step towards health studies, we took Multiwave III measurements on electric occupations which have been previously associated with cancer (1). Biologically-based exposure metrics for the mechanisms listed above were then calculated with new software written to analyze Multiwave III data.

Figure 1. A three-dimensional trace of the ELF magnetic field vector $\mathbf{B}_{ELF}$(t) and the static field vector $\mathbf{B}_o$ measured over five 60 Hz cycles by the Multiwave® System II near a transformer (3). Also shown are some physical characteristics calculated from the waveforms with Multiwave software.



Methods

Measurements were taken on workers recruited at Los Alamos National Laboratory, New Mexico, USA from the following occupations that previous studies had designated "electrical work" (1): electric lineworkers, electricians, welders, electronic technicians, and repairers of commercial and industrial electronic equipment. The number of electric workers and the sample of non-electric jobs was determined by a power calculation for the TWA magnitude of the ELF magnetic field. For at least half the work day, each worker wore a Multiwave III in a vest with its sensor located on the chest. In order to eliminate artifactual variations in the static magnetic field from the earth, the vest was made without metal fasteners, and kept the probe fixed to the worker's body. Once a second, the Multiwave III took a measurement of 3-axis magnetic field waveforms within a 1/30 sec. window and a 0-3000 Hz bandwidth, and stored them as a time series on a PCMIA memory card. After monitoring, the Multiwave data was transfered to a PC for analyses. Graphing software for the Multiwave was used to check that valid data had been acquired. C++ software was written to calculate biologically-based metrics for the four mechanisms listed above and physical magnetic field characteristics directly from the waveform data. For each worker and metric, the software calculated summary metrics for the total monitoring period, *e.g.* the time-weighted average (TWA), maxiumum, first-order autocorrelation, etc. Finally, means tests were performed for each summary metric to determine whether the electrical occupations were more strongly exosed than the non-electric jobs.

Results

Thirty-eight partial-period personal samples were monitored in the 6 different job classifications. We calculated TWA exposures to the ELF magnetic field magnitude and the following biologically-based metrics:

- induced current density in the brain
- fullband intensity ($B_o^2 + B_{ELF}^2$) for the free radical mechanism
- ELF component perpendicular to $\mathbf{B}_o$ vector for the magnetosome mechanism
- for the ion resonance mechanism, the component of the electric dipole perpendicular to the impulse which put the ion into its first excited state

Table 1 gives an example of these results, compared to the TWA of the ELF magnetic field magnitude. Compared to the non-electric jobs, TWA exposures to both the induced brain currents and the ELF magnitude are significantly elevated in all electric occupations, plus electricians and welders. However, the elevation is more pronouced for induced brain currents (p=0.00003 for all electrical jobs) than for the ELF magnitude (p=0.00081).

Table 1. Means tests of the time-weighted averages for a biologically-based exposure metric and the ELF magnetic field magnitude in the electrical occupations compared to a sample of non-electrical jobs

Job Category (# of subjects)	Geometric Mean TWA (GSD†)	
	Induced brain current Density (μA/m^2)	ELF magnitude (μT)
Non-electrical (n=8)	0.08 (1.5)	0.08 (2.2)
Line workers (n=11)	0.21 (4.7)	0.25 (9.8)
Electronic repairers (n=8)	0.15 (2.7)	0.21 (2.7)
Electricians (n=5)	0.56 (3.1)*	0.71 (4.2)*
Welders (n=3)	0.47 (2.9)*	0.43 (3.0)*
Electronic technicians (n=3)	0.46 (14.9)	0.69 (18.3)
All electric jobs (n=30)	0.28 (3.8)*	0.33 (5.3)*

*p<0.05 compared to the non-electric jobs (log transformed) † GSD is unitless

Conclusions

This pilot study suggests that electrical jobs previously associated with brain cancer may be more highly exposed to the induced currents in the brain than to the ELF magnetic field magnitude measured in the epidemiologic studies. More importantly, this pilot study demonstrated the feasibility of measuring worker exposures to biologically-based metrics with the Multiwave III personal waveform monitor.

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Preface

This book contains the extended abstracts to the X2001 Conference on Exposure Assessment in Epidemiology and Practice in Göteborg, Sweden, June 10-13, 2001. The excellent work performed by the contributing scientists has made this book a first-class, up-to-date, state of the art review on what is known about exposure assessment today.

The outstanding scientific quality of the extended abstracts was secured through the work of five international programme committees. The chairmen for the committees were: Chemical, Patricia Stewart; Ergonomic, Alex Burdorf; Physical, Ulf Bergqvist; Psychosocial, Annika Härenstam and Biological, Jean-Francois Caillard.

Financial support to the conference and thereby to the publishing of this book was made possible by contributions from The National Institute for Working Life, Stockholm, Sweden; The Swedish Council for Working Life and Social Research, Stockholm and Volvo. Without the excellent skills of the organizing committee - Ulrika Agby (administration and layout), Ann-Sofie Liljenskog Hill (administration) and Christina Lindström Svensson (administration) - the production of this book would not have been possible.

We want to express our gratitude to the contributing authors, session chairmen and to the participants who presented papers and contributed in the discussions, for making X2001 an outstanding meeting.

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