Occupational exposure to electromagnetic field and prevention of possible adverse effects in workers: results of 20 years of research at the University of Modena and Reggio Emilia

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Abstract: *The occupational risk related to electromagnetic fields (EMF) exposure in workplaces was one of the main research fields developed in the last 20 years by the Chair of Occupational Medicine and the Chair of Hygiene of the Public Health Section of the Department of Biomedical, Metabolic and Neural Sciences, University of Modena and Reggio Emilia. During this period we have approached several topics in the field of exposure and prevention of EMF risk in occupational settings, including:*

- *the occupational and environmental Extremely Low Frequency – Electromagnetic Fields (ELF-EMF) exposure and effects in different groups of workers;*
- *the possible mechanisms of ELF-EMF effects in biological tissues;*
- *the development of best practices to manage and prevent the EMF related occupational risk in workers according to the European Directives, with particular consideration for health surveillance of exposed workers;*
- *the occupational risk and the health surveillance of Magnetic Resonance Imaging operators;*
- *the epidemiology of proposed adverse long-term effects of occupational EMF exposure.*

1. Introduction

Electromagnetic Fields (EMF) are almost ubiquitous in workplaces, and the large majority - almost all – of workers are potentially exposed. Consequently, an adequate evaluation of the occupational risk related to EMF exposure is important to implement an effective prevention, as recognized by authoritative Institutions as the International Labour Organization (ILO) [1] and the World Health Organization (WHO) [2,3]. In Europe a specific Directive, the 2013/35/EU [4], replacing the previous Directive 2004/40/EC [5], has been recently implemented in European Countries, including Italy [6,7], introducing the legal requirement of health surveillance of EMF exposed workers and other important measures for the prevention of EMF related occupational risk. The EU Directive considers only the possible adverse short term effects of EMF exposure in workers, as it states that currently there is no adequate scientific evidence on the possibility of long term adverse health effects, introducing occupational limits based on the results of the works of the International Commission of Non Ionizing Radiation Protection (ICNIRP) [8-10].

Since early 2000s' the Chair of Occupational Medicine of the University of Modena and Reggio Emilia, in collaboration with the Chair of Hygiene and the Department of Animal Biology, is conducting research to evaluate occupational EMF in exposed workers and to study the possible health risk, with the aim of producing recommendation for an effective prevention of the occupational EMF risk. These research activities were presented in more than thirty published scientific contributions in last 20 years: a summary of the results of the studies conducted will be given in the following paragraphs. Furthermore our Research Unit

is included in the *"Centro nazionale di ricerca Interuniversitario sulla Interazioni fra Campi Elettromagnetici e Biosistemi"* (ICEMB) [11] and it is collaborating with several national and international scientific associations and institutions as:

- in Italy:

  a) the Italian Association of Medical Radioprotection (Associazione Italiana di Radioprotezione Medica – AIRM) and the Italian Society of Occupational Medicine (Società Italiana di Medicina del Lavoro – SIML) to produce the guidelines for the health surveillance of EMF exposed workers [12], currently in the process of being updated;

  b) the Italian National Workers' Compensation Authority (Istituto Nazionale per l'Assicurazione contro gli Infortuni sul Lavoro – INAIL), the National Institute of Health (Istituto Superiore di Sanità (ISS) and a national Committee for the safety and health at the workplaces ("*Coordinamento Tecnico per la sicurezza nei luoghi di lavoro delle Regioni e delle Province autonome*") to produce specific operative indications, currently in the process of being updated, for the evaluation of EMF related occupational risk in the workplaces and for the prevention of possible adverse effects in accordance to the national legal requirements [13];

- international activities:

  c) the WHO in the International EMF project, participating to the International Advisory Council (IAC) annual meetings [14];

  d) the International Commission on Occupational Health (ICOH), as active members of the Scientific Committee "Radiation and Work" [15], and organizing specific scientific sessions on the EMF related occupational risks at the world ICOH conferences in 2015 and 2018.

2. Main results of the research activities carried out at the Chair of Occupational Medicine of the University of Modena and Reggio Emilia in the last twenty years

As stated in the introduction, the research activities carried out in the last 20 years at the Research Unit of the University of Modena and Reggio Emilia have approached several topics of interest for the prevention of EMF risk in occupational settings. Here following we present a very brief summary of the major findings of our research.

- *Experimental studies with mussels' animal models to evaluate possible intra-cellular alterations related to low frequency EMF exposure.*

Since early 2000s' we performed experimental studies using different invertebrate animal models to evaluate possible intra-cellular alterations related to low frequency EMF exposure [16-21]. We focused in particular on the possible alterations of K^+ and Ca^{2+} channels in the plasma membrane of mussels' immunocytes exposed to 50 Hz sine wave magnetic fields of various strengths. We found that 50 Hz EMF exposure reduced the shape changes in the immunocytes induced by a chemotactic substance (N-formyl-Meth-Leu-Phe), and this effect involved K^+ and Ca^{2+} channels with reversible alterations, suggesting that the damage to these ions channels induced by short EMF exposure at appropriate intensities is not permanent [16-21]. We report here a Table from our paper [16] where the shape factors (SF) values (i.e. the changes in cell shape in immunocytes) of Mitylus galloprovincialis immunocytes after exposure to 50 Hz EMF of various intensities are presented (Table 1).

TABLE 1. Shape Factor values of Mytilus galloprovincialis immunocytes after exposure to 50 Hz EMF of various intensities (adapted from Ottaviani et al. 2002 [16])

Shape Factor						
EMF exposure intensity (μT)	EMF exposure duration (min)	0	5	10	15	20
200	30	0.81±0.01	0.66±0.01*	0.54±0.01*	0.55±0.01*	0.46±0.01*
300	15	0.79±0.02	0.63±0.01*	0.56±0.02*	0.53±0.01*	0.52±0.01*
	30	0.81±0.01	0.72±0.01*,**	0.69±0.02*,**	0.66±0.01*,**	0.60±0.01*,**
400	15	0.83±0.01	0.78±0.01	0.72±0.01	0.67±0.01*	0.64±0.02*
	30	0.83±0.02	0.78±0.01	0.72±0.01	0.69±0.02*	0.68±0.01*
500	15	0.80±0.02	0.79±0.01	0.77±0.01	0.72±0.02	0.68±0.01*
	30	0.81±0.01	0.76±0.01	0.74±0.02	0.70±0.01	0.65±0.01*
600	15	0.84±0.01	0.80±0.01	0.79±0.02	0.79±0.01	0.73±0.02
	30	0.83±0.02	0.77±0.01	0.79±0.01	0.78±0.02	0.74±0.01

The mean±SD of 50 immunocytes for each exposure to 50 Hz EMF is shown. The shape factor values were calculated after exposure of the animals to EMF for 15 and 30 minutes followed by the addition of N-formyl-Meth-Leu-Phe. Statistical analysis was peformed by ANOVA.
**p<0.01 vs. time 0 **p<0.01, 15 min vs. 30 min.*

- *Research aimed to study the occupational EMF exposure of different groups of workers and the possible health effects*

The main objectives of the research aimed to study occupational EMF exposure were to assess the individual extremely low frequency (ELF) EMF exposure in a large group of workers, and to evaluate the specific contribution of occupational and environmental exposure, also using a specific Job Exposure Matrix (JEM). Furthermore, we also evaluated samples of the peripheral blood of the exposed workers, to study possible alterations in the lymphocytes [22-33].

The main study carried out for the occupational ELF-EMF exposure evaluation [30] involved a large group of workers from the ceramics, mechanical engineering, textiles, graphics, retail, food, wood and biomedical industries, with results of personal EMF exposure measurements for 123 different working tasks coded according to the ISCO 88 classification (International Labour Organization, 1991) and 543 workers (383 men and 160 women), aged 17–62 years (mean value 38 years). In all workers ELF-MF exposure was measured using personal magnetic field meters (EMDEX Lite, Enertech Consultants, Campbell, CA, USA), specifically designed to assess and monitor exposure to power frequency (50/60 Hz and their harmonics) magnetic fields, and able to measure the broadband magnetic flux density B in the frequency range 40–1000 Hz (Figure 1).

Figure 1. EMDEX Lite personal dosimeter (Enertech Consultants, Campbell, CA, USA) used to assess and monitor exposure to power frequency (50/60 Hz and their harmonics) magnetic fields in groups of workers

All participants wore the meter in a waist-height pouch, both at work and during non working hours, and they were instructed to make a short note in a diary of the periods of the day spent at work, at home, or elsewhere, while wearing the instrument. The meters were programmed to record the B field at any 10-s time step.
Individual exposure levels measured using personal meters worn for 2 complete work shifts resulted in >5750 measurements, with a median exposure during the work-shift of 0.14 μT (5° - 95° pct= 0.04-2.50 μT). In table 2 the distribution of the workers according to different individual ELF-EMF exposure levels is shown. In the large majority (approximately the 80%) of the workers, occupational exposure to ELF-EMF was found to be lower than 0.4 μT, for the 95% of the workers it was < 2.5 μT. Non occupational exposure resulted lower compared to the occupational one, concluding that occupational activities gives the largest contribution to the overall 24 hours individual ELF-EMF exposure.

TABLE 2. Distribution (%) of 543 workers involved in various industrial activities in Italy according to different individual ELF-EMF exposure levels in (adapted from Gobba et al. 2011 [31])

EXPOSURE LEVELS	*% WORKERS*
< 0.2 μT	**65**
< 0.3 μT	**75**
< 0.4 μT	**80**

Moreover, as ELF-EMF were classified as a possible carcinogen to humans (Group 2B IARC) related to epidemiological results on childhood leukemia, we examined a sample of workers to evaluate the Natural Killer (NK) activity in peripheral blood lymphocytes (PBL). We monitored individual ELF-EMF exposure during 3 complete work-shifts, using EMDEX Lite meters, and collected peripheral blood samples in 52 workers. In the whole group the median TWA occupational exposure resulted 0.21 μT: according to the exposure levels found, workers were classified as lower exposed (26 subjects exposed to ≤0.2 μT) or higher exposed (26 subjects exposed to ≥0.2 μT). In the highly exposed group we observed a trend of a reduced NK activity compared to the lower exposed group, but the difference was not significant. When selecting a subgroup of workers (12 subjects) exposed to ≥1 μT we found a significant reduction in NK activity in this group compared to workers exposed to ≤0.2 μT, suggesting a possible reduction of the defence role of the NK cells in workers exposed to high levels of ELF-EMF [30]. The possible genotoxicity of ELF-MF, and also the effect on melatonin were also studied, without evidence of any significant effect in exposed workers [23, 26, 27].
More recently, in collaboration with Tampere University (Finland) our research in the evaluation of occupational exposure to ELF-EMF focused more on preventive interventions to reduce the exposure. In particular we tested e.g. the possibility to decrease the ELF-EMF exposure with a Faraday Cage under a 400 kV power line, performing experiments with different nets for the “roof” of the cage, and we found that the roof had a very significant effect on the electric fields (1.0 kV/m → 0.02–0.06 kV/m) as the grounded Faraday cage decreased the electric field more than 50% inside the cage.
The quality of the net was not that important, but it supported the idea that the smaller the mesh size, the better the field attenuation. Earlier, we also tested different jackets and coveralls under the 400 kV power lines. It can be stated that normal coveralls or jackets do not decrease human exposure to electric fields, but with protective coveralls, it is possible to

decrease electric field exposure to about half. We did not measure magnetic fields in this phase, but we assume that magnetic fields are attenuated much less than electric fields.
In conclusion, it is possible to create safer and more comfortable working conditions under the 400 kV power lines by using metallic cage and grounding handled metallic objects [33].

- *Scientific contributions to identify the best practices to manage and prevent the EMF related occupational risk, according to the European Directives, with particular consideration for workers' health surveillance*

As stated in the introduction, the occupational risk related to EMF exposure has aroused increasing attention during the past two decades, and, as Chair of Occupational Medicine, our recent research has been focused in particular to the identification of best practices for the management and prevention of this occupational risk, according to the European Directives, and with particular consideration for workers' health [12, 13, 34-41]. Since 2013, in the European Union (EU), the Directive 2013/35/EU, replacing the previous Directive 2004/40/EC, has introduced the legal obligation of an 'appropriate health surveillance' (HS) for workers exposed to electromagnetic fields (EMF). Until now no agreement exists on the criteria, and on the contents, of such an HS. The EU Directive specifically refers to the protection from the risks associated with known direct biophysical and indirect short-term effects caused by EMF, while does not address to the suggested long-term effects since scientific evidence of a causal relationship is considered not adequate. Accordingly, a specific objective of the workers' HS is the prevention of established effect, such as the stimulation of muscles, nerves or sensory organs (including temporary annoyance or effects on cognition) and limb currents, or any thermal effects. The HS should be focus in particular to the recognition of the workers 'at particular risk', e.g. workers with active implanted medical devices (cardiac pacemakers, ICD, insulin pumps, etc.) or pregnant workers; nevertheless a comprehensive definition of the conditions inducing a 'particular risk', and of the safe thresholds, are still lacking. HS is therefore mainly aimed to evidence the occurrence of clinical symptoms possibly related to EMF and the existence of conditions possibly inducing particular risk, while specific laboratory tests are not required, except on individual clinical basis [41].

- *Research on the EMF related occupational risk and possible adverse health effects in Magnetic Resonance Imaging operators.*

More recently, considering that Magnetic Resonance Imaging (MRI) is a rapidly expanding technology in recent years and MRI operators are exposed to high levels of electromagnetic fields (EMF), mainly static magnetic fields and low frequency time-varying magnetic fields (TvMF), we focused our research on the EMF related occupational risk and possible adverse health effects in Magnetic Resonance Imaging operators [42-50]. In particular, we studied the possibility of an increased prevalence in these workers of various sensorial non-specific symptoms, included also some more specific 'core symptoms' (vertigo, nausea, head ringing, magnetophosphenes and metallic taste), using an ad hoc questionnaire based on scientific literature. We performed a subjective investigation of >200 MRI operators from different Italian hospital and research centers equipped with a MRI scanner. As no measurements were available, we considered the intensity of the scanners used and the reported mean number of MRI procedures followed per year by the operators as a proxy of the exposure. We found a positive but non-significant correlation between the total number of MRI procedures followed and the total number of sensorial symptoms reported by the workers. Among the symptoms studied, the significant association was found for nausea, drowsiness and metallic taste (Table 3). It has to be noted that nausea and metallic taste are among the "core symptoms", proposed

also in other scientific literature studies, and therefore they could be considered more specific for being monitored during MRI operators' health surveillance performed by occupational physicians [49].

Table 3 – Mean number of annual procedures conducted by the Italian MRI operators referring or not sensorial symptoms (adapted and updated from Zanotti et al. 2018 [49])

	Mean number of procedures		
	Symptom YES	Symptom NO	p value
Vertigo	(n=9)		
	628.9±518.6	607.9±712.5	0.21
Nausea*	(n=2)		
	105.0±77.8	61.5±182.7	**0.02**
Concentration problems	(n=1)		
	671.9±1058.3	603.2±664.9	0.28
Memory loss	(n=6)		
	528.3±523.4	611.8±709.1	0.46
Drowsiness	(n=43)		
	793.2±808.5	549.9±657.8	**0.04**
Headache	(n=36)		
	652.5±717.4	597.9±701.2	0.22
Metallic taste	(n=2)		
	2150.0±1909.2	591.4±671.6	**0.04**
Instability	(n=10)		
	649.0±722.8	606.6±703.7	0.47
Magnetophosphenes	(n=0)		
	0.0±0.0	609.0±702.8	–
Tinnitus	(n=6)		
	718.3±496.0	605.2±709.7	0.17
Sleep disorders	(n=25)		
	726.0±854.0	589.8±676.1	0.37

**for nausea we have reported here only the results indicating a significant difference for MRI operators using scanners with an intensity >3 T*

- *Epidemiology of possible adverse long-term effects related to high frequency EMF exposure*

During last years, our research interest shifted also to the radiofrequency (RF) part of the EMF spectrum, considering the increasing attention, also in occupational settings, on possible RF exposure related long-term adverse effects, with particular regard to mobile phone use, especially after the 2011 International Agency for Research on Cancer (IARC) classification of RF-EMF as possibly carcinogenic to humans (group 2B). Considering the large increase in mobile phone users from the '80s, an increase in incidence of these very rare brain tumors should be expected. We are currently performing research to review scientific literature regarding epidemiologic studies on the possible association between RF exposure and brain cancers, monitoring also the incidence trends of gliomas, and possibly of acoustic neuromas, in last decades in Italy [51-54]. Epidemiologic data collected to date do not support different conclusions on the possible carcinogenicity of RF-EMF.

3. Concluding Remarks

The research activities carried out in the last 20 years at the University of Modena and Reggio Emilia have approached several areas in the field of occupational exposure to EMF and prevention in workers, The results of our studies on exposure levels to ELF-EMF in workers engaged in various industrial activities in Italy enabled us to propose an Italian occupational Job Exposure Matrix. Among the preventive measures in EMF exposed workers, an important role has to be given to the health surveillance, a medical procedure to be performed by trained occupational physicians in accordance to the 2013 European Directive. For an appropriate health surveillance, a special attention has to be deserved to the recognition of workers with particular sensitivity for EMF risk (e.g. workers wearing implanted active medical devices): our group is working to the development of adequate protocols. Recently, one of the occupational settings with possibly high exposure levels are the operators involved in MRI work: the personnel engaged in this activity has to be adequately protected from possible sensorial effects induced by the intense static magnetic field of the MRI scanner, in particular if the workers perform rapid movements close to the scanner; we are working for a better definition of the symptoms to be investigated, and to monitor the occurrence and trends of such symptoms in MRI operators. Finally, regarding the possible long-term adverse effects of low EMF exposure in occupational settings, the data collected until now do not support the hypothesis of any causal-related adverse health effect in workers.

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