International Journal of Hygiene and Environmental Health 218 (2015) 331–344

Contents lists available at ScienceDirect

International Journal of Hygiene and Environmental Health

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

Actual and perceived exposure to electromagnetic fields and non-specific physical symptoms: An epidemiological study based on self-reported data and electronic medical records

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ARTICLE INFO

Article history:
Received 4 December 2014
Received in revised form 2 February 2015
Accepted 2 February 2015

Keywords:
Non-specific physical symptoms
Electromagnetic fields
Non-ionizing radiation
IEI-EMF
Epidemiological studies

ABSTRACT

Background: There is continuing scientific debate and increasing public concern regarding the possible effects of electromagnetic fields (EMF) on general population's health. To date, no epidemiological study has investigated the possible association between actual and perceived EMF exposure and non-specific physical symptoms (NSPS) and sleep quality, using both self-reported and general practice (GP)-registered data.

Methods: A health survey of adult (≥18) participants ($n = 5933$) in the Netherlands was combined with the electronic medical records (EMRs) of NSPS as registered by general practitioners. Characterization of actual exposure was based on several proxies, such as prediction models of radiofrequency (RF)-EMF exposure, geo-coded distance to high-voltage overhead power lines and self-reported use/distance of/to indoor electrical appliances. Perceived exposure and the role of psychological variables were also examined.

Results: Perceived exposure had a poor correlation with the actual exposure estimates. No significant association was found between modeled RF-EMF exposure and the investigated outcomes. Associations with NSPS were observed for use of an electric blanket and close distance to an electric charger during sleep. Perceived exposure, perceived control and avoidance behavior were associated with the examined outcomes. The association between perceived exposure was stronger for self-reported than for GP-registered NSPS. There was some indication, but no consistent pattern for an interaction between idiopathic environmental intolerance (IEI-EMF) and the association between actual exposure and NSPS.

Conclusions: In conclusion, there is no convincing evidence for an association between everyday life RF-EMF exposure and NSPS and sleep quality in the population. Better exposure characterization, in particular with respect to sources of extremely low frequency magnetic fields (ELF-MF) is needed to draw more solid conclusions. We argue that perceived exposure is an independent determinant of NSPS.

Introduction

The extensive use of mobile phone devices and associated communication systems and the increasing installation of mobile phone base stations and high-voltage overhead power lines has led to public concern and continuing scientific debate regarding the potential health effects of exposure to electromagnetic fields (EMF) in the general population (Kowall et al., 2012). Recently, the International Agency for Research on Cancer (IARC) classified exposure to radiofrequency (RF) EMF as "possibly carcinogenic" (Baan et al., 2011) and there is evidence that extremely low

Abbreviations: EMF, electromagnetic fields; RF-EMF, radiofrequency EMF; ELF-MF, extremely low-frequency magnetic field; NSPS, non-specific physical symptoms; IEI-EMF, idiopathic environmental intolerance attributed to EMF; GP, general practice.

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http://dx.doi.org/10.1016/j.ijheh.2015.02.001
1438-4639/

frequency magnetic field (ELF-MF) may be associated with childhood leukemia (Zhao et al., 2014).

In addition to these diagnosed medical conditions, also a broad range of symptoms has been suspected to be associated with EMF, such as headache, fatigue, dizziness, sleep problems, ear symptoms and skin sensations (Genuis and Lipp, 2011). Self-reported (hyper)sensitivity and/or attribution of such symptoms to EMF sources, has been described by the WHO as idiopathic environmental intolerance attributed to EMF (IEI-EMF) (Baliatsas et al., 2012a; Hillert et al., 2006). Recent evidence from experimental and observational studies consistently suggests that there is no convincing evidence for an association between such symptoms and related physiologic reactions and exposure to EMF (Augner et al., 2012; Baliatsas et al., 2012b; Leitgeb, 2012; Röösli et al., 2010a; Rubin et al., 2010, 2011). Since the cause of these complaints seems to be unclear, they are often referred to as "Medically Unexplained (Physical) Symptoms" (MUPS) (van den Berg, 2007) or alternatively, "Non-specific (Physical) Symptoms" (NSPS) (Baliatsas et al., 2011, 2014).

The current methodological challenges in this research field denote that there is still scope for better research, especially in the epidemiological domain (Baliatsas and Rubin, 2014). While experimental ("provocation") studies can assess only short-term exposure and effects in small population subgroups, epidemiological studies fill this gap by allowing for the investigation of long-term exposure and outcomes in large samples under normal living conditions. However, exposure characterization remains a major challenge.

Exposure in daily life occurs from far-field sources (e.g. fixed transmitters for radio and television and mobile phone base stations) as well as from an array of near-field sources (e.g. DECT telephones and wireless networks). All these contribute to an individuals' personal exposure to a varying degree depending on proximity, source type, source usage and a number of other contextual parameters (Frei et al., 2010).

On the one hand, assessment of exposure that relies exclusively on self-report leads to severe misclassification (Frei et al., 2010; Hutter et al., 2012; Inyang et al., 2008; Shum et al., 2011) and should rather be used as an indicator of the individual perception of being exposed (Baliatsas et al., 2012b; Röösli, 2008). On the other hand, only a limited number of epidemiological studies has used methodologically advanced proxies of actual field strength such as spot measurements, personal exposimeters and prediction modeling (Röösli et al., 2010a; Baliatsas et al., 2012b). Still, these approaches are also not free of limitations.

For example, spot measurements provide information only on exposure for specific locations at specific (typically short) times (Frei et al., 2010); personal exposure measurements, although more advanced as a surrogate, are costly, labor-intensive and prone to shortcomings related to e.g. calibration, and body shielding (Bolte et al., 2011; Mann, 2010). It is also unclear whether the use of personal exposure monitors may bias response and systematically alter participants' exposure-related behavior and/or their tendency to perceive exposure. Furthermore, the association between ELF-MF exposure and NSPS in the population has been scarcely investigated (Baliatsas and Rubin, 2014). Bearing these methodological issues in mind and the fact that a biological mechanism for NSPS in relation to EMF is unknown, it is of importance to take into account exposure from all relevant sources (Frei et al., 2012). A prediction model based on modeled exposure from fixed transmitters and exposure-relevant activities may be the best compromise in terms of both adequate characterization and cost-effectiveness (Bolte et al., 2011).

Proper outcome assessment is also a fundamental and still challenging part of research on EMF and NSPS, since the cut-off points for considering a symptom as present or severe vary across studies and it is unknown whether they can be of clinical relevance (Baliatsas et al., 2012b, 2014). The use of data based on symptoms registered in electronic medical records (EMR) of general practices (GP) overcomes such disadvantages and facilitates the comparability of outcome assessment between studies (van den Berg, 2007). Assessment based on symptom scores can be a sound approach, given the possibly large variation of physiological reactions to EMF, if a bioelectromagnetic mechanism exists (Tuengler and von Klitzing, 2013) and considering that scores on symptom number and duration are consistent indicators of severity in environmentally sensitive people and the broader population (Baliatsas et al., 2014; van den Berg et al., 2005).

In addition to research on the possible association between actual EMF exposure levels and NSPS in the population, it is also important to explore the psychological framework through which symptoms may occur, expanding the standard risk-factor approach. A strong body of evidence from experimental studies suggests that NSPS can occur when people believe they are exposed, irrespective of whether their belief is accurate or not (Röösli, 2008; Röösli et al., 2010a; Rubin et al., 2010; Szemerszky et al., 2010). It has been suggested that this could indicate a so-called "nocebo" effect, in which the perception of exposure triggers a self-fulfilling expectation of symptom occurrence (Rubin et al., 2010; Szemerszky et al., 2010).

A number of studies have also emphasized the predictive value of psychological factors in the report of NSPS attributed to EMF, such as environmental worries, dysfunctional cognitions, avoidance of exposure as a strategy to cope with the perceived environmental stressor, anxiety, depression, and increased body awareness and somatosensory amplification (Frick et al., 2002; Johansson et al., 2010; Koteles et al., 2011; Landgrebe et al., 2008; Nordin et al., 2010; Rubin et al., 2008; Witthöft and Rubin, 2013). These seem to be conceptually in line with a generic mechanism of environmental stress (Lazarus and Folkman, 1984; van Kamp, 1990) and more recent cognitive and behavioral models elaborating on medically unexplained symptoms (Rief and Broadbent, 2007; Witthöft and Rubin, 2013). However, the majority of these studies have been focusing on small samples of environmentally sensitive subgroups and in many cases, actual exposure was not considered. In contrast, there is limited knowledge on the role of perceived exposure and potentially relevant psychological variables such as perceived control and coping, in EMF epidemiology (Baliatsas et al., 2011, 2012b). Although a few recent studies (Frei et al., 2012; Heinrich et al., 2011; Mohler et al., 2010, 2012) included variables such as environmental worries, these were solely treated as confounders.

Finally, although people with IEI-EMF experience poorer health, increased illness behavior and more severe NSPS compared to non-sensitive individuals (Baliatsas et al., 2014), very limited evidence exists on the moderating role of IEI-EMF on the association between symptomatology and actual and perceived exposure (Röösli et al., 2010b).

The investigation of the predicting and moderating role of perceived exposure and psychological variables, taking objective exposure estimates into account, could add further to the knowledge about potential determinants of NSPS within the context of environmental health. The current study therefore adopts a multidisciplinary approach on exposure characterization and outcome assessment, investigating proxies of RF-EMF and ELF-MF as well as perceived exposure in relation to both self-reported and GP-registered data. Furthermore, it makes a first step toward the investigation of the potential role of psychological variables in symptom report.

The main research questions addressed were: (1) What is the association between self-reported and GP-registered NSPS