Environmental Research 158 (2017) 295–300

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

24-h personal monitoring of exposure to Power Frequency Magnetic Fields in adolescents – Results of a National Survey

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ARTICLE INFO

Keywords:
Power frequency
Exposure
Magnetic fields
Extremely Low Frequency
Personal Monitoring

ABSTRACT

Objectives: The aim of this exposure assessment study was to gain information about the exposure levels of adolescents in Israel to power frequency (50 Hz) magnetic fields (MF) through personal monitoring, and to provide reliable data for national policy development.

Methods: 84 adolescents, 6–10th grade students, carried an EMDEX II meter attached to their body for 24 h. The meter recorded the MF every 1.5 s. The students documented their activities and microenvironments, such as apartment (awake or asleep), school, transportation, open public areas and other indoor environments.

Results: The geometric mean (GM) of the daily time weighted average (TWA) of all the participants was 0.059 µT (STD = 1.83). This result is similar to those of personal exposure surveys conducted in the UK (GM 0.042–0.054 µT), but lower than levels found in the US (GM 0.089 − 0.134 µT). The arithmetic mean was 0.073 µT, 23% higher than the GM. Fields were lowest at school (GM 0.033 µT), and average outdoor exposures were higher than indoor ones. 3.6% of the participants were exposed to daily TWA above 0.2 µT.

The typical time spent above 0.2 µT ranged from few minutes to few hours. The time spent above 0.4 µT and 1 µT were much shorter, around 1–15 min and from few seconds to 2 min, respectively. Momentary peaks ever recorded were in the range of 0.35–23.6 µT

Conclusions: Exposure of adolescents in Israel is similar to data reported in other countries, being below 0.1 µT for the vast majority, with very few average exposures above 0.2 µT. Analysis of the different microenvironments allows for a cost-effective and equitable policy development.

1. Introduction

Many epidemiological studies have examined the association between residential exposure to power frequency (50/60 Hz, Extremely Low Frequency – ELF) magnetic fields (MFs) and childhood cancer in general, and childhood leukemia in particular. Two pooled analyses (Ahlbom et al., 2000; Greenland et al., 2000), summarizing the results of epidemiological research published up to 2000, pointed to a consistent increase in the risk of developing childhood leukemia in children exposed to residential MF levels above 0.3–0.4 µT (OR of 1.7–2). Another pooled analysis (Kheifets et al., 2010) identified 14 studies published since the two previous analyses, of which seven met their inclusion criteria. The odds ratio for exposure above 0.3 µT compared to < 0.1 µT was 1.4 (0.9–2.4). The exemption of the most influential study, from Brazil, which is suspected to be particularly prone to bias, cause the odds ratio to increase and become similar to previous pooled analysis.

The International Agency for Research on Cancer (IARC) categorized human exposure to ELF MFs as “possibly carcinogenic” (2B) (IARC, 2002) (re-confirmed by WHO (2007), based on limited epidemiologic evidence, negative animal data and lack of known mechanism. The uncertainty about the reasons for the observed association has significant impact on worldwide national and local policies, as well as on public concerns. Due to the uncertainty implied by the IARC classification, as well as lack of knowledge about MFs exposure levels in Israel, the Israeli policy of limiting exposure of the general public to MFs is among the strictest in the world.

Although exposure surveys and epidemiological studies including exposure assessments have been conducted in many countries (Kheifets et al., 2006; WHO, 2007), their findings cannot be directly applied to Israel. Differences in factors such as daily behavior, population density, domestic voltage, power consumption, and wiring configurations may lead to significant differences of exposure in different countries (Kheifets et al., 2006). For example, Merchant et al. (1994) and Preece

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http://dx.doi.org/10.1016/j.envres.2017.06.027
Received 22 March 2017; Received in revised form 28 May 2017; Accepted 22 June 2017

et al. (1996) found that MF measured values in the UK are considerably lower than in the USA.

MFs exposure assessment can be performed by three measurement methods (Swanson and Kaune, 1999; WHO, 2007): a) The simplest method is "*Spot measurement*": a momentary reading is taken at one or more points. The major disadvantage of this method is its inability to identify temporal variations. b) In "*Long term (*or *continuous) measurement*", MFs are measured at one or more places for longer periods, usually 24–48 h. Comparisons between the two methods have found only a poor-to-fair correlation (WHO, 2007). The major disadvantage of this method is its inability to identify spatial variations. c) "*Personal monitoring*" is carried out by a MF meter worn by the subject, typically for 24–48 h. The advantage of personal monitoring is its ability to capture the actual exposure of the subject to all sources and at all places. Thus, personal monitoring might be used as reference for the other two methods (Kaune and Zaffanella, 1994). Another advantage of this method is its ability to identify both the distribution of exposure between subjects and among different microenvironments such as apartments, schools, transportation, outdoor environment, etc. (Roosli et al., 2010). Swanson and Kaune (1999) reported that MFs measured in residential apartments by this method are usually higher, typically by 40% than those measured by spot or long-term measurements. The disadvantage is that personal monitoring requires subject's participation, is impractical for very large number of subjects, and probably inappropriate for retrospective assessment, particularly, in a case-control setting. In addition, it is worth mentioning that a personal meter represents partial-body exposures, hence its relevance for epidemiology need further discussion. Furthermore, it is not appropriate for studies of childhood cancer, where exposure of interest occurs some years in the past, and where participation and representativeness of measurements might differ between cases and controls, both of which can lead to bias.

A surrogate for magnetic field exposure introduced by Wertheimer and Leeper (1979) considered the configuration of power line wiring, including both distribution and high voltage overhead transmission lines, and their distances to the residences of cases and controls. Using wire code as an exposure measure had the advantage of minimizing participation bias by not requiring recruitment and enrollment of cases and controls. Additionally, because power lines tend to maintain the same configuration over many years, wire codes were thought to represent a more stable exposure index than measured magnetic fields. However, wire codes are not an accurate predictor of contemporaneous measurements (Kavet, 1995; Kheifets et al., 1997; Rankin et al., 2002; Maslanyj et al., 2009).

A better alternative, albeit focused only on transmission lines, is using calculated fields, which are based on geometry (i.e., attachment height of conductors, phase spacing, tower location), operating characteristics (temporal characteristics of line load(s), direction(s) of load flow, and phase relationship), and the tower route proximity relative to a residence (Vergara et al., 2015). However, these theoretical calculations depend on availability of historical data and/or assumptions, and usually refer to high voltage power lines only; hence, they are very limited in characterizing everyday exposures from all sources.

Previous works include exposure surveys and estimates of exposure based on many case-control studies in different countries (Linet et al., 1997; UKCCS, 1999; Swanson and Kaune, 1999; Schüz et al., 2001; Kheifets et al., 2006; WHO, 2007). A comparison of large "*Personal monitoring*" exposure surveys (Zaffanella, 1993; Zaffanella and Kalton, 1998; Brix et al., 2001; Yang et al., 2004; Decat et al., 2005) performed by Kheifets et al. (2006) and WHO (2007) generally estimate that 7–12% of the general public is exposed to MFs above 0.2 μT (arithmetic mean), and 4–5% above 0.3 μT (with the exception of Korea with 7.8% above 0.3 μT). Only 1–2% have median exposures in excess of 0.4 μT.

In general, exposures appear to be lowest in Europe, higher in US and Canada and highest in Asia. The later is confirmed by a survey of exposure in households with children under the age of 7 years in Taiwan. While based on in-home measurements, and not personal exposures, they found mean exposures of 7.3% and 5.4% above 0.3 μT and 0.4 μT respectively (Li et al., 2007).

The *ORCHID* project, Hebrew abbreviation of "*National Survey of MFs exposure in Israel*", was initiated by Soreq NRC. The aim of the project, the first of its kind in Israel, was to collect extensive and reliable information regarding the daily exposure of adolescents to power frequency MFs through "Personal monitoring".

2. Material and methods

The *ORCHID* project was conducted in three educational centers. The first two centers were *national centers for gifted children,* one in the city of *Rehovot* (19 adolescents, mostly 9th grade, i.e. approximately 15 years old), and another in the city of *Yavne* (20 children, 6th grade pupils, i.e., approximately 12 years old). In both centers, the participants went through a program of two-hour weekly meetings throughout one semester. During the semester, they conducted different types of MFs measurements, analyzed the data by themselves, and finally presented their results and conclusions, discussing them with their classmates.

The third group was part of an educational program at the *Davidson Institute of Science Education* of the *Weizmann Institute of Science*. Approximately 80 10th grade adolescents (i.e. approximately 16 years old), from all over Israel, participated in 3 meetings in which they were instructed about ELF Magnetic Fields in general and the project in more detail. The study participants might not be representative of the general adolescent's population in Israel.

The educational program in which the three groups participated elucidated the importance of the national ELF exposure survey in general, and of the quality of the measurements in particular. *ORCHID's* educational aspects have been reported elsewhere (Hareuveny et al., 2014).

During the period of May 2013 to June 2014, a calibrated EMDEX II meter (Enertech Consultants, Campbell, CA, USA) was given to each of the participants for 24-h personal monitoring. The survey was conducted during weekdays only. The EMDEX II isotropic meter was operating in a broadband mode (40–800 Hz), continuously recording the MFs every 1.5 s. To avoid measurement bias the meter was set to display the battery status, and not the MF. Although the participants were already well trained, each was given both oral and written detailed instructions before the measurements. They were asked to continue their regular daily behavior (e.g., to avoid unusual contact with appliances) while wearing the meter on their waist or hanging it on their neck, and to document their major activities in a time-activity logbook. The logbook included event number (see hereinafter), hour, microenvironment and comments. Microenvironments were selected in advance based on previous studies and knowledge of the Israeli specific behavior (e.g. use of transportation).

The EMDEX II meter has a push button, which adds an "*Event*" marker to the results file whenever pushed. The participants were asked to mark an event whenever they entered one of the following eight microenvironments: (1) Apartment, awake; (please note that the term apartment is used herein to describe all kinds of residential accommodations, including apartments, single family residents and other) (2) Apartment, asleep - meter was asked to be located as close as possible to the bed; (3) School; (4) Transportation - cars, buses, etc. It is important to note that trams are very rare in Israel; (5) Open public areas such as streets, gardens - both walking and cycling; (6) Other indoor environments (*e.g.* shops, commercial mall); (7) Measurements to be excluded (*e.g.* during swimming and sport lessons) when the meter was not worn, (8) Miscellaneous. After circa. 24 h the meters were collected and the data was downloaded to a PC. Data was examined for quality and completeness and records with high exposures were flagged for further work.

For each participant, we calculated 3 parameters, summarizing personal exposure during the 24-h monitoring period (excluding the