Personal Digital Assistant (PDA) Cell Phone Units Produce Elevated Extremely-Low Frequency Electromagnetic Field Emissions

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Initial tests indicate that personal and occupational use of personal digital assistants (PDAs or palm-held wireless units) produce high intensity bursts of extremely-low frequency electromagnetic fields (ELF-EMF). These emissions could result in comparatively high ELF-EMF exposure in persons that carry a PDA close to the body (i.e., in a pocket or on a belt); or held to the head for cell phone conversations. ELF-EMF emissions of 10 μT were recorded on PDAs during normal office use over a 24 h test period. Results of ELF-EMF measurements show that email transmit and receive functions produce rapid, short-duration ELF-EMF spikes in the 2–10 μT range, each lasting several seconds to over a minute apparently depending on file download size. Some units produced spikes as high as 30–60 μT during email activities. Cell phone activity on PDAs produced continuously elevated ELF-EMF readings in the 0.5–1 μT range, as opposed to the rapid spiking pattern for email receipt and transmission. Switching the PDA unit from ''OFF'' to ''ON'' position resulted in single ELF-EMF pulses of over 90 μT on two units. Email downloads into the PDA can occur randomly throughout the day and night when the unit is ''ON''; thus the user who wears the PDA may be receiving high-intensity ELF-EMF pulses throughout the day and night. The frequency of email traffic on the PDA, and the power switching unit (battery unit) may affect the frequency and intensity of ELF-EMF emissions. Bioelectromagnetics.

Key words: wireless communication devices; emissions; extremely-low frequency electromagnetic fields; precautionary principle

INTRODUCTION AND BACKGROUND

Use of the personal digital assistant (PDA) has become common in the workplace in the last 5 years. A PDA is a handheld wireless device that combines computing, telephone/fax, Internet, and networking features. A typical PDA can function as a cell phone, fax sender, Web browser and personal organizer. Unlike portable computers, most PDAs began as pen-based, using a stylus rather than a keyboard for input. PDAs are also called palmtops, hand-held computers and pocket computers.

PDAs emit both radiofrequency radiation (RF) and extremely-low frequency electromagnetic fields (ELF-EMF). There has been considerable public and scientific interest in evaluating the possible carcinogenicity of cell phones with respect to radio-frequency radiation emissions [Kundi et al., 2004] but not yet for ELF-EMF emissions. There have been few studies reporting on the ELF-EMF emissions from PDAs to date [except Jokela et al., 2004]. Since PDAs can function as cell phones (but provide many other functions than cell phones), the same constellation of possible long-term health effects of these devices with respect to RF exposure would be of public health relevance.

Fifty and 60-Hz ELF-EMF, also known as power-frequency fields, have been reported to be associated with increased health risks since 1979, with the publication of epidemiological results for childhood leukemia in children living near electrical power lines [Wertheimer and Leeper, 1979]. The International Agency for Research in Cancer (IARC) has concluded

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that ELF-EMF is classifiable as a Group 2B (Possible) Carcinogen [IARC, 2001]. The World Health Organization [2002] reported this finding. The NIEHS Working Group and the California Department of Health Services EMF Program Report (2002) concluded that the evidence for increased risk for leukemia makes ELF-EMF exposure classifiable as a 2B (Possible) Carcinogen (Table 21.2, page 379).

MATERIALS AND METHODS

Subjects

Seven participants from two companies in the Silicon Valley area of California who work in high-tech and real estate sales positions, and are typical users of PDAs, consented to be participants in the testing of emissions of their own PDA units (no testing of human subjects was performed). The PDAs were measured during normal, daily business activities. Six participants used a PDA model that runs a CDMA 800/1900 MHz digital protocol and Bluetooth 1.2 for wireless networking. One participant used a 850/900/1800/1900 MHz GSM protocol for cell phone and Bluetooth for wireless networking.

We provided each participant with a recording computer (the EMDEX Lite 60-Hz gaussmeter by Enertech Consultants, Inc. of Campbell, CA). The EMDEX Lite meters are data loggers that record magnetic field measurements for the *x*- *y*- and *z*-axis and compute the resultant (b-field) between 40 and 800 Hz. They were calibrated to record at 4 or 30 s intervals. The test period was specified to be 24 h or more; however, one test resulted in shorter emissions characterizations (Table 1). One test was conducted December 24–25, 2005 at 30 s interval; five tests were conducted January 23–24, 2006 and one test was conducted February 16–17, 2006 at 4 s interval. Each participant attached the EMDEX Lite 60-Hz gaussmeter to the back of their PDA in the same orientation, and turned the gaussmeter to ''ON'' and ''RECORD.'' Following the test period, each participant turned the ''RECORD'' switch off, and returned the meters to us for download and analysis of results. EMDEX Lite identification numbers were recorded for each meter (Table 1). Each meter produced a graphic printout of magnetic field over time. Descriptive statistics (minimum, maximum, mean, median, and standard deviation information), intermittency and exposure-periods were calculated using Enertech software [EMCALC, 2000]. All magnetic field measurements are based on the resultant (square root of the sum of the squares of the *x*-, *y*- and *z*-axis measurements of magnetic field). The software allows for two ways to view the graphed data; we have provided various views by scaling the *y*-axis that reports magnetic field (μT) to 10 μT and 1.6 μT. This allows for greater detail to be viewed, but the reader is cautioned to observe which graphs use the various axis settings for scale.

RESULTS

Results of the survey indicate that PDAs produce intermittent ELF-EMF magnetic field emissions (Fig. 1a and b) in the range of 2 μT to several tens of microtesla. ELF-EMF emissions up to 93.5 μT were recorded during email activities (send/receive mode operational), depending on the PDA unit. Table 1 shows the ID number and hours of survey for each PDA unit tested. Six units had a 24 h or more test period; one unit had a test period of 7 h. Table 1 also shows maximum and minimum ELF-EMF emissions information from each PDA. The total microtesla-hours (μT-hr) emitted by each PDA, and total percent of emissions at 1 μT and above is also shown. Since the test time was variable among units, this metric is not useful for comparisons across all PDAs; however, it does indicate that considerable ELF-EMF emissions occur when the PDA is in normal use during the workday (see results for PDA Units 3 and 5 in Table 1).

In general, very high intensity but short-duration pulses or spikes of ELF-EMF reflect email send/receive activity, and more continuous ELF-EMF elevated fields over time reflect cell phone calls. Email activity usually results in pulses or spikes that last from a few seconds to as much as a full minute. Cell phone calls typically lasted anywhere from a few minutes to 10 min (data not shown).

During email activities, peaks predominantly in the 3–4 μT range were recorded for PDA Unit 1; peaks in the range of 1–3 μT were recorded for PDA Unit 2; peaks in the range of 2–4 μT were recorded for PDA Unit 3; peaks in the range of 1–2 μT were recorded for PDA Unit 4 and 7 during email activity. PDA Unit 5 had email emission peaks commonly over 10 μT, and some peaks reached 30 and 60 μT during email activity. PDA Unit 6 had peaks generally in the 8–13 μT range during email activity (Table 1).

Emissions by the percent of total microtesla-hours that occur in events recorded at 1 μT and above are also reported in Table 1. Such events are remarkable since they reflect high, intermittent pulses of ELF-EMF occurring above 1 μT with great frequency compared to the overall emissions. For PDA Unit 1, twenty-eight percent (28%) of total ELF-EMF as measured by microtesla-hours were recorded at 1 μT and above. Thirty-four percent (34%) of total ELF-EMF emissions for PDA Unit 3, forty-five percent (45%) of for PDA

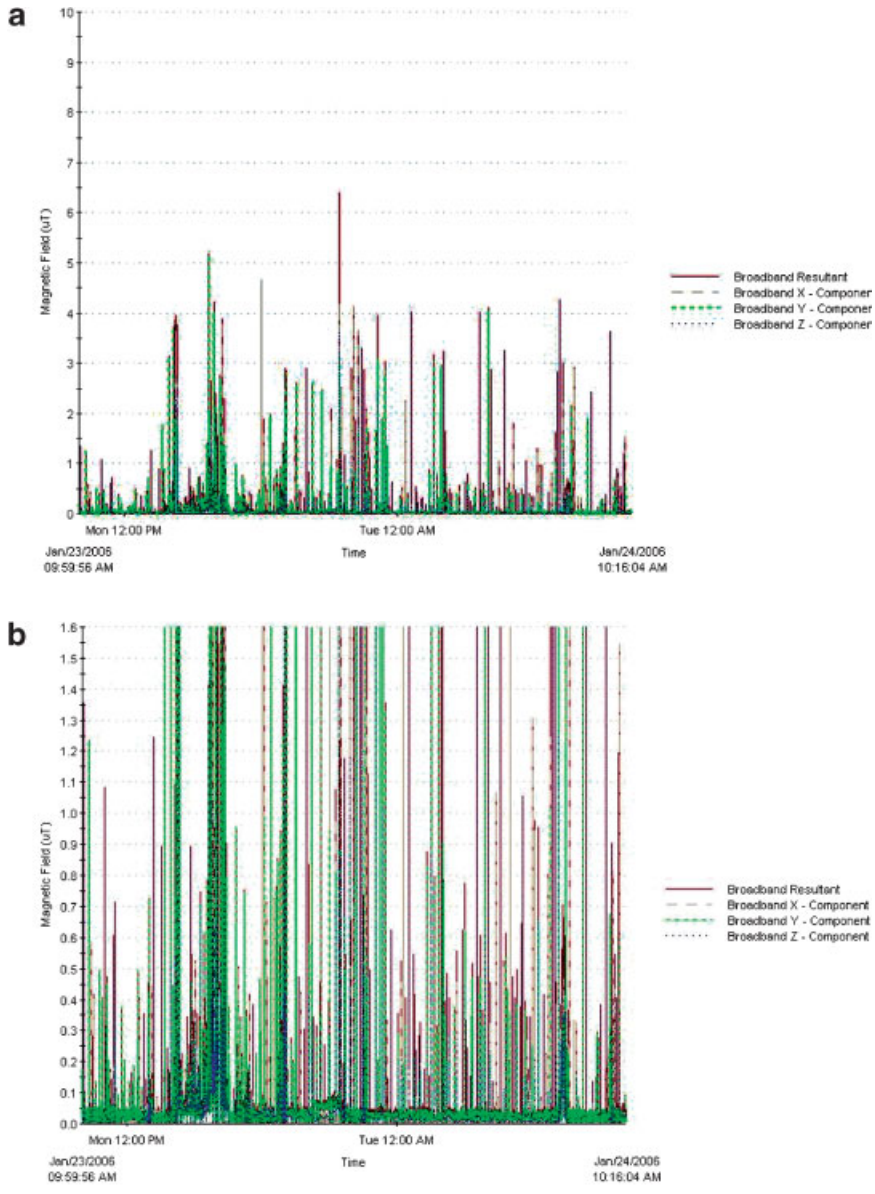

Fig. 1. **a**: Unit 3 PDA (magnetic field over time 10 μT *y*-axis display). **b**: Unit 3 PDA (magnetic field over time 1.6 μT *y*-axis display).

TABLE 1. ELF-EMF Emission Characteristics by PDA Unit

PDA unit #	Survey (hours)	Max. (μT)	Min. (μT)	Total μT-hr	Total % >10 μT	Email use (peak range)	Phone use (peak range)
Unit 1	24	5.3	0.005	1.6	27.90	3–4	0.5–1
Unit 2	7	3.7	0.005	1.0	6.10	1–3	NA
Unit 3	24	6.4	0.005	2.1	33.50	2–4	0.5
Unit 4	29	4.3	0.005	0.9	5.50	1–2	0.5
Unit 5	24	97.5	0.005	4.4	44.50	10–60	1–3
Unit 6	26	90.1	0.003	1.7	70	10–13	NA
Unit 7	24	3.1	0.005	1.8	8	1–2	0.5–1

Unit 5 and seventy percent (70%) for PDA Unit 6 were at 1 μT and above.

PDA Units 5 and 6 recorded maximum ELF-EMF emissions of over 90 μT (97.5 and 90.1 μT, respectively). These events may have occurred when the units were first turned on, and not during normal email send/receive functions or cell phone use, although this cannot be confirmed without further testing. Figure 1a and b shows the general ELF-EMF pattern of magnetic field (μT) for Unit 3 over time. Figure 1a shows the data using a 10 μT *y*-axis scale measuring magnetic field intensity; Figure 1b shows a 1.6 μT *y*-axis scale. Details of this pattern of PDA use and resulting ELF-EMF activity can be better distinguished by decreasing the scale.

PDA Unit 6 had a minimum of 0.003 μT and commonly showed 10 μT and above when sending and/or receiving email. PDA Units 1 and 3 recorded up to 4 μT when sending and/or receiving email. PDA Unit 5 recorded up to 10 μT when sending and/or receiving. PDA Unit 4 recorded less than 2 μT when sending and/or receiving email.

DISCUSSION AND CONCLUSIONS

Use of PDAs has grown exponentially in the last 5 years and represents a new source to humans of ELF-EMF emissions. Use of PDAs on a regular basis could conceivably contribute to the overall ELF-EMF body exposure; particularly when the PDA is worn on the belt, or carried in a pocket close to the body. Because ELF-EMF exposure has been determined to be classifiable as a Group 2B (Possible) Carcinogen [NIEHS Working Group, 1998; NIEHS, 1999; IARC, 2001; WHO, 2002; California Department of Health Services, 2002], the contribution of ELF-EMF from use of PDAs is useful to document and may be advisable to limit in accordance with precautionary public health policies [European Environmental Agency, 2001; Grandjean, 2004]. DNA strand breaks and cell death are reported with ELF-EMF exposure [Lai and Singh, 2004] although some experimental evidence does not support the carcinogenicity of ELF-EMF [McNally et al., 1999]. ICNIRP public exposure standards remain in place and are based on thermal standards which allow for ELF-EMF exposures of 83 μT at 60-Hz and 100 μT at 50 Hz.

In the absence of scientific certainty or proof of effects of ELF-EMF on human cancers, miscarriage and fertility, yet recognizing there is evidence for such a link, prudence dictates a conservative, public health-based approach to public education and prudent avoidance measures at this time. Brain cancer has been associated with ELF-EMF exposure in occupational studies [Mack et al., 1991; Floderus et al., 1993; Armstrong et al., 1994; Theriault et al., 1994; Kheifets et al., 1995; Savitz and Loomis, 1995; Feychting et al., 1997 (meta-analysis); Kheifets, 2001]. Others have failed to find such an association [Törnqvist et al., 1991; McLaughlin et al., 1987; Sahl et al., 1993].

In addition to brain cancer, ELF-EMF has been reported to increase the risk of adult leukemia and lymphoma, male and female breast cancer, and ALS or Lou Gehrig's disease, where exposures have been linked to various sources of ELF-EMF including power lines, appliances such as video-display terminals (VDTs), switchboard equipment and work in the telephone and utility industries [Matanoski et al., 1991; Floderus et al., 1993; Feychting and Ahlbom, 1994; Loomis et al., 1994; Rosenbaum et al., 1994; Feychting et al., 1997; Kheifets et al., 1997]. Armstrong et al. [1994] reported that pulsed electromagnetic fields (PEMFs) were significantly associated with increased risk of cancer in utility workers although other utility worker studies report negative results [Sahl et al., 1993]. Miscarriage has been associated with intermittent ELF-EMF exposure at 1.6 μT [Lee et al., 2002; Li et al., 2002] but not with a measure of time-weighted average (TWA) exposure metric, which is consistent with the results of Schnorr et al. [1991] who used the TWA exposure metric and found no increased risk for spontaneous abortion.

Average Residential and Occupational Exposures

To provide context for emissions related to PDAs, some common levels of EMFs in daily life are provided here. Exposures to ELF-EMF where electrical power or electrical devices are in use have been assessed in numerous exposure assessment studies. Many common household electric devices produce 10–50 μT at the unit, but magnetic fields for such appliances fall off rapidly with distance, so emissions do not occur directly at the body. Very few common appliances require the user to place the head or body directly against the appliance; so PDAs will result in atypically elevated ELF exposures for the user in comparison to appliances with equally elevated magnetic fields at their source.

The earth's geomagnetic (static) field is another source of exposure, but this field is a natural part of the environment under which all life on earth evolved, and is unlike the artificial magnetic field produced by an appliance or PDA. Appliances or PDAs emit ELF signals that contain both intensity and frequency information; it is the combination of these information categories that has been shown to be biologically active at low intensities [Adey, 1992; Liboff, 1992]. The earth's geomagnetic field intensity can vary from about

30 to 70 μT depending on location on the earth's surface, and this can sound quite high when improperly compared to electric appliances. However, the geomagnetic field is not comparable to man-made ELF magnetic fields from appliances or PDAs in terms of potential health concerns.

Average US residential exposures provide useful comparisons to PDA emission levels for context, and are in the 0.05–0.09 μT range [Zaffanella, 1994]. Surveys of average magnetic field exposures in US offices range from 0.04 to 0.07 μT [NIEHS, 2002] and 0.1 μT to 0.2 μT [EPRI, 1994a, b]. The high range ELF-EMF exposures for US workers have been identified by Zaffanella (1998) and Bowman [NIEHS, 2002] for welders (to 9.6 μT); power line workers (to 3.5 μT); electricians (to 3.4 μT); and machinists (to 2.8 μT). When in use, appliances can produce localized ELF-EMF at several tens of μT, but exposures fall off rapidly with increasing distance. For example, an ELF-EMF measurement at a clock radio or transformer for an answering machine might register 30–40 μT at the appliance, but fall to ambient (less than 0.01 μT) at three feet distance. Electric subpanels in buildings produce emissions profiles similar to PDAs at close range [Sage and McGibbon, 1991; NIOSH, 1995; Sage and Biergiel, 1995; NIOSH, 1996; Sage, 1997; Sage, 2000], but people rarely stand or sit beside them for extended periods of time. As electrical load is drawn through a subpanel, it will produce emissions that vary in intensity similar to a PDA in the email send/receive operational mode.

Caution in interpreting the data is warranted. The authors speculate that on the basis of a link between ELF-EMF and cancer in humans, there is sufficient evidence to trigger interim prudent actions to reduce avoidable exposures to ELF-EMF where it is easy and cost-effective to do so. People use PDAs in a variety of ways, and can substantially reduce personal exposure below those emission levels discussed here. This study measures ELF-EMF emissions only, and not personal exposures. However, for people who do wear the PDAs on their person—as most people do—the ELF-EMF exposures could be sufficiently elevated as to dwarf other emissions from typical personal and office sources of ELF-EMF. With respect to potential health effects and pregnancy outcome [Lee et al., 2002; Li et al., 2002] these ELF emissions are creating some of the higher ELF-EMF exposures to which people at home and work are routinely exposed and at levels that have been correlated with adverse effects on miscarriage (intermittent ELF-EMF above 1.6 μT). ELF emissions at 25 μT were reported to significantly reduce sperm count, testosterone levels and the weight of seminal vesicles in exposed animals, suggesting that long-term exposure to ELF could have adverse effects on mammalian fertility and reproduction [Al-Akhras et al., 2006]. Exposure of male and female rats exposed to 25 μT of ELF magnetic fields reduced fertility in both sexes, and the number of implantations and living fetuses per litter were statistically significantly reduced [Al-Akhras et al., 2001]. Combined with reported genotoxicity of 900 MHz radiofrequency radiation from cell phone use on mitochondrial DNA in the male germ line [Aitken et al., 2005], and human semen quality and sperm mobility [Feyes et al., 2005], the potential effects of PDAs on fertility and reproduction may be of public health consequence.

Precautionary actions that would potentially reduce ELF-EMF exposure from PDAs could include (1) carrying the PDA in a briefcase or purse rather than wearing the unit in a pocket or on a belt, (2) keeping the PDA ''OFF'' or ''not transmit/receive mode'' except to download and send emails or for other internet functions; (3) placing the PDA in the opposite car seat when traveling, rather than in the lap or on the person; (4) using an earpiece (headset) for all cell phone calls—again placing the PDA away from the body by several feet; and (5) using a land-line for telephone calls rather than the PDA whenever possible.

Further Work

Personal exposure assessment and evaluation of possible health risks due to ELF-EMF is lacking. This is a small, pilot study and results warrant further investigation. There are more than three (3) million PDA users in the United States, and the reliance on PDA-type devices is growing quickly. Since participants did not keep detailed logs of each activity, some events which show high peak pulse ELF-EMF could be related to battery charging, dialing out to connect a cell phone call that did not result in a live call, turning the PDA unit on and off, or running low on battery. Such spikes in ELF-EMF could be attributable to non-routine events. As the recording interval was once each four (4) or thirty (30) seconds, some very rapid ELF-EMF pulses will not have been recorded (pulsed ELF-EMF of only one or 2 s could be missed). Future work could include more participants, longer survey periods, and written logs of personal activities to correlate with events triggering ELF-EMF emissions.

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