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Safety Management of Electromagnetic Fields in the Work Environment

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Declaration:
Hereby I declare that this doctoral thesis, my original investigation and achievement, submitted for the doctoral degree at Tallinn University of Technology, has not been submitted for doctoral or equivalent academic degree.

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Elektromagnetväljade ohutusjuhtimine töökohtadel

TARMO KOPPEL

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List of publications

I M. Carlberg, **T. Koppel**, M. Ahonen, L. Hardell. 2017. Case-control study on occupational exposure to extremely low-frequency electromagnetic fields and glioma risk. *Am J Ind Med*., 60, 494–503, **ETIS 1.1,** ISI Web of Science.

II L. Hardell, **T. Koppel**, M. Carlberg, M. Ahonen, L. Hedendahl. 2016. Radiofrequency radiation at Stockholm Central railway Station in Sweden and some medical aspects on public exposure to RF fields. *International Journal of Oncology*, 49, 1315–1324. **ETIS 1.1,** ISI Web of Science

III **T. Koppel,** I. Vilcane, P. Tint. 2017. Risk management of magnetic field from industrial induction heater - a case study. "*Proceedings of the 18th International Scientific Conference: Engineering for Rural Development 2017*", 27–28 April, Jelgava, 1024–1037, **ETIS 3.1.**

IV **T. Koppel,** I. Vilcane. 2018. Safety compliance of occupational exposure to electromagnetic fields. *Research in Economics and Business: Central and Eastern Europe*, vol 10(1), 5–28. **ETIS 1.2**.

V Supportive article A1: **T. Koppel,** P. Tint. 2014. Reducing exposure to extremely low frequency electromagnetic fields from portable computers. *Agronomy Research*, **12**(3), 863–874. **ETIS 1.1**, ISI Web of Science**.**

The contribution

I **_Article I._** In *Article I,* the author performed an occupational job matrix analysis, assessed the exposure of occupational ELF-EMF exposure and co-wrote the manuscript. In the article the authors link occupational magnetic fields' exposure to long term health effects. The study indicates that current safety limits do not protect workers from all possible health effects and substantiates the need for an ALARA (as low as reasonably achievable) approach in managing safety in the workplace.

II **_Article II._** In *Article II,* the author performed the in-situ investigations, including conducting the measurements, gathering the data, and identifying sources of electromagnetic exposure. In this article, the authors highlight elevated exposure areas, the reasons for the elevated exposure, and they discuss the health implications of poorly managed EMF safety. The author's contribution also includes designing and executing the study and writing the manuscript.

III **_Article III._** In *Article III,* the author conducted measurements at the industrial work sites, investigated the exposure from the magnetic fields, analyzed the compliance with new legislation and developed new methods to reduce workers' exposure. In this article, the means to reduce workers' exposure to electromagnetic fields and a hierarchical model to assist employers in complying with the relevant safety legislation are proposed. The author's contribution also includes designing and executing the study, gathering the data, performing the analysis and writing the manuscript.

IV **_Article IV._** In *Article IV,* the author performed a questionnaire study to investigate how the implementation of new electromagnetic fields' safety legislation has been organized and to assess EMF safety compliance as it is viewed by relevant stakeholders. Links between the companies' safety management and levels of compliance with legal requirements are revealed. Key components are identified which would assist companies in properly and successfully managing EMF safety. The author's contribution also includes designing and executing the study, gathering the data, performing the analysis and writing the manuscript.

V **_Article A1._** In *Article A1* the author investigated the computer workers' exposure to electromagnetic fields, and conducted measurements, identified reasons for elevated and unnecessary exposure, and developed and tested the means of reducing exposure. The findings are intended to guide the companies in reducing office workers' exposure, within the meaning of ALARA approach in safety management, and therefore provide the means to demonstrate compliance with the relevant safety legislation. The author's contribution also includes designing and executing the study, gathering the data, performing the analysis and writing the manuscript.

Abbreviations

ALARA – as low as reasonably achievable
EF – electric field
ELF – extremely low frequency
ELV – exposure limit values
EMF – electromagnetic fields
EU – European Union
IF – intermediate frequency
JEM – job exposure matrix
LF – low frequency
VLF – very low frequency
MF – magnetic field
MRI – magnetic resonance imaging
PC – personal computer
PRA – probabilistic risk assessment
RF – radiofrequency
OHS – occupational health and safety
Wi-Fi – wireless fidelity (also WLAN)
WLAN – wireless local area network

Introduction

Occupational safety and health are focused on minimizing loss by taking preventive measures to protect both human and physical assets in the workplace. The discipline is involved with monitoring the workplace and advising the management to prevent and minimize losses. The amount of production required to cover costs from accidents can be substantial and may far outweigh the costs of granting a safe and healthy work environment (Friend & Kohn, 2018).

The work environment may include many risk factors, including the physical risk of exposure to electromagnetic fields. Occupational exposure to electromagnetic fields is a known risk factor and considered the most complicated physical hazard in the workplace (Gregg M. Stave, 2017). The legislation requires that measures be taken to reduce exposure and to mitigate risks in order to guarantee worker safety ("Occupational Health and Safety Act," 1999; The European Parliament and the Council, 2013; Vabariigi Valitsuse määrus 01.04.2016 nr 44, 2016). In recent years the EU has issued a new directive, 2013/35/EU (The European Parliament and the Council, 2013) and a consequent national decree followed in all EU member states (Vabariigi Valitsuse määrus 01.04.2016 nr 44, 2016). Understanding the effect of electromagnetic fields (EMFs) on human health and safety has gained more attention during recent years, since the aforementioned changes in legislation, but also in response to new findings regarding the health effects of exposure that have emerged in recent studies. Consequently, companies are faced with new challenges in managing the safety of electromagnetic fields and in fulfilling their obligations as prescribed by the new legislation.

Demographic changes in the population, specifically the increasing proportion of older people, will have a toll on much of the world. An older population will lower both labor force participation and saving rates, which in turn will slow economic growth (Bloom, Canning, & Fink, 2010). Demographic changes call for increasing worker productivity, and keeping older workers longer at work, to compensate for the slowdown in economic growth. As workers become more productive, their safety becomes an increasingly important and relevant concern. Population aging deeply affects the labor market and the workforce age composition. (Berg, Hamman, Piszczek, & Ruhm, 2017). Population aging affects all developed countries, and is mainly due to increased life expectancy and declining birth rates (Danson, 2007). It is necessary to increase the employment levels of all workers, including older workers. Maintaining good health will enable older workers to extend their professional careers beyond retirement age, and this in turn would help address the impact of the aging population (Verbrugghe, Kuipers, Vriesacker, Peeters, & Mortelmans, 2016).

Many workforce skills are age-dependent. An aging population will place a higher demand on these types of skills, and will therefore raise the cost of these skills. Industries that are based on skills that depreciate with age will be less productive in countries with an older population (Cai & Stoyanov, 2016). Hence, improving workplace safety and safeguarding workers' health and wellbeing are essential components of policies developed to deal with a higher proportion of older workers. Electromagnetic fields are increasingly important within the context of the safe working environment, and new approaches and solutions are essential in guaranteeing the well-being and productivity of the workforce and supporting the economy in general.

Electromagnetic fields exist wherever electricity is used (Maxwell, 1865). Specifically, magnetic field exposure could be problematic where machinery consumes a lot of power; such processes are native to many industrial technologies. Although electromagnetic fields are most common in industrial processes, lower level electromagnetic fields can also be found in the office environment, generated by computers and other office equipment. EMFs need to be taken into account in the workplace risk assessment (Riigikogu, 1999). Based on the principles of the occupational safety, employers should minimize the workers exposure to electromagnetic fields. Based on the new occupational EMFs legislation, the safety of risk groups needs to be guaranteed and the working conditions affiliated with risk groups should be assessed on an individual basis. Risk groups may include workers wearing passive or active medical implants, pregnant female workers and adolescent workers (European Commission, 2014; European Commission, 2015; The European Parliament and the Council, 2013; Vabariigi Valitsuse määrus 01.04.2016 nr 44, 2016). Zradziński et al. simulated external LF and IF magnetic field effect on insulin pump needle in the human body and determined it to increase the individual's exposure to the LF and IF magnetic field up to seven times (Zradziński, Karpowicz, & Gryz, 2018). Whereas external EMF amplifies the field near the passive implants, active implants electronic circuitry may become compromised. External EMFs may induce malfunction in active medical implant. Workers increasingly wear these devices, especially pacemakers, cardioverter defibrillators or insulin infusion pumps. The safe distance of the active medical implant to strong EMFs source in the working environment may be several meters, whereas standard safety distance may be significantly shorter (Zradziński, Karpowicz, Gryz, & Leszko, 2018).

Electromagnetic fields are considered a new and emerging risk factor (European Commission, 2008; European Agency for Safety and Health at Work, 2013). Assessing risks in the electromagnetic domain is a challenge as whole extent of the health implications of different types and forms of exposure is unknown. Accurate risk assessments are limited by this lack of knowledge. Risk assessments are well established where considerable data exists with clearly defined boundaries for their use (Aven, 2016). The European Agency for Safety and Health at Work has called for research to identify better exposure assessments, as these are crucial for evaluating workers' exposure conditions (European Agency for Safety and Health at Work, 2013).

Unlike many other occupational risk factors, human beings are not capable of sensing EMFs, until adverse health effects begin to manifest. Therefore, it is of utmost importance to raise the safety awareness of workers. Current EMF safety arrangements in companies are little known. Additionally, there remains an uncertainty about long-term health effects from prolonged exposure to EMFs.

Engineering systems are designed and operated under unavoidable risk and uncertainty conditions. Identification, quantification, evaluation and reduction of risks and balancing benefits with costs should be an integral component of the overall managerial decision-making process (Haimes, 2015).

There is a paucity of research and consequent scientific knowledge regarding EMF safety management. In order to plan and implement scientifically valid EMF safety management, more studies are needed. These should address exposure and safety in the workplace and should incorporate and add to scientific knowledge regarding the effects of EMF exposure. There is also a need to assess the degree to which companies are complying with the new legislative requirements.

There is a lack of long term health studies, especially regarding the long term occupational exposure to electromagnetic fields. This has resulted in safety limits that are based only on the short term health effects. However, humans are commonly exposed to the long term effects both publicly and occupationally. Therefore, science must focus on designing more long term studies in order to develop truly protective safety limits for both public and occupational venues. Also, the European Agency for Safety and Health at Work has issued research priorities, stating that research is needed on the health effects from long-term occupational exposure to the EMFs (European Agency for Safety and Health at Work, 2013).

The aim of this research was to compose an operational model for managing EMF safety and to establish a basis for such. EMFs were studied using both quantitative and qualitative approaches, including measurements, questionnaires and workplace observations. The research addressed current practices and rules of managing safety from electromagnetic fields. This endeavor was guided by the new requirements for health and safety with regard to electromagnetic fields. In order for companies to comply with the legal requirements, workplaces should be analyzed and measured. Clearly, EMF exposure levels vary across different occupations. There are prescriptions set by the legislation on how to reduce workers' exposure. The author sought to determine how thoroughly these new legislative requirements were being implemented in the workplace.

Taking into account the newly established evidence of adverse health effects from long-term exposure to electromagnetic fields, the author intended to determine if long-term occupational exposure to the ELF-EMF is connected to such health outcomes (article I). ELF-EMF may be considered the most common type of occupational exposure as it includes the 50 Hz power grid frequency.

In order to establish a basis for an EMF safety management operational model, the following research tasks were included:

- Determining EMF levels in work environments including industrial sites, offices which use computers, and public spaces.
- Assessing workers' exposure to the electromagnetic fields by means of a job exposure matrix and the corresponding risk of long term health effects.
- Devising EMF exposure reduction measures.
- Assessing the EMF safety compliance of companies from the point of view of relevant stakeholders.

In this research, the author tackled the risks and management of electromagnetic fields in the workplace. Different methodological approaches, as described in Chapter Two, are taken to provide a comprehensive picture of relevant issues in EMF safety management. The purpose of managing EMF safety is to make work and the work environment safe for the worker. The central research task was to determine how to arrange for EMF safety, taking into account the new legislative requirements.

This study was intended to help improve management's safety knowledge of this risk factor, by encompassing scientifically reasonable approaches in designing EMF safety. The study included analysis of the exposure levels of workers, and development of methods to reduce exposure, with respect to the new occupational EMF legislation. The author analyzed the EMF exposure in different settings, including means of work (articles I, II, III, A1), encompassing industrial, office, and public settings.

Subsequently, the EMF safety compliance of companies was investigated (article IV). New, safer ways to work when exposed to electromagnetic fields were proposed, corresponding to the new legislative requirements (The European Parliament and the Council, 2013; Vabariigi Valitsuse määrus 01.04.2016 nr 44, 2016).

The author proposed and tested methods of EMF exposure reduction, which can be used by employers to demonstrate compliance with the occupational exposure norms, and public safety norms. For this purpose, technical and other means of reducing EMFs were tested (articles III, A1). Based on the evaluation of EMFs and experimental work, the author proposed a method to a high level of safety which would conform both with public and occupational EMF safety legislation. By following methods of exposure reduction, the safety of risk groups can also be guaranteed. If the employer can demonstrate compliance with public safety limits, which guarantees the safety of workers within risk groups, he avoids the complex procedures of managing risks to workers who are affiliated with risk groups. The contextual links between the aforementioned items and the framework of the current work are pictured in Figure 1. The majority of research methods were quantitative, but qualitative methods were also employed.

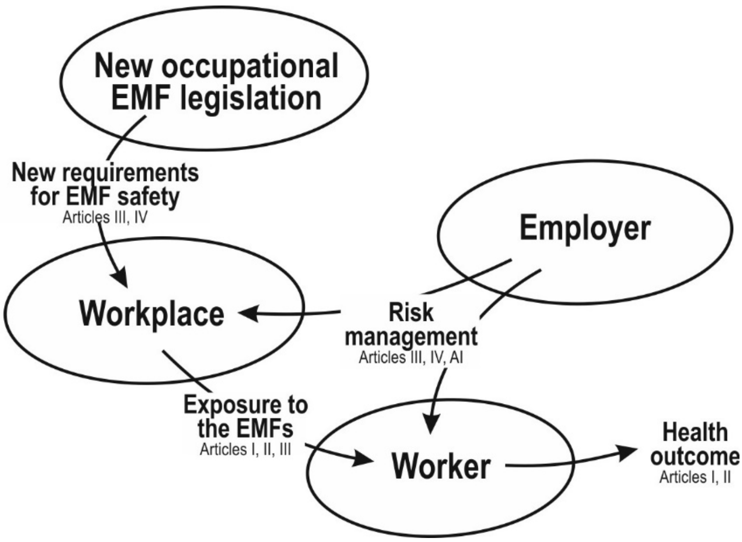

Figure 1. *The framework of the current research.*
Composed by the author.

The contribution. In all articles (where applicable), the author has designed and executed the study, conducted measurements, collected the data from the parties involved and drafted the manuscripts. In Article I, occupational magnetic field exposure was linked to long term health effects. This linkage was not currently accounted for in EMF safety management procedures or in the legislation regarding EMF exposure. In Article II, elevated exposure areas and the reasons for the elevated exposure were revealed; health implications of poorly managed EMF safety were discussed. In Article III, recommendations to reduce risks from electromagnetic field exposure were proposed together with a hierarchical model to aid employers in EMF risk management and to demonstrate compliance with respect to the relevant safety legislation. In Article IV, links between company safety management and compliance indicators are revealed, which can be used by employers to develop EMF risk management procedures, including company EMF safety training strategies. The study elaborated on how legal aspects of EMF safety are considered in different levels of subgroups and also illustrated the need to reduce exposure when safety issues are poorly managed.

The novelty. Assessing EMF safety compliance is a novel topic, since limited scientific research has been conducted and little attention has been paid regarding EMF safety management prior to the new EU directive 2013/35/EU. The current work presented subtle links explaining the level the EMF safety management in companies, and therefore will help companies in achieving compliance.

In order to conform with the new EMF legislation, a principle of minimizing the workers exposure was advised, which assures that worker exposure levels meet the legislative requirements of both occupational and public EMF exposure. The author proposed an operational model, ordering EMF exposure reduction measures in a hierarchical manner (Article IV). The model guides employers in organizing EMF safety in a manner that gives preference to risk mitigation measures which benefit the most as opposed to the few. Thereby, the employer is able to demonstrate a high level of compliance with safety legislation, and can assure workers that their workplaces are safe and healthy. Consequently, this supports the sustainability of the organization, as the reputation of the company gains from protecting worker health and wellbeing. Managing EMF safety is also a good way for the employer to avoid possible future claims for adversely affecting worker health. Such workers' disabilities would also be a burden on society due to increased spending of the health fund, including workers disability pensions and other medical costs.

This also assures that the working conditions of the affiliated risk groups conform with the safety legislation. One of the key changes in EMF legislation has introduced the requirement for specific and individual risk assessment with regard to workers affiliated with risk groups. The current research illustrated elevated exposure scenarios and work methods. A secondary aim of the study was to provide the means of minimizing workers’ EMF exposure.

The current study also paid attention to the long term health effects of EMF exposure. Current safety norms are based on short term health effects. In Article I, an increased risk of long term health effects was found from prolonged occupational exposure to ELF/EMFs, the implications of which prescribe a thorough revision of safety management systems in cases where workers have elevated exposure to power frequency magnetic fields.

Next, this study argued for the importance of safety training and other employer contributions supporting the safety awareness regarding EMFs, including the means of identifying EMF exposure, and how to reduce exposure to a safe levels.

The research also elaborated on how new legal aspects of EMF safety are considered in different levels of subgroups and noted the need for reducing exposure when safety issues are poorly managed. Also, the author established a link between the employers’ contribution in educating and training specialists and workers and the resulting safety compliance of both the workplaces with high EMF exposure and the company in general.

The author’s motivation can be described by his commitment in analyzing and developing the EU and national EMF legislation in the period of 2009-2016. As an Estonian expert, the author contributed to the writing of the EU directive 2013/35/EU and the consequent national decree, issued on 1.04.2016. The legislation required in-depth knowledge of worker exposure and the means of its reduction.

Also, the author was tasked with educating Estonian work environment specialists, occupational health doctors and work inspectors with regard to their roles with respect to the new EMF legislation. Additionally, the author consulted with companies regarding EMF risk management and conformance with the legislation. The aforementioned tasks required a high level of knowledge and expertise.

Overview of the approval of research results

All the results from the current study have been published and presented by the authors at international scientific conferences and doctoral seminars (PhD colloquia), following the acceptance of peer-reviewed abstracts.

I The results of the *Article I* “Case-control study on occupational exposure to extremely low-frequency electromagnetic fields and glioma risk” were published in 2017 in American Journal of Industrial Medicine.

II The results of the *Article II* “Radiofrequency radiation at Stockholm central railway station in Sweden and some medical aspects on public exposure to RF fields” were published in 2016 in International Journal of Oncology.

III The results of the *Article III* “Risk management of magnetic field from industrial induction heater- A case study” were presented during the 18th International Scientific Conference: Engineering for Rural Development 2017”, 27-28 April, Jelgava, 2017.

IV The results of the *Article IV* “Safety compliance of occupational exposure to electromagnetic fields” were published in 2018 in Research in Economics and Business: Central and Eastern Europe.

V The results of the *Article A1* “Reducing exposure to extremely low frequency electromagnetic fields from portable computers” were presented in Tartu in 2014 on the 5th International Conference “Biosystems Engineering 2014” and published in the journal Agronomy Research.

1. Theoretical framework

1.1 Safety management

Safety management is something that the organization does, as opposed to something that the organization has. It is a process, rather than a product. Safety management requires the organization to address partially unknown processes to maintain safety under current conditions and during bothe expected and unexpected developments. Hence, safety management controls processes (Hollnagel, 2016).

Safety management is a systematic and planned company-driven activity that aims at controlling existing health and safety hazards (Kuusisto, 2000). The aim of safety management is to intervene in the causal processes which can lead to accidents (Booth & Lee, 1995). Safety management is an inherent function of business management. Of the many business activities, the role of safety management in a company's financial outcome might be the least comprehensible by business managers.

An organization's management is responsible for strategic development, articulation, recording and communication of the strategic health and safety management system. This system includes policies and practices supporting worker health and safety (Yorio, Willmer, & Moore, 2015).

A safety management system should include the following: safety policy, procedures, and rules; training; communication; incident reporting and analysis; safety audits and inspections; rewards and recognition; employee engagement; safety meetings and committees; suggestions and concerns feedback; discipline (Fernández-Muñiz, Montes-Peón, & Vázquez-Ordás, 2007; Frazier, Ludwig, Whitaker, & Roberts, 2013).

Most current occupational health and safety management systems do not consider safety factors attributed to specific working conditions in specific workplaces. A complete safety management system should address all the potential hazards associated with the key elements that comprise the organization: people, physical workplace and management. People are the subjects of safety management. The physical workplace is used by people for conducting work tasks, e.g. to produce goods and services. Management is responsible for organizing the transformation of resources and other organizational inputs into outputs (Makin & Winder, 2008).

Safety management is often viewed within the framework of risk management. Risk management supports a company's decision-making and everyday operations and includes measurements and supervision of all company-wide business risks. Risk management should account for synergies between different risks, expressed by a diversification effect, representing combined risks. Next, risk management should be viewed as a dynamic process, rather than an approach to a single static event. After risks are identified, they need to be measured and assessed. Risk analysis follows, in which the risk measurement results are evaluated. The risk analysis should determine if the measured risks require action. Controlling risks in collaboration with corporate management, leads to risk-based corporate management (Wolke, 2017).

The main benefit of risk management is to enhance the effectiveness and efficiency of a company's operations, business processes, and the delivery of goods and services. (Hopkin, 2018).

Lately, the concept of risk management has widened to include a new term – enterprise risk management (ERM). ERM means that companies account for all the risks comprehensively in a coherent way, as opposed to managing each risk on an individual basis. This involves integration of all risks in the company and the alignment of risk management with company's governance and strategy (Bromiley, McShane, Nair, & Rustambekov, 2015).

As previously discussed, a safety management system should approach hazards with regard to people, workplace and management. This applies also to safety management with regard to electromagnetic fields. Therefore, safety should be considered specific to the risk factors and the workplace environment and business processes. Moreover, considering the inclusion of the concept of risk groups in the recent EMF safety legislation (The European Parliament and the Council, 2013; Vabariigi Valitsuse määrus 01.04.2016 nr 44, 2016) dictates that the individual worker should be at the center of the EMF safety management system.

The formation of EMF safety management systems should focus on key factors of general OHS performance (Tremblay & Badri, 2018). The commitment of the management level is an important key factor. OHS performance is dependent on proper risk management. Training is essential for the staff to accept and implement good safety practices (Abudayyeh, Fredericks, Butt, & Shaar, 2006; de Koster, Stam, & Balk, 2011; Hallowell, Hinze, Baud, & Wehle, 2013; Mirabi, Asgari, Tehrani, & Mahmoodi, 2014). Training of staff to accept good practices is also relevant for the system to succeed (British Standard Institute, 2007; Hallowell et al., 2013). Production managers, supervisors and other middle management should show leadership in OHS (Hinze, Thurman, & Wehle, 2013; Mirabi et al., 2014; Snyder, Krauss, Chen, Finlinson, & Huang, 2011). Companies' compliance with safety rules and participation in hazard identification and risk management are inherently part of safety behavior (Liu, Chen, Cheng, Hsu, & Wang, 2013; Mirabi et al., 2014; Sgourou, Katsakiori, Goutsos, & Manatakis, 2010). Prevention should encompass continuous improvement of OHS, and this is the fundamental principle of the safety system (British Standard Institute, 2007).

1.2 Safety legislation

The directive is a legal tool that enables the European Union to enforce common principles across the member states. A safety directive is a set of minimum requirements for the safety issues in occupational exposure to occupational hazards. The European Union (EU) has engaged in occupational health and safety by committing to improvement of the work environment and the protection of workers (Treaty on the Functioning of the European Union, Article 153 p.1, a, European Union, 2012). This also grants the EU authority to issue relevant directives. The EU's obligation to protect workers is stated in Article 31(1) of the Charter of the Fundamental Rights of the European Union: "every worker has the right to working conditions which respect his or her health, safety and dignity" (European Commission, 2000).

In 1989 a framework directive (89/391/EEC) was laid down to introduce general prevention principles of occupational health and safety. The directive applies to all fields of activity, except those of the armed forces, police and civil protection services. It provides principles for the prevention of risks, assessment of risks, protection of safety and health, communication, consultation, and training (Council of the European Communities, 1989). Since the framework directive was established, several other directives on physical hazards have been issued, including hazards involving vibration – Directive 2002/44/EC (The European Parliament and the Council of the European Union, 2002), noise – Directive 2003/10/EC (The European Parliament and the Council of the European Union, 2003), and artificial optical radiation Directive 2006/25/EC (The European Parliament and the Council of the European Union, 2006).

The European Parliament (EP) issued a new directive on occupational exposure to electromagnetic fields on 26.06.2013 (The European Parliament and the Council, 2013). Consequently, a national legislation in Estonia was adopted in 1. July 2016, which introduced many new EMF safety management requirements to the enterprises (Vabariigi Valitsuse määrus 01.04.2016 nr 44, 2016).

This directive was not the first, as earlier attempts were made to regulate worker safety in the Union (The European Parliament and the Council, 2004, 2008). In addition to the workers' directive, the European Union has issued safety limits to protect the general public from exposure to electromagnetic fields (The Council of the European Communities, 1999).

One of the reasons the EMF safety legislation has taken such a long time to develop was that stakeholders, namely the Magnetic Resonance Imaging (MRI) sector, expressed disagreement with the earlier 2004 version of the directive. The stakeholders argued that safety limits proposed by the 2004 directive would limit the use of MRI devices. Workers close to an MRI scanner could be exposed to the EMFs (namely in the range of 110 Hz to 5 kHz) above the proposed safety limits (Hill, McLeish, & Keevil, 2005). Also the directive would hinder the use of MRI in interventional and surgical medical procedures, researching new techniques that would allow better clinical information and would provide a better alternative to the use of ionizing radiation for diagnostic purposes (European Science Foundation, 2010; Keevil et al., 2005; Keevil & Krestin, 2010).

The relevance of the electromagnetic fields as a working environment risk factor is emphasized by the European Union by classifying it amongst "emerging health risks" (European Commission, 2008). An advisory structure called Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) has been set up to provide European legislators with a comprehensive assessment of risks to both public and workers' safety (Scientific Committee on Emerging and Newly Identified Health Risks SCENIHR, 2007, 2009, 2013).

Figure 2 depicts the stakeholders of the EMF safety legislations and the many factors of their interaction.

Figure 2. *Stakeholders of the EMF safety legislation.*
Composed by the author.

1.3 Economic considerations of EMF safety

European legislators understand that strict regulations would not be good for businesses and that European companies, as viewed relative to global competition, need entrepreneur-friendly legislation. In fact, the Treaty on the Functioning of the European Union, which is the legal basis for the EU directives, states under article 153 p.2 (b) that "such directives shall avoid imposing administrative, financial and legal constraints in a way which would hold back the creation and development of small and medium-sized undertakings" (European Union, 2012).

Favoring companies in this way may undermine the protection of workers from occupational risk factors. Significant improvements in the work environment are usually not possible without significant expenditures. When mitigating exposure to electromagnetic fields in the work environment, such investments tend to be high, due to the cost of the shielding materials, new machinery, and loss of productivity when reorganizing work procedures.

High-level exposure to EMFs might be the result of many industrial processes and are apparent in a number of jobs. It is evident that the EU will not issue legislation that would disable these industries from performing their native processes. In order to cope with the European Union's legislation, one should also consider the task faced by European legislators to find a reasonable and a balanced approach which will satisfy both the safety of the workforce and which is endurable for the companies.

Past global and financial crises in EU may also be seen as a cause for deteriorating working conditions in companies, as expressed by the European Trade Union Confederation (European Trade Union Confederation, 2013). The issue was also addressed by the European Parliament with a resolution on the European strategy for health and safety at work (2013/2685(RSP), which called for rapid responses to provide a high level of health and safety at work in response to the economic developments and social crisis impact on the working environment (European Parliament, 2013).

Occupational health and safety measures might often be seen as an irrelevant cost by the employer. In larger enterprises, more attention is paid to health and safety services, such as safety experts and occupational health doctors (González, Cockburn, Irastorza, Houtman, & Bakhuys Roozeboom, 2010). Smaller companies report fewer occupational health and safety management measures as compared to larger establishments. Independent companies reported fewer occupational health and safety management measures compared to those that are part of a larger entity (Stolk, Staetsky, Hassan, & Kim, 2012).

Managers report employee participation as a key factor for successful occupational health and safety management. This means that the role of social partners is important in implementing effective measures. Workers' participation, whether formally through works councils and shop floor trade unions or informally, by direct involvement, is associated with better quality management of health and safety (González et al., 2010). Countries with better occupational health and safety management have smaller differences in reported occupational health and safety practices between smaller and larger establishments than countries reporting less occupational health and safety practices (Stolk et al., 2012).

1.4 Workers exposure to the electromagnetic fields

The safety of workers is an important factor and one of the key functions of every organization. The working environment may encompass several risk factors of which electromagnetic fields (EMFs) are one. The importance of having a good safety understanding of electromagnetic fields in the workplace is because, unlike many other occupational health and safety risk factors, EMFs are invisible, odorless, and cannot be detected by a human being until harm is done and the adverse effects occur. An electromagnetic field (EMF) is a physical field that accompanies electrical output. All electrical appliances produce this field.

ELF-EMFs are generated by alternating electric current. The exposure to electromagnetic fields is commonly characterized as exposure either to electric, magnetic or electromagnetic fields. EMFs can broadly be divided into four groups, depending on their frequency: static, low frequency, intermediate frequency and radiofrequency electromagnetic fields (Article IV).

The industrial work environment may include a diverse range of electrical machinery, therefore creating many scenarios of electromagnetic field exposure. Even when equipment of the same make and model is used at different workstations, the workstation layout, and other nearby devices can cause the exposure levels to be different. Therefore, adequate risk assessment is not possible based solely on the equipment manufacturer's information regarding the electromagnetic emission level, for example. In practice, it is necessary to measure the actual work settings in order to accurately determine the workers' exposure levels, as risk assessment by numerical calculations, simulations or by the machinery's documentation would leave much room for error. The result of an inaccurate risk assessment may put workers health and safety at risk.

For example, induction heater operators and other personnel close to these workstations may be exposed to high magnetic fields, one of the strongest in the industry. These fields need to be measured, and the safety of workers assessed according to the framework of the relevant national legislation. The European Agency for Safety and Health at Work has pointed out that exposure to intermediate frequency (IF) fields, such as from induction heaters, should be studied as there are only a limited amount on research done on IF exposures (European Agency for Safety and Health at Work, 2013).

Occupational exposure to EMFs is a known risk factor. Recently more attention has been paid to the long term health effects of exposure to electromagnetic fields. Several studies have pointed out risks related to long term occupational exposure (Carlberg, Koppel, Ahonen, & Hardell, 2018; Grundy et al., 2016; Huss, Spoerri, Egger, Kromhout, & Vermeulen, 2018; Jalilian, Teshnizi, Röösli, & Neghab, 2017; Turner et al., 2014). Current safety limits are based on short term health effects (Vabariigi Valitsuse määrus 01.04.2016 nr 44, 2016) (The European Parliament and the Council, 2013), which rely on third party guidelines (ICNIRP-International Commission on Non-Ionizing Radiation Protection, 1998).

1.5 Extremely low frequency electromagnetic fields (ELF EMFs)

Exposure to the ELF-EMFs is the most common occupational exposure as most machinery operates on the grid power. The frequency of the mains power in Europe is 50 Hz as in the most of the world; 60 Hz is used in the Americas and in some parts of Asia. The exposure to the ELF magnetic fields depends on the amount of current – the more electrical power the machine uses the higher the magnetic field. Next to the electrical machinery, high exposure to the ELF magnetic fields may emanate from power lines, transformers and other power distribution installations. Electrical motors and other devices incorporating coils are also typical sources of high ELF magnetic field exposure. By increasing turns of the current carrying wire, the magnetic field is also multiplied. Therefore, workstations next to powerful electrical motors, as in those used for electrical transport, are usually accompanied by strong ELF magnetic fields. Powerful electrical motors and other devices carrying a lot of current can be found in many industrial settings. The workers' exposure levels in such cases depend on the workstation's distance from the device. For example, people working with hand-held electrical power tools have a high exposure to the magnetic field, whereas other workers nearby would have no significant exposure. At the same time, workers stationed away from even stronger sources, may be exposed at insignificant levels. Therefore, designing instrumentation relative to working areas, and positioning workers with respect to the locations where electrical power is generated and distributed will play a crucial role in determining the resultant exposure levels.

1.6 Effects from Radiofrequency electromagnetic fields (RF EMFs)

On 31 May 2011, the WHO International Agency for Research on Cancer (IARC) categorized the radiation fields from mobile phones, and from other devices that emit similar non-ionizing electromagnetic field (EMF) radiation in the frequency range 30 kHz–300 GHz, as a Group 2B, i.e. a ”possible” human carcinogen (Baan R, Grosse Y, Lauby-Secretan B, El Ghissassi F, Bouvard V, Benbrahim-Tallaa L, Guha N, Islami F, 2011; IARC Working Group, 2013)(II, 1,2). Nine years earlier, IARC had also classified the electromagnetic fields from overhead electric power lines as a Group 2B carcinogen (World Health Organization., International Agency for Research on Cancer., & IARC Working Group on the Evaluation of Carcinogenic Risks to Humans (2001 : Lyon, 2002).

The IARC decision on mobile phones was based mainly on two sets of case-control human studies: the Hardell group of studies from Sweden (Hardell, Carlberg, & Hansson Mild, 2006a, 2006b, 2011) and the IARC Interphone study (Cardis et al., 2011; Interphone Study Group, 2010, 2011). Both provided complementary and generally mutually supportive evidence of increased risk for brain tumors, i.e. glioma and acoustic neuroma.

Recently a report was released from The National Toxicology Program (NTP) under the National Institutes of Health (NIH) in the USA on the largest animal study to date on cell phone RF radiation and cancer (National Toxicology Program, 2018; Wyde et al., 2016). An increased incidence of glioma and malignant Schwannoma in the heart was found.

Within the scientific community, it is likely one could find parties that would welcome legislation addressing all the newly discovered biological effects, resulting in quite strict safety limits (BioInitiative Group, 2007; BioInitiative Group, 2012). At the same time, scientists following a more conservative approach, would prefer to wait until the scientific body of research irrefutably makes the case for newly reported effects before changing the legislation (European Health Risk Assessment Network on Electromgnetic Fields, 2010; Scientific Committee on Emerging and Newly Identified Health Risks SCENIHR, 2009).

1.7 Long term health effects

In a small study from Sweden on 84 glioma cases, 20 meningioma cases, and 155 controls, an elevated risk for glioma was seen in exposed occupations with an average mean value of >0.4 µT (Rodvall et al., 1998). In a Canadian case-control study on brain tumors, the highest occupational average ELF-EMF exposure >0.6 µT was compared to exposure < 0.3 µT and gave for astrocytoma grade IV (glioblastoma multiforme) an odds ratio (OR) = 5.36, 95% confidence interval (CI) = 1.16-24.78, adjusted for exposure to ionizing radiation and vinyl chloride (Villeneuve, Agnew, Johnson, & Mao, 2002). Higher OR was obtained for the last held job. The authors concluded that exposure to ELF-EMF may increase the risk of brain tumors.

No statistically significant association between occupational ELF-EMF exposure and brain tumors was found in a cohort study from the Netherlands (Koeman et al., 2014). The results were based on 233 cases. In a study on U.K. electricity supply workers no evidence was found for increased glioma risk for distant or recent estimated ELF-EMF exposure based on job title (Sorahan, 2014).

During the last two decades, an increasing number of studies have associated brain tumors with use of wireless phones (Coureau et al., 2014; Hardell & Carlberg, 2015; Hardell et al., 2011; Interphone Study Group, 2010). During use, wireless phones emit radiofrequency electromagnetic fields (RF-EMF). In May 2011, IARC evaluated the carcinogenic potential of RF-EMF. The expert group classified RF-EMF in the frequency range 30 kHz-300 GHz as “possibly carcinogenic to humans,” Group 2B (Baan R, Grosse Y, Lauby-Secretan B, El Ghissassi F, Bouvard V, Benbrahim-Tallaa L, Guha N, Islami F, 2011; IARC Working Group, 2013).

In the international Interphone study, glioma was associated with occupational ELF-EMF exposure in recent time windows i.e. short lag time before diagnosis whereas no increased risk was found for meningioma (Turner et al., 2014).

2. Research methodology

2.1 Research design

The current study employed different research methods to investigate the safety of electromagnetic fields. Evaluation methods assessing safety management systems may include 1) measurement of safety performance, 2) safety audits and 3) management reviews (Kuusisto, 2000). Safety performance measurement is means to monitor the extent which safety policies and objectives are fulfilled. This includes assessing compliance with planned health and safety activities (British Standards Institution, 1996; Kuusisto, 2000).

A mixed approach using both quantitative and qualitative research methods are needed in researching safety, in order to have reliable findings in which may be applied to raise safety level (Fernández-Muñiz et al., 2007; Fernández-Muñiz, Montes-Peón, & Vázquez-Ordás, 2009, 2012a, 2012b).

In the current study, quantitative research methods were used, with some qualitative elements. Qualitative methods included questionnaires complemented by interviews. Qualitative methods also included questioning the workers and in-situ visual observations of worker activities and work procedures. Safety compliance analyses were conducted with regard to legislative requirements.

Quantitative research methods included questionnaires, exposure assessment by measurements, and database reference. Figure 3 provides an overview of research methods used. Measurement results were subjected to statistical analysis by calculating means and total band specific or wide band exposure. Time domain and spatial distribution analysis were also conducted on the exposure measurements.

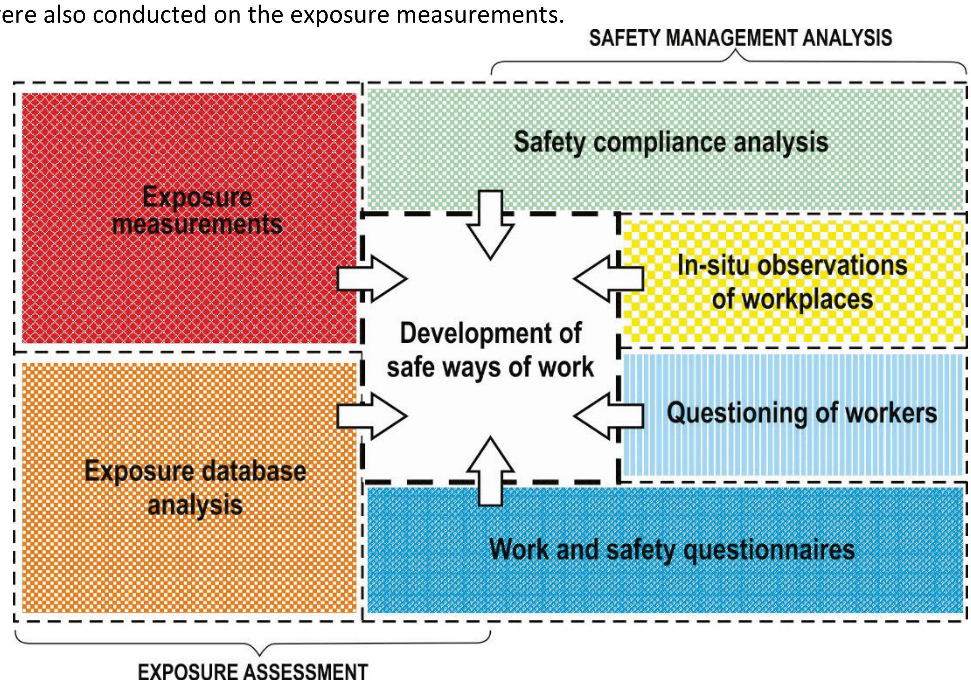

Figure 3. *The system of EMF safety research methods used in this study.*
Composed by the author.

2.2 Data and methods

Safety management of electromagnetic fields in companies. A questionnaire was used to determine the level of electromagnetic safety management (N=190). The sample included working environment specialists, workers, occupational health doctors and labor inspectors. The questionnaire included questions on their role with regard to implementing the new legislation requirements, such as EMF safety awareness and perception, company EMF safety compliance, EMF safety arrangements for strong EMF workplaces, and EMF safety arrangements for risk groups. The questionnaire focused on the key issues addressed by the new occupational EMFs directive (2013/35/EU). The companies targeted were industrial companies with processes presumed to be accompanied by elevated electromagnetic fields. The activities were determined from the Estonian economic field of activities classifier (EMTAK). The target population is undetermined as this information is unavailable. The data was assessed by the structured questionnaire approach. Averages were calculated for variables with multiple items. A Pearson product-moment correlation coefficient was conducted to evaluate the relationship between the EMF safety variables. To test the differences of subgroups' means, an independent samples t-test was performed. Additionally, the assumption of homogeneity of variances was tested via Levene's F test. $p<0.05$ was considered statistically significant.

Measurements at industrial workplaces. In a manufacturing work environment investigation, measurements of the low frequency (LF) magnetic field were conducted across the working area where the induction heater was positioned. The measurements were done by three means: 1) spatial measurements, 2) spectrum measurements, 3) exposimetry measurements. Visual observations of the worker's movements aided in determining the worker's path during work procedures. Worker's movements were plotted on the work area ground plan and spatial analysis conducted to assess the exposure temporal dynamics. Video recordings were done and later analyzed to measure the time the worker spent at any of the locations (grid points) at the workstation.

Exposure to the magnetic field was estimated by a time-weighted average. The time-weighted average accounted for each time period the worker spent in locations where procedure-specific tasks were performed complemented by the exposure to the magnetic field at the corresponding locations.

Measurements at service-oriented workplaces and public space. The Stockholm Central Railway Station in Sweden was investigated for public radiofrequency (RF) radiation exposure. For RF measurements at service- oriented workplaces and public space, EME Spy 200 exposimeter with a valid calibration was used to collect the exposure data. The 20 predefined measured frequency bands cover the frequencies of most public RF radiation emitting devices currently used in Europe. This band selective exposimeter covers 88 to 5,850 MHz.

Measurements at office workplaces. Workers' exposure to EMFs in the ELF and VLF range from portable computers was measured, including both electric and magnetic fields. The author focused on four factors that typically affect the laptop PC's exposure levels in office environments: 1) battery or external power, 2) internal or external keyboard/mouse, 3) internal or external display 4) grounded or ungrounded casing and 5) distance to peripheral electrical wires and power adapter. Ten exposure scenarios could be deduced based on the different combinations of these determinants. An office worker would be exposed to one of these when using a laptop PC.

A new 14-point express measurement protocol (Fig. 4), developed by the author was used. 14-point protocol involves the entire body of an office worker (head, torso and limbs), and provides a widespread view of electromagnetic field exposure. These 14 points provide an adequate sample for an overview of a worker's exposure. At the same time, the method could be considered an express method, since the data could be collected within a few minutes. The procedure involves moving the meter horizontally covering the possible positions of the worker's body at the work station.

IBM SPSS Statistics 21.0 was used to conduct an independent samples *t*-test to compare the means of the subsamples. Additionally, the assumption of homogeneity of variances was tested using a Levene's *F*-test. $p<0.05$ was considered statistically significant.

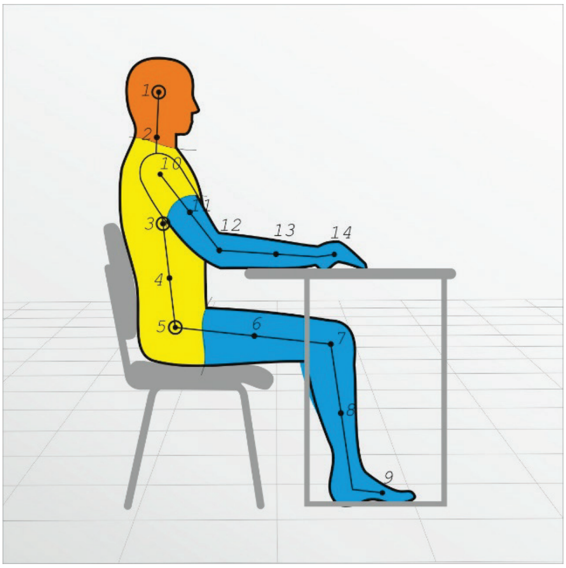

Figure 4. *The 14-point measurement system by Koppel. Points are distributed across body regions as characterized by the vulnerability to the EMFs: head, torso, limbs.* Composed by the author.

Long-term occupational exposure. The workers' exposure was assessed using the prior results from a questionnaire sent to the subjects. The questionnaire contained questions relating to general working history and various other exposures that are not part of this thesis. The questionnaire also inquired about the use of mobile and cordless phones, including time period, average daily use, hands-free devices, external antennas, and at which ear the user mostly used the phone, or equally both.

In this study only glioma cases were included. All controls were used as a comparison group. Adjustment for potential confounding factors was made, including year of diagnosis (each control had the same year of "diagnosis" as the respective case), age at diagnosis, gender, and socioeconomic index (SEI).

The INTEROCC ELF Magnetic Field Job-Exposure Matrix (ELFJEM) was used for associating occupations with ELF exposure (µT) (Turner et al., 2014). The Job Exposure Matrix (JEM) used International Standard Classification of Occupations 1988 (ISCO88) four digit codes to classify most jobs included; ISCO68 five digit codes were used for more specific electrical jobs.

Cumulative exposure in microTesla-years, average exposure in microTeslas, and maximum exposed job in microTeslas were calculated for the cases and controls for lifetime work history and in shorter time windows.

3. Results

EMF safety compliance of companies. A questionnaire-based study was conducted that showed results regarding perception of EMF safety, depending on stakeholder position within the company. The results confirmed that contributing to safety education of both the workers and the working environment specialists has a positive effect on safety compliance and other related safety issues within the company, which helped the organization to demonstrate the fulfillment of legislative requirements.

EMF safety component scores are presented in Table 1. Workers' safety training was assessed by all stakeholders, whereas workers themselves also assessed their EMF safety awareness and perceptions.

Table 1. *Assessed score (0-1) of EMF safety management components as assessed by the stakeholder subgroups (mean values of subgroups).*

code	Variable	Stakeholder group			
		Workers (W)	**Working environment specialists (S)**	**Occupational health doctors (D)**	**Labor inspectors (I)**
A	Workers EMF safety awareness and training	0.42	0.45	0.50	0.38
B	EMF safety compliance of the companies	0.09	0.33	NA	0.20
C	EMF safety arrangement of strong EMF workplaces	0.19	0.45	NA	0.21
E	EMF propagation and safety principles (health effects) knowledge	NA	0.44	0.63	0.57
D	EMF safety arrangement for the risk groups	0.50	0.65	NA	NA

Notes: NA – not asked.
Composed by the author.

A large discrepancy can be seen between workers and working environment specialists assessing EMF safety arrangements and company compliance (B). The independent samples t-test revealed a statistically significant effect, $t(44) = -3.20$, $p = .003$. This could indicate that workers do not perceive the EMF safety measures to be as stringent as working environment specialists claim or intend them to be.

Workplaces with high exposure to EMFs (C) were addressed with a dedicated set of questions. The same discrepancy was also detected here, where working environment specialists reported the safety arrangements to be more than twice as good as perceived by the workers. The independent samples *t*-test was statistically significant, $t(49) = 2.44$, $p = .018$. The score given by labor inspectors supports the workers point of view, being statistically lower than the working environment specialists' mean score, $t(24) = 2.38$, $p = .026$.

A correlation analysis is presented in Table 2, to characterize the EMF safety management in companies, based on the workers and working environment specialists subgroup.

Table 2. *Correlations between EMF safety variables for workers and working environment specialists (N=152).*

	AG	PT	CS	AW	A	B	C	D	E
AG	1								
PT	.671**	1							
CS	-.072	-.258**	1						
AW	.049	-.025	-.043	1					
A	.036	-.009	.054	.692**	1				
B	-.021	-.210	.220	.661**	.493**	1			
C	.057	-.142	.341*	.142	.381**	.824**	1		
D	.023	-.229	.007	.084	.270	.479**	.541**	1	
E	-.142	-.233	.023	.646**	.869**	.702**	.472	.409	1

Notes:

**. Correlation is significant at the 0.01 level;

*. Correlation is significant at the 0.05 level.

Composed by the author.

Abbreviations: AG – age; PT – professional tenure; CS – company size; AW – awareness if strong EMFs are present at company's workplaces; A – workers EMF safety training; B – company's EMF safety compliance: C – EMF safety arrangement of strong EMF workplaces; D – EMF safety arrangement for the risk groups; E – EMF propagation and safety principles knowledge.

The analysis reveals the key factors influencing EMF safety management in companies. Firstly, working environment specialists' awareness (AW) whether their company has strong EMFs producing equipment is strongly positively correlated with (B) EMF safety compliance of the company, (E) EMF propagation and safety principles knowledge. Hence, training of working environment specialists, i.e. (E) EMF propagation and safety principles knowledge, also correlates strongly with the (B) EMF safety compliance of the company.

EMF safety management is a step by step process. The task of the employer is to 1) inform the worker about EMF conditions, 2) educate the worker how to reduce exposure and, most importantly, 3) motivate the worker to follow the EMF safety management procedures (Figure 5). Also, in order to control the effectiveness of the EMF safety management, the employer should regularly check the compliance of real safety (workers behavior) with formal safety according to EMF safety management legal requirements and company policies. Measurements of exposure levels are an inherent part of the control mechanism.

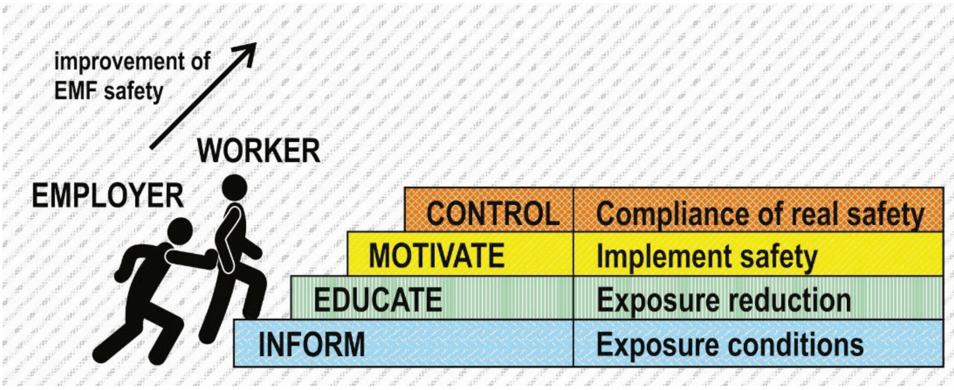

Figure 5. *The improvement of EMF safety management.*
Composed by the author.

Exposure to EMFs and reduction in industrial workplaces. The induction heaters' magnetic field level is determined by the power of the system, i.e., the amount of current carried by the cables and the coil. The measurement results characterize the exposure scenarios at the typical power level which is representative of exposure to workers of these workstations.

A strong magnetic field is spread to the immediate vicinity of the induction heating system (Article III, Figure 3). All the main components of the system are the significant sources, including the induction coil, cables carrying the current, and the current generator control unit.

Based on the visual observations and interviewing the staff, high exposure circumstances were identified, many of which could be avoided. Article III, Table 1 presents an overview of such scenarios.

The field distribution map displays the magnetic field to decrease at an exponential rate and coming to relatively negligent levels at a distance of 3-5 meters. The recommended intervention scenario is composed and simulated based on the field distribution data. Several intervention methods are applied to reduce the induction heater operator's exposure to the electromagnetic fields.

The main intervention strategy involves increasing the distance between the induction heater system (heater coil and the control unit) and the worker. The worker comes to the heater workstation only when the unit is switched off at the beginning of the procedure while placing the blank in the coil, and afterwards, to remove the heated unit.

The recommended intervention prescribes a procedure resulting in a significant decrease in exposure: the accumulating dosage is only 5.2% and time-weighted average is 4.6% of the actual highest exposure scenario (Article III, Table 2). When comparing the recommended intervention scenario to the worst case nominal scenario, there is an even greater difference, 0.9 % and 0.8 % respectively.

In Table 3, the safety measures prescribed by the new legislation are analyzed with respect to the current investigation and recommendations are drawn. Based on the data gathered at the workstation and work area, shortcomings which caused high exposure of the worker were identified. Present work procedures were analyzed and alternative solutions developed, with the aim of reducing workers' exposure (Article III, Table 4). The recommendations were based on the new safety requirements by the directive 2013/35/EU (The European Parliament and the Council, 2013) and the corresponding Estonian national legislation from 1.04.2016 (Vabariigi Valitsuse määrus 01.04.2016 nr 44, 2016).

Table 3. *Solutions to reduce workers' exposure to the magnetic field from an induction heater.*

Safety measures prescribed by the relevant legislation	Customized solutions to reduce exposure at the induction heater workplace
Other working methods that entail less exposure to EMFs	The workers should minimize time or completely avoid staying in the vicinity of the MF source. The employer should rearrange work procedures to prevent the worker going near the heater while it is active. The worker should only approach the heater when the unit is not active. The same principle is applied in arranging work of other workers nearby, e.g. workers delivering parts.
Equipment emitting less intense electromagnetic fields, taking into account the work to be done	Since the induction heater system generates a magnetic field to heat up the metal, the propagation of the magnetic field can be considered intentional and inevitable. Therefore, the choice of alternative induction heater models would not allow significant reduction in the propagated magnetic field, unless these models are accompanied by shielding solutions. The heating of the units and melting of aluminum may be achieved by other approaches and technologies to heat the metals, but for certain products induction heating may be the only option.
Technical measures to reduce the emission of EMFs including interlocks, shielding etc.	The control panel should be positioned separately from the main system, to avoid exposing the worker while operating the system. This would enable the worker to activate the system (pressing the start button) from a distance. Another option would be placing a shield around the induction heater coil.
Delimitation and access measures to limit or control access	Zoning principles should be followed by marking lines on the floor and equipment, showing both occupational and public safety limits at levels of e.g. 100%, 50% and 10%. Access to the high exposure area should be limited for workers whose tasks are not related to induction ovens.
Measures to manage spark discharges and contact currents	Applicable mainly to electric fields.

Maintenance programs	The employer should organize regular maintenance of the induction heater system, to ensure that malfunction or unauthorized readjustment of the system would not increase the workers' exposure. To avoid accidentally overexposing workers, adjustments and maintenance tasks should not be allowed while the heater is active.
The design and layout of workplaces and workstations	Placing the control unit close to the heater also causes a significant rise in the workers' exposure level. Rearrangement of work equipment, including repositioning the control unit farther away from the heater (at least 5 meters is recommended) would decrease the worker's exposure. Trays with blanks and processed units are positioned in the work area considering if the heater is active or not. Other work stations should be positioned away from the induction heater, as exposing these workers is totally unnecessary.
Limitations of the duration and intensity of the exposure	See first item.
Personal protection equipment	Due to the physical nature of the magnetic field propagation, there is no practical personal protective equipment suitable for the workers. However, metal elements on the worker's body and metal pieces in garments should be avoided, as these tend to focus the field, and hence increase the worker's exposure.
Training of workers	The workers should be trained to be aware of field distribution around the system so they can avoid high exposure areas. The worker should not be allowed to worker to wait right next to the heater for the heating process to complete.

Composed by the author.

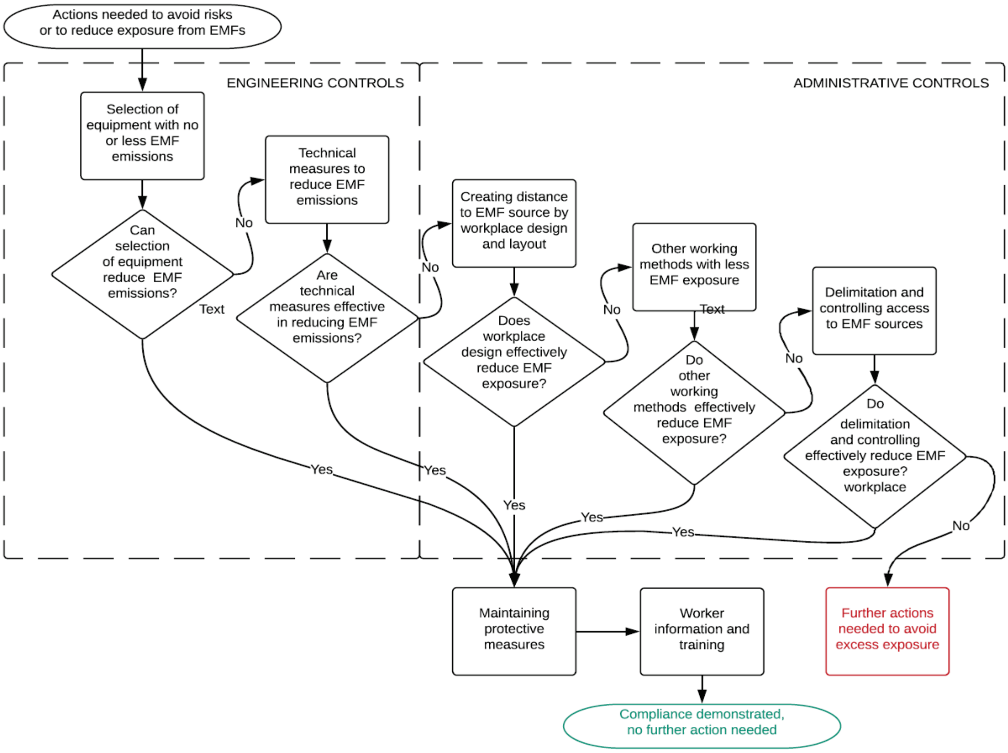

Figure 6. *Operational model for EMFs reduction measures.*
Composed by the author.

Figure 6, based on Table 1 above, illustrates the main activities and provisions designed to avoid or reduce risks, based on the recommendations presented in Table 3. The operational model was developed based on the investigation in the induction heater workstations, but is also applicable to other business domains. The model prescribes a hierarchy of activities to be taken when starting to mitigate workers' exposure within the framework of the EMF safety management system. The operational model is hierarchical, since it starts with solutions that would produce the most benefit for the majority of the workforce in the company. The aim of the process is to achieve a proper level of safety and to demonstrate compliance with the national law and practice. Implementation of protective measures should follow the hierarchical approach, first enacting solutions which significantly reduce EMF emissions at the source. In cases where this is not applicable, other measures should be considered. These include creating distance to the EMF source, implementing other working methods or limiting access to the source.

Exposure to EMFs at servicing workplaces and public spaces. RF measurements were taken in public and occupational areas of Stockholm Central Railway station. High mean measurements were obtained for GSM + UMTS 900 downlink, varying between 1,165 and 2,075 µW/m². High levels were also obtained for UMTS 2100 downlink: 442 to 1,632 µW/m². Also LTE 800 downlink, GSM 1800 downlink, and LTE 2600 downlink were in the higher range of measurements. Hot spots were identified, such as a location close to a wall-mounted base station, which yielded over 95,544 µW/m² and thus exceeded the exposimeter's detection limit. Almost all of the total measured levels were above the precautionary target level of 30 to 60 µW/m² as proposed by the BioInitiative Working Group in 2012.

Spatial analysis of the distribution of registered RF exposure indicated the occurrence of several hot spots such as places people use to sit or stand as they are waiting for their train or meeting with other persons.

The major finding of the study was that total RF radiation mean exposure for a walking round, varied between 2,817 to 4,891 µW/m². GSM and UMTS 900 downlink contributed to most of the radiation dose. The vast majority of the mobile telephone exposure was from the downlink bands, meaning the sources were the base station antennas placed around the railway station. Exposure from uplink levels was an insignificant percentage of the downlink exposure.

All measured mean and median levels were well below ICNIRP's exposure guidelines at 2–10 W/m², but most of the measured levels were above the scientific benchmark of 30 to 60 µW/m² as proposed by the BioInitiative Report (Group et al., 2012).

Exposure to EMFs in office workplaces and means for reduction. EMF exposure from portable computers in office workplaces were investigated. The highest exposure levels were found where the laptops were on an external power source with no intervention applied. Five exposure scenarios included when the laptop PC was: A – connected to the wall power outlet, K' – using internal input device (keyboard and mouse), M' – using internal monitor, G' –having an ungrounded casing and W'– with wires and power supply unit loosely positioned next to the user's body, usually on the ground. To illustrate the exposure over the worker's body, Figure 8 pictures a Scenario A' with no intervention. Figure 7 presents average, minimum and maximum values, classified per exposure scenario across the sample.

Scenario abbreviations (interventions): A – on external power source; B – on battery power; K – on external keyboard (otherwise on internal keyboard); M – on external monitor (otherwise on internal monitor); G – casing grounded (otherwise ungrounded); W – wires routed away from body; e.g. AG – combination of two scenarios including laptop on external power source and with the casing grounded.

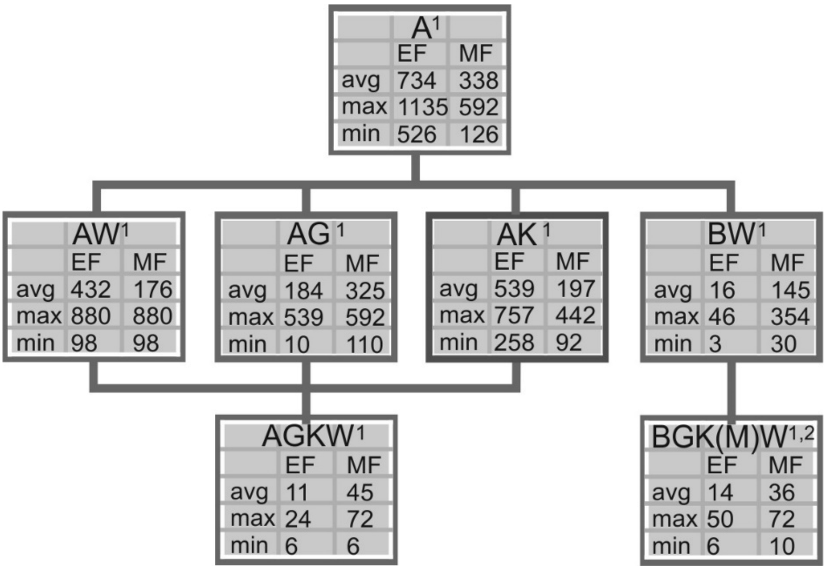

Figure 7. *The effectiveness of various intervention scenarios, expressed as average (avg), maximum (max) and minimum (min) values for each intervention group's electric field (EF; V/m) and magnetic field (MF; nT);[1] see previous paragraph for abbreviations; [2] scenarios BGKW and BGKMW are presented as one group due to their similarity in results.*
Composed by the author.

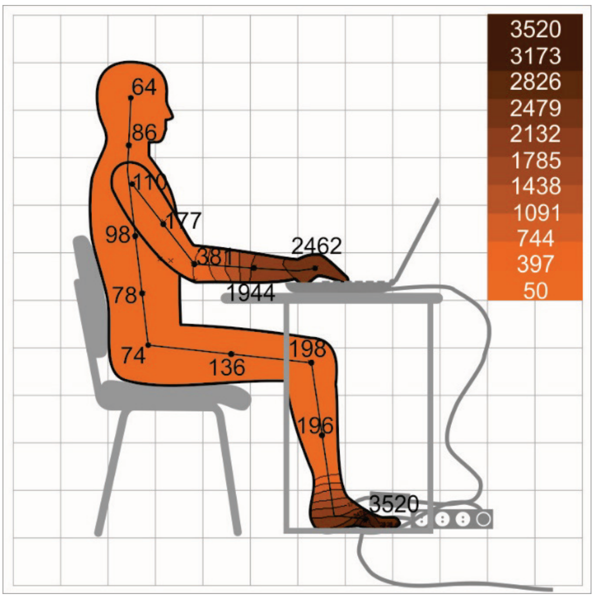

Figure 8. *The highest electric field was measured where the PC was lacking casing ground. Such exposure scenarios are commonly encountered when the power plug lacks a third connector (casing ground) and when a ground cannot be established by way of an external display unit or other peripheral device connected to ground. Conversely, the lowest electric fields were measured at the business class laptop PCs with an extra outer metal casing and with the PCs casing properly connected to the ground.*
Composed by the author.

Positioning of the PC's power adapter (Scenario AW) was also found to have a large effect on exposure levels. Often, the workplace had adapters with the power wires running loosely on the floor, right next to or below the user's feet. Other peripheral devices, including extension cords, placed close to the user's body, were also found to raise exposure levels.

Mean exposure levels proved to be statistically significantly different between most of the scenarios tested. Table 4 presents the results of independent samples *t*-tests. The interventions were applied in two stages. In the first stage AW, AG, AK, BW scenarios were introduced. In the second stage all the first stage intervention scenarios were combined resulting in a scenario AGKW, except for intervention B, which was tested separately and which results in an alternative second stage scenario BGKMW. In the case of electric fields, all the tested scenarios show a significant difference from the original Scenario A. The second stage intervention was tested separately and also yielded a significant difference from Scenario a (external power). However, the difference in mean electric field exposure of battery-powered second stage intervention (BW compared to BGKMW) was not statistically significant. Testing for magnetic field exposure, all the scenarios except for AG proved to be significantly different from initial Scenario A. Understandably, the magnetic field in Scenario AG was not significantly different from that in Scenario A, as grounding has no effect on magnetic field propagation.

Table 4. *Independent samples t-tests across intervention scenarios.*

Nr	Tested scenario	With respect to	Electric field			Magnetic field		
			df	***t***	***p***	**df**	***t***	***p***
1	AW	A	34	5.9	<.000	34	4.2	<.000
2	AG	A	24	10.1	<.000	24	.55	.585
3	AK	A	21	3.4	.003	21	2.7	.013
4	AGKW	A	12	18.8	<.000	12	12.3	<.000
5	BW	A	12	18.7	<.000	17	4.3	.001
6	BGKMW	A	34	25.0	<.000	12	6.8	<.000
7	AW	AGKW	22	-7.7	<.000	23	-4.2	<.000
8	AG	AGKW	12	-4.3	.001	12	-6.1	<.000
9	AK	AGKW	9	-10.4	<.000	9	-5.2	<.000
10	BW	BGKMW	43	-.17	.864	20	-4.6	<.000

Note: df-degrees of freedom.
Composed by the author.

Job Exposure Matrix. This was a large case-control study on brain tumors and occupational exposure to ELF-EMF. The results were based on analyses of 1346 glioma cases (86% of the total sample was included in the analyses; 11.4% did not complete the questionnaire and 2.4% were excluded since they had no job codes registered) and 3485 controls (86% of the total sample was included; 12.6% did not complete the questionnaire and 1.1% were excluded since they had no job codes registered).

Sample cumulative lifetime exposure to ELF-EMF ranged between 0.05 and 556 μT-years for glioma cases and 0.04 to 468 μT-years for the controls. The main occupations among those with high exposure to ELF-EMFs (≥8.52 μT-years) were machine-tool operators (28 cases, 56 controls) and welders and flame cutters (26 cases, 57 controls). These same occupations were also the main ones in all time windows. In the highest average exposure category >0.27 μT, an increased risk for glioma of borderline significance was found (OR = 1.3, 95% CI = 1.0-1.6, linear trend p = 0.04.

4. Discussion

In this chapter, the findings of the research are discussed, including safety management, exposure to EMFs, long term health effects from occupational exposure to EMFs and reducing workers' exposure to EMFs.

Safety management

Based on the new legislation regarding occupational exposure to electromagnetic fields, employers are tasked with detailed obligations to protect workers' safety. The overall results indicated that, compared to the legislative expectations, little attention is paid to training workers regarding electromagnetic fields as a risk factor in the work environment, or how these fields propagate, how to recognize EMF overexposure, or what are the safe practices of work around high EMFs.

Differences in perceptions were found regarding several issues as reported by workers compared to working environment specialists. For example, in comparison to workers, working environment specialists reported better management of risks at high EMF workplaces and also in addressing the needs of workers in risk groups. This inconsistency may be explained by failure in safety management procedures and schooling programs; it is possible that what is written on a paper does not necessarily exist in practice.

The European study about worker representation and consultation on health and safety found that worker representation in developing safe working methods was more evident in larger organizations, in the public sector, in organizations with older workers, and in workplaces where health and safety and the views of workers are seen as a priority. The involvement of workers indeed plays a significant role in ensuring that new occupational health and safety policies are implemented (Stolk et al., 2012) (González et al., 2010).

Also, the European Agency for Safety and Health at Work emphasizes the need for risk communication in the context of new technologies, where there is high uncertainty regarding risks from electromagnetic fields (European Agency for Safety and Health at Work, 2013).

The organization of safety is different in small size enterprises (SSE), likely because small business owners and managers are isolated and overworked, they do not use the services offered by the OHS sector, and they usually do not belong to business groups; they also appear to be poorly informed regarding safety issues (Champoux & Brun, 2003).

Effective work interventions are mostly those aimed at improving employee physical or mental health, whereas integrated interventions targeting occupational health and safety management with injury prevention, or organizational cost savings are less effective (Cooklin, Joss, Husser, & Oldenburg, 2017).

The findings of the current study are in line with those found by Järvis et al. (2016), regarding shortcomings in real safety as compared to formal safety. The current study also revealed discrepancies in the EMF safety scores between the working environment specialists and workers.

The findings of this study indicate that implementation of an EMF safety system should be integrated into the general safety management system of the company. By doing so, companies would be able to benefit from a fully functioning EMF safety system.

Koubabenan et al. (2015) pointed out that perceived risk and safety climate is related to first-line managers' involvement in safety management. The more the first-line managers perceive risks as probable and serious, the more they get involved in safety management. Additionally, immediate supervisor encouragement was seen to be more influential than the role of senior management in safety (Kouabenan, Ngueutsa, & Mbaye, 2015). Workers' engagement levels and safety management systems can even be used to predict accident rates. Likewise, safety management systems can be used to predict worker engagement levels (Wachter & Yorio, 2014).

Fatahi et al. (2016) investigated perception of health risks of electromagnetic fields by MRI radiographers and airport security officers and found that MRI radiographers had lower perceived risk from EMFs than the general working population and the security officers. Their study concluded that despite the fact that different occupations seemed to reflect different perceptions of EMF, the level of occupational EMF exposure did not predict the perceived health risk (Fatahi, Demenescu, & Speck, 2016).

Workers often are faced with more than one type of risk factor. Prioritizing risks may be a challenging task in safety management. Probabilistic Risk Assessment (PRA) is widely used in many industries. PRA is a comprehensive approach accounting all risks, taking a structured approach it is capable in analyzing and assessing risks in complex systems. PRA is applied to projects in industries ranging from spacecraft to nuclear power plants (Parry, 1996; Thigpen, Stewart, Boyer, & Fougere, 2017). PRA however is not perfect, although experts' opinions can be used in practical settings, there is little reliance on normative expertise when structuring the use of expert opinions (Mosleh, Bier, & Apostolakis, 1988). PRA has been developed further, adding hybrid causal logic involving event sequence diagrams, fault trees and Bayesian networks. This allows inclusion of soft causal factors such as human and organizational aspects of the system (Groth, Wang, & Mosleh, 2010). The analytic hierarchy process (AHP) has been proposed to facilitate risk assessment process and to reduce the dependency from erroneous judgements. It is a structured multiple attribute decision method (Saaty, 1990, 1994). With the help of AHP inconsistency from expert judgements could be minimized by reducing bias in the decision making process (Aminbakhsh, Gunduz, & Sonmez, 2013). The core of the AHP relies on ratio scales to assess complex problems. In AHP the problem is structured in a hierarchical way, then followed by a prioritization process (Saaty, 1994). AHP is composed of 1) structure decomposition, 2) comparing judgements and 3) synthesizing a hierarchical structure of priorities. Decomposing a problem facilitates building hierarchies of criteria, where the importance of each criteria is to be determined (Aminbakhsh, Gunduz, & Sonmez, 2013). AHP principles can also be transferred to EMF safety management. This hierarchical approach to reduce workers exposure to EMFs empowering employers with a decision making tool that could reduce the risk of overexposures and accidents, hence avoiding worker's compensation costs and other indirect costs.

Exposure to EMFs

An important factor in assessing workers' exposure to EMFs is the availability of relevant exposure data, corresponding to the workplace and specific jobs. Stam (2014) investigated the exposure levels at different workplaces with respect to the new EU directive (2013/35/EU) and found there is very little information for different workplace scenarios on EMF exposure and limited guidance on good practices (Stam, 2014). In their 2018 study, Stam & Yamaguchi-Sekino investigated published exposure data on occupational environments, concluding that often, only the maximum magnetic field at the workplace is listed as an indication of a worst-case scenario. These field levels are not necessarily representative of the main exposure and may not accurately represent good working practice (Stam & Yamaguchi, 2018). They also concluded that due to the usage of new devices, higher exposures may be occurring in specific workplaces, locations or scenarios, than have previously been recorded, since these devices may produce more than one frequency. Also, detailed worker exposure data is not yet available for some of the newer diagnostic and therapeutic devices (Stam & Yamaguchi, 2018).

The current study has indicated that in assessing workers' exposure not only the amplitude and frequency of the electromagnetic fields should be considered, but attention also needs to be paid to 1) the duration of the exposure, and 2) type of exposure, including the distribution over the worker's body and over the size of the workplace. A more complex approach is required, involving several assessment methods to investigate the occupational electromagnetic fields.

There is a lack of sufficient occupational exposure data, needed to facilitate future EMF studies on occupational exposure. Exposure data with other exposure determinants will allow better estimation of workers' exposure levels. This will be most useful in studying the effects of EMF on chronic diseases, while worst case scenario exposure data can be used to study acute effects, such as electromagnetic interference (EMI) with medical implants (Vila et al., 2017).

In the RF EMF study, Stockholm Central Station in Sweden was selected since it is a place for many servicing workplaces involving daily communication with a large group of people. These may be persons transferring between the metro and train, as well as people having meetings or who are waiting for a transfer. The area also incorporates many shops and services, all having employees. The results of the study showed that people both in public areas and in work locations may be exposed to unnecessarily elevated levels of EMFs. The author investigated electromagnetic fields in various contexts with the focus on revealing causes for elevated exposures and suggesting safer ways to work. Interestingly, the base station antenna causing a high exposure, as shown in Figure 8 in Hardell et al (2016; Article II) was dismantled following the publication. Still there is good coverage for mobile communication in that area.

The investigation revealed hotspots in the measured areas, due to the placement and aim of the indoor antennas. In subway walkways the antennas placed low, right above people's heads, creating elevated EMF zones. In these locations, the field level exceeded the exposimeter's highest detection level, hence making accurate assessment impossible.

The findings of the study showed mean exposure in Stockholm Central Railway station to vary between 2817 to 7891 $\mu W/m^2$. GSM and UMTS 900 downlink contributed most to the radiation dose. These results are in line with other researchers'' findings in similar areas: Estenberg and Augustsson measured radiofrequency fields in rural, urban and city locations, concluding that the highest arithmetic mean was located in the city of Stockholm, followed by urban areas and then rural areas. They also confirmed that the major sources of EMF were GSM and UMTS downlinks (Estenberg & Augustsson, 2014).

Likewise, Urbinello et al. found that total mean exposure levels from mobile phone base stations were higher in downtown and business areas compared to residential areas. Also, as in the current study, they found that exposure varied considerably relative to space (Urbinello, Huss, Beekhuizen, Vermeulen, & Röösli, 2014). This confirms the finding that radiofrequency hotspots are created by mobile phone base station antennas.

Also Bolte et al. conducted a body-worn exposimeter study in Netherlands which showed that railway stations are one of the highest public exposure areas; they also connected elevated exposure to the many people occupying the same premises and using RF generating devices such as mobile devices (Bolte, van der Zande, & Kamer, 2011).

Long term health effects from occupational exposure to the EMFs

The current study confirms an increased risk of long term health effects for occupational ELF-EMF exposure, based on a large case-control study conducted in Sweden on brain tumors and occupational exposure to ELF EMFs. Statistically significant risks in the shortest latency periods (1-4, 5-9, and 10-14 years) were found for astrocytoma grade IV, whereas no risk for occupational ELF MF was found for longer latencies or for other types of glioma. This indicates a late carcinogenic effect with tumor promotion/progression. The INTEROCC study showed an increased risk for all glioma in the 1-4 year latency period but not for longer latencies. The results were similar for low-grade and high grade glioma (Interphone Study Group, 2010). Interestingly, our study did not find any interaction between occupational ELF MF exposure and wireless phone use. Thus, exposure to ELF MF and RF radiation seem to be independent risk factors for long term health effects.

Reducing workers' exposure to the EMFs

In this study, alternative means of conducting work to minimize exposure in the workplace were investigated. Within the framework of EU directive 2013/35/EU, most options of Article 5 are applicable and viable in reducing the worker exposure.

The standard working procedure developed for the heating process using the induction heater, exposes the worker to unnecessary levels of electromagnetic radiation. However, the circumstances of the exposure relative to the working procedures grant several possibilities for reducing the exposure.

The results of the induction heater investigation showed that the exposure to the MF during the induction heating procedure could be significantly reduced by implementing relatively effortless mitigation measures, including workplace rearrangement and work procedures redesign. Time-weighted average exposure could be lowered from 2.57 µT (maximum observed procedure) to 0.12 µT (recommended procedure after interventions). The investigation also revealed that little attention is paid to training workers affected by high EMF levels. The requirements of the new EMF legislation dictate the necessity of planning appropriate training programs for all parties involved, including employers, workers and work environment specialists.

The literature also shows that workers' exposure tends to be episodic and subject to on/off switching of the device, but also due to the worker changing positions within the work area. As a result, the worker is exposed in short intervals to a relatively high field, when moving towards or away from the EMF source (Decat, Deckx, Meynen, De Graef, & Jonlet, 2006; NRPB - National Radiological Protection Board (UK), 2001; World Health Organization. et al., 2002).

In investigating office workstation EMF emissions from portable computers a new 14-point express measurement method was introduced by the author. Unlike a single spot measurement method, measuring 14 body points provides a comprehensive map of the EMF exposure across the worker's body, revealing a range of exposures. Due to the heterogeneous nature of the EMF distribution, encompassing all possible areas of the worker's workspace is needed to demonstrate the workplace's compliance with the safety legislation.

The investigation concluded that for effective exposure reduction measures, a combination of various interventions should be applied. Applying just one measure may, mitigate some aspects of EMFs or lower the exposure, but only from a certain body region. The largest reduction of EMFs was achieved when at least three intervention measures were applied together: the whole body average exposure to the magnetic field was lowered by 89% (Scenario BGKMW) and to the electric field by 99% (Scenario AGKW), see figure 7.

The results of the investigation parallel findings from the literature, Ekman et al. (2012) found the mean electric fields from PCs to vary from 10 to 678 V/m, with a maximum detected field of 1050 V/m, and pointed out that the cause for the higher field levels was lack of PC casing grounding (Ekman, Hagström, Auranen, Hänninen, & Huttunen, 2012).

The results of the current study also showed that when comparing the exposure levels at specific spots over the user's body, the computer user's highest exposures were recorded in the palms and feet. Similar results were found by Zopetti et al. and in a follow up study by Bellieni et al. (Bellieni et al., 2012; Zoppetti, Andreuccetti, Bellieni, Bogi, & Pinto, 2011).

In the current study, results found for the user's exposure conditions under scenario AGKW are comparable to findings in studies by Baltrenas and Christiane (Baltrenas, Buckus, & Vasarevicius, 2011; Christiane, 2011).

5. Conclusions

The aim of this study was to provide a basis for the development of an operational model for EMF safety management. With this in mind, electromagnetic fields were studied from multiple aspects, including both quantitative and qualitative approaches. As a result, a model was developed introducing a system for managing EMF safety. The model prescribes a set of hierarchical steps to mitigate risks from the workers' exposure to EMFs. As a function of the model, the employer is able to demonstrate compliance with the legislative requirements governing EMF exposure and to provide the workers with a healthy work environment. Considering that before the EU directive 2013/35/EU, little attention had been paid to EMF safety management, the model provides needed guidelines for the employer on how to comply with the new requirements on workers' safety.

In establishing the basis for the model, the research resulted in the following findings, which represent contributions to the scientific literature, and also provide practical value.

The research improved the scientific understanding of consequences from exposure to electromagnetic fields (EMF). There are long term health effects from occupational exposure to extremely low frequency (ELF) electromagnetic fields that are not currently covered by safety legislation. The current safety limits are based on short term health effects.

Significantly elevated radiofrequency (RF) EMF hotspots were measured resulting from poor set up of RF antennas. The spatial distribution of the exposure level revealed that the antennas were positioned poorly, and with overlapping radiation patterns, resulting in hotspots which exposed people to high levels of RF EMFs which are unnecessary for mobile communication services.

Industrial workers are exposed to high levels of magnetic radiation from production devices. Investigations revealed that to a large extent the exposure is unnecessary, and that by following the technical and administrative intervention solutions developed by the author, the workers' exposure could be drastically reduced. The key factor is to empower the worker with relevant knowledge regarding the health effects of EMF, and information on the radiation pattern around the device and risk mitigation principles.

Contributing to safety education of both the workers and the working environment specialists will have a positive effect on safety compliance and other related safety issues within the company, and will thereby help the organization to demonstrate the fulfillment of legislative requirements. Working environments specialists reported higher compliance with EMF safety arrangements compared to the workers, but overall, safety management practices were still poor relative to the legislative requirements.

The author concludes that there are several steps the worker can take to control his/her overall exposure without significant additional effort or expense. Rearrangement of devices and adoption of new operational habits can reduce exposure to the EMFs even by orders of magnitude. Intervention measures may include increasing the distance from the source of the EMF and shielding the EMF source. The best reduction of EMF exposure will be achieved when several measures are implemented simultaneously.

In managing EMF safety, the employer should proceed step by step. The hierarchical process suggested by the author starts with the employer informing the worker about EMF conditions. Secondly, the employer should educate the worker how to reduce his/her exposure. Thirdly, the employer should motivate the worker to follow the EMF safety management procedures. And lastly, the employer should conduct regular reviews on the implementation and operational effectiveness of the EMF safety management system, including workers' safety behavior. Measurements of electromagnetic fields in workplaces are an inherent part of guaranteeing worker safety and the effectiveness of the EMF safety management system.

Implications. The results of the current study are directly applicable to the work environments within all companies and other organizations charged with their workers' safety, but can also be applied in part to the general public, in situations where people seek to mitigate risks from EMFs. The results may be useful in developing national safety requirements (Ministry of Social Affairs), for controlling safety arrangements in companies (Work Inspectorate), but are mainly designed for use by work environment specialists to develop and implement EMF safety measures within their companies. The latter function is emphasized in response to the poor state of EMF risk management that currently exists in companies, and the approval of the new occupational EMF safety requirements.

Future research. Given that there are many unknowns regarding the safety of electromagnetic fields, future research would first need to focus on assessing risks from long term occupational exposure to electromagnetic fields. Current safety limits (The European Parliament and the Council, 2013; Vabariigi Valitsuse määrus 01.04.2016 nr 44, 2016) are based on short term health effects (ICNIRP-International Commission on Non-Ionizing Radiation Protection, 1998; ICNIRP, 2009, 2014), which cover only a limited number of health mechanisms. By now, many new health mechanisms have been established, some of which may have profound health and safety implications under chronic exposure conditions (Belpomme, Hardell, Belyaev, Burgio, & Carpenter, 2018; Belyaev et al., 2016; Hardell & Carlberg, 2018; National Toxicology Program, 2018; Wyde et al., 2016; Yakymenko et al., 2016). Considering that many workers remain at their workstations for the entire working day, the author advises following the ALARA (as low as reasonably achievable) principle in workplace safety management. Guidelines should be work- and device-specific, as exposure scenarios are different from workplace to workplace and from machinery to machinery. Given the unknown factors regarding human health effects, the safety management guidelines should be aimed to minimize exposure, which would help to reduce possible long term health effects.

In future research, the basis for the current EMF safety management model needs to be expanded. It is recommended that future studies obtain information on the effectiveness of current EMF risk mitigation measures. These studies should focus on the effect of safe working conditions for the worker's long term productivity.

The new legal requirements regarding management of occupational safety from EMFs have generated a greater need to develop new science-based recommendations for workplace EMF safety management, considering different types of occupational exposure. Currently, EMF safety management is based on a limited number of proper studies, and various aspects of management need to be identified, such as the organizational factors that encourage or hinder the implementation of EMF safety policies, and their integration into the general management system. Also, future studies need to relate adopted models of EMF safety management to economic and financial performance, which may provide an incentive for management.

List of Figures

All figures are composed by the author.

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All tables are composed by the author.

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Abstract

Safety Management of Electromagnetic Fields in the Work Environment

Occupational exposure to electromagnetic fields is a known risk factor and considered the most complicated physical hazard in the workplace. The legislation requires measures to be taken to reduce exposure and to mitigate risks in order to guarantee worker safety.

Electromagnetic fields are considered a new and emerging risk factor. Assessing risks in the electromagnetic domain is a challenge as whole extent of the health implications of different types and forms of exposure is unknown.

EMFs were studied using both quantitative and qualitative approaches, including measurements, questionnaires, interviews and in-situ workplace observations. The research addressed current practices and rules of managing safety from electromagnetic fields. Safety compliance analyses were conducted with regard to legislative requirements. This endeavor was guided by the new requirements for health and safety with regard to electromagnetic fields.

This study was intended to help improve management's safety knowledge of this risk factor, by encompassing scientifically reasonable approaches in designing EMF safety. The study included analysis of the exposure levels of workers, and development of methods to reduce exposure, with respect to the new occupational EMF legislation. The author analyzed the EMF exposure in different settings, including means of work, encompassing industrial, office, and public settings. The EMF safety compliance of companies was investigated. New, safer ways to work when exposed to electromagnetic fields were proposed. The author proposed and tested methods of EMF exposure reduction, which can be used by employers to demonstrate compliance with the occupational exposure norms, and public safety norms. As a result, a model was developed introducing a system for managing EMF safety. The model prescribes a set of hierarchical steps to mitigate risks from the workers' exposure to EMFs.

The research improved the scientific understanding of consequences from exposure to electromagnetic fields (EMF). There are long term health effects from occupational exposure to extremely low frequency (ELF) electromagnetic fields that are not currently covered by safety legislation.

Significantly elevated radiofrequency (RF) EMF hotspots were measured in open spaces resulting from poor set up of RF antennas. Investigations also revealed that industrial workers are exposed to high levels of magnetic radiation from production devices that to a large extent is unnecessary. By following the technical and administrative intervention solutions developed by the author, the workers' exposure could be drastically reduced.

Contributing to safety education of both the workers and the working environment specialists will have a positive effect on safety compliance and other related safety issues within the company. Working environments specialists reported higher compliance with EMF safety arrangements compared to the workers, but overall, safety management practices were still poor relative to the legislative requirements. In comparison to workers, working environment specialists also reported better addressing the needs of workers in risk groups.

There are several steps the worker can take to control his/her overall exposure without significant additional effort or expense. Rearrangement of devices and adoption of new operational habits can reduce exposure to the EMFs even by orders of magnitude. Intervention measures may include increasing the distance from the source of the EMF and shielding the EMF source. The best reduction of EMF exposure will be achieved when several measures are implemented simultaneously.

In managing EMF safety, the author advises the employer to proceed step by step. The hierarchical process starts with the employer informing the worker about EMF conditions. Secondly, the employer should educate the worker how to reduce his/her exposure. Thirdly, the employer should motivate the worker to follow the EMF safety management procedures. And lastly, the employer should conduct regular reviews on the implementation and operational effectiveness of the EMF safety management system.

Lühikokkuvõte

Elektromagnetväljade ohutusjuhtimine töökohtadel

Tööalane kokkupuude elektromagnetväljadega (EMV) on teadaolev riskitegur ning seda peetakse töökohal kõige keerulisemaks füüsiliseks ohuks. Õigusaktides esitatakse mitmeid meetmeid töötajate ohutuse tagamiseks, kokkupuute vähendamiseks ja riskide leevendamiseks.

Elektromagnetvälju loetakse uudselt esilekerkivaks riskiteguriks. Elektromagnetiliste riskide hindamine on väljakutse, kuna erinevate ekspositsiooniviiside mõju tervisele on veel teadmata. EMV-de uurimisel kasutati nii kvantitatiivseid kui ka kvalitatiivseid lähenemisviise, sealhulgas mõõtmisi, küsimustikke, intervjuusid ja kohapealseid töökoha vaatlusi. Uuringus käsitleti elektromagnetväljade ohutuse juhtimise tavasid ja reegleid. Ohutusvastavuse uurimine viidi läbi seadusandlike nõuete suhtes. Ettevõtmine oli paljuski ajendatud ja juhitud uutest elektromagnetväljade tervishoiule ja ohutusele seatud nõuetega.

Selle uuringuga soovitakse aidata ettevõtete juhtkondadel parandada teadmisi kõnealuse riskiteguri kohta, hõlmates teaduslikult põhjendatud lähenemisviise EMV ohutuse kavandamisel. Uuring hõlmas töötajate ekspositsioonitasemete analüüsi ja kokkupuute vähendamise meetodite väljatöötamist lähtuvalt uuest EMV seadusandlusest. Autor analüüsis EMV ekspositsiooni erinevates seadistustes, sealhulgas tööviisidel, hõlmates tööstus-, büroo- ja avalikke keskkondi. Uuriti ettevõtete elektromagnetväljade ohutuse korraldust vastavushindamise teel. Pakuti välja uusi ohutumaid viise elektromagnetväljadega töötamisel. Autor pakkus välja ja katsetas EMV kokkupuute vähendamise meetodeid, mida tööandjad võivad kasutada, et demonstreerida vastavust nii tööalaste kui avalike kokkupuutenormidega. Selle tulemusena töötati välja mudel EMV ohutuse juhtimise süsteemi loomiseks. Mudel näeb ette hulga hierarhilisi samme, et leevendada töötajate kokkupuude elektromagnetväljadega.

Uurimus parandas ka teaduslikke arusaamu elektromagnetväljadega kokkupuutue tagajärgedest. Tööalasel kokkupuutel eriti madalate sagedusega (ELF) elektromagnetväljadega on pikaajalised tervisemõjud, mida ohutusalased õigusaktid praegu veel ei hõlma.

Avalikes ruumides mõõdeti ja tuvastati oluliselt kõrgendatud raadiosageduslikke (RF) piirkondi antennide ebasoodsa seadistuse tõttu. Uuringud näitasid ka seda, et tööstustöötajad puutuvad kokku tugevate magnetväljadega, mis lähtuvad tootmisseadmetest, kusjuures selline ekspositsioon on suures osas ebavajalik, et vastavat protseduuri läbi viia. Autori poolt välja töötatud tehniliste ja halduslike sekkumiste lahenduste järgimisel võib aga töötajate kokkupuudet oluliselt vähendada.

Nii töötajate kui ka töökeskkonnaspetsialistide ohutusalase harimise edendamisel on positiivne mõju ohutusnõuetele ja muudele sellega seotud ohutusprobleemidele ettevõttes. Töökeskkonna spetsialistide hinnangul on ettevõtete vastavus EMV ohutusnõuetega kõrgem, kui seda hindasid olevat töötajad. Üldiselt oli ohutusjuhtimine siiski nõrgal tasemel võrreldes sellega, mis õigusaktides kirjas. Võrreldes töötajatega, leidsid töökeskkonnaspetsialistid ka, et riskirühma töötajate ohutus on paremini tagatud.

Töötajal on mitmeid võimalusi, et kontrollida ning vähendada oma üldist ekspositsiooni ilma oluliste täiendavate jõupingutusteta või kulutusteta. Seadmete ümberkorraldamine ja uute käitumisharjumuste kasutuselevõtt võib vähendada elektromagnetväljadega kokkupuudet isegi suurusjärgkude võrra. Sekkumismeetmed võivad hõlmata kauguse suurendamist EMV allikani ja EMV allika ekraneerimist. EMV ekspositsiooni efektiivseimad vähenemised saavutatakse aga mitme meetme samaaegsel rakendamisel.

EMV ohutusjuhtimisel soovitab autor tööandjal edeneda samm-sammult. Hierarhiline protsess algab sellega, et tööandja teavitab töötajat EMV olukorrast tema töökohal. Teisena peaks tööandja õpetama töötajale, kuidas efektiivselt vähendada oma kokkupuudet. Kolmandaks peaks tööandja motiveerima töötajat järgima EMV ohutusjuhtimise tavasid. Lõpuks, peaks tööandja korrapäraselt kontrollima EMV ohutusjuhtimise süsteemi järgimist ning rakenduslikku tõhusust.

Appendix 1

Article 1

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RESEARCH ARTICLE

Case-control study on occupational exposure to extremely low-frequency electromagnetic fields and glioma risk

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Background: Exposure to extremely low-frequency electromagnetic fields (ELF-EMF) was in 2002 classified as a possible human carcinogen, Group 2B, by the International Agency for Research on Cancer at WHO.

Methods: Life time occupations were assessed in case-control studies during 1997-2003 and 2007-2009. An ELF-EMF Job-Exposure Matrix was used for associating occupations with ELF exposure (μT). Cumulative exposure (μT-years), average exposure (μT), and maximum exposed job (μT) were calculated.

Results: Cumulative exposure gave for astrocytoma grade IV (glioblastoma multiforme) in the time window 1-14 years odds ratio (OR) = 1.9, 95% confidence interval (CI) = 1.4-2.6, p linear trend <0.001, and in the time window 15+ years OR = 0.9, 95%CI = 0.6-1.3, p linear trend = 0.44 in the highest exposure categories 2.75+ and 6.59+ μT years, respectively.

Conclusion: An increased risk in late stage (promotion/progression) of astrocytoma grade IV for occupational ELF-EMF exposure was found.

KEYWORDS
astrocytoma, electromagnetic fields, ELF-EMF, glioma, occupational exposure, RF-EMF, risk factors, wireless phones

1 | INTRODUCTION

Few risk factors are established for brain tumors except ionizing radiation.[1] In 2002 International Agency for Research on Cancer (IARC) classified extremely low-frequency electromagnetic fields (ELF-EMF) as “possibly carcinogenic to humans,” Group 2B based on an increased risk for childhood leukemia.[2] More recently a pooled analysis showed about twofold increased risk for childhood leukemia at exposure level above 0.3-0.4 μT,[3] further supporting the association. Some other malignant diseases have been associated with ELF-EMF exposure such as breast cancer,[4,5] and malignant lymphoma and leukemia in adults.[6] In a review of published literature up to July 1, 1994 an increased risk for childhood leukemia was found for the existence of, or distance to power lines in the vicinity of residence.[7] An increased risk of chronic lymphocytic leukemia (CLL) was found for occupational ELF-EMF exposure. Furthermore the review showed an increased risk for brain tumor in the electronic/electric industry.[7]

During more recent years additional studies have been performed. In a small study from Sweden on 84 glioma cases, 20 meningioma cases, and 155 controls an elevated risk for glioma was seen in exposed occupations with an average mean value of >0.4 μT.[8] In a Canadian case-control study on brain tumors highest occupational average ELF-EMF exposure >0.6 μT compared to exposure < 0.3 μT gave for astrocytoma grade IV (glioblastoma multiforme) odds ratio (OR) = 5.36, 95% confidence interval (CI) = 1.16-24.78, adjusted for exposure to ionizing radiation and vinyl chloride.[9] Higher OR was obtained for the last held job. The authors concluded that exposure to ELF-EMF may increase the risk of brain tumors and influence the risk as promoters. The risk for brain tumors was assessed for occupational exposure to ELF-EMF in a case-control study from USA.[10] Exposure was assessed for 489 glioma cases, 197 meningioma cases, and 799 controls. No statistically significant increased risk was obtained for these tumor types including glioblastoma multiforme. Results for different time windows (time before tumor diagnosis) were not given.

In a French case-control study on occupational ELF-EMF exposure a somewhat increased risk was seen for glioma, OR = 1.20, 95% CI = 0.66-2.17, and for meningioma OR = 3.02, 95%CI = 1.10-8.25.[11] This was a small study including only 105 glioma cases, 67 meningioma cases, and 442 controls. No statistically significant association between occupational ELF-EMF exposure and brain tumors was found in a cohort study from the Netherlands.[12] The results were based on 233 cases. In a study on U.K. electricity supply workers no evidence was found for increased glioma risk for distant or recent estimated ELF-EMF exposure based on job title.[13] No results were given for subtypes of glioma.

A meta-analysis on the association between EMF-ELF and the susceptibility to cancer was based on 42 studies.[14] A weak association between ELF-EMF exposure and all cancer was seen when all the eligible studies were pooled; OR = 1.08, 95%CI = 1.01-1.15, regardless of the exposure models. The results for brain tumors was based on 12 studies yielding OR = 1.10, 95%CI = 0.96-1.26.

Thus the results on ELF-EMF exposure and glioma risk are mostly inconsistent and hampered by small studies, different methods, and lack of results on subtypes of glioma including exposure in specific time windows.

In laboratory studies ELF-EMF was mutagenic, but also potentiated the mutagenicity of ionizing radiation using microsatellite analysis for DNA damage in human glioma cells.[15] A possible involvement of O6-methylguanine DNA adducts in the development of glioma was discussed by Ohgaki.[16]

Animal studies on ELF-EMF exposure alone have been inconclusive. Long-term ELF-EMF exposure was a risk factor for chronic myeloid leukemia in female mice.[17] Rat studies showed that exposure to ELF-EMF enhanced the carcinogenic effect of γ radiation[18] and that life-span exposure to ELF-EMF and formaldehyde induced statistically significant carcinogenic effect.[19]

During the last couple of decades an increasing number of studies have associated brain tumors with use of wireless phones.[20–23] During use they emit radiofrequency electromagnetic fields (RF-EMF). In May 2011 IARC evaluated the carcinogenic potential from RF-EMF. The expert group classified RF-EMF in the frequency range 30 kHz-300 GHz as "possibly carcinogenic to humans," Group 2B.[24,25]

In the international Interphone study glioma was associated with occupational ELF-EMF exposure in recent time windows whereas no increased risk was found for meningioma.[26] The authors concluded that such exposure may play a role in late stage carcinogenesis of glioma.

Similarly, as in Interphone, our results on use of wireless phones and brain tumor risk were based on case-control studies. We used a structured questionnaire but here with certain differences regarding the Interphone study, such as that we used postal questionnaires sent to cases and controls supplemented over the phone instead of personal interviews, even bedside interviews of cases as performed in Interphone. Furthermore we assessed in addition to mobile phones also use of cordless phones (DECT); the latter use not assessed by Interphone. Detailed comparison of the studies may be found elsewhere.[27]

ELF-EMFs are generated by alternating electric current. Most common exposure to ELF-EMFs is from appliances operating on the mains power. The frequency of the mains power is 50 Hz in the most of the world, but also at 60 Hz used in Americas and in some parts of Asia. The exposure to the ELF magnetic fields depends on the current—the more electrical power is used the higher the magnetic field. Therefore, next to the electrical appliances, high exposure to the ELF-EMFs may also occur where electrical power is generated and distributed, example power lines, transformers etc. Another typical high ELF magnetic field exposure source is the electrical motors and other devices incorporating coils. By increasing turns of electrically conductive element that is wire by which the electrical current flows, also the magnetic field is multiplied. Therefore, occupations involving powerful electrical motors in the working area, for example electrical transport, are usually accompanied by strong ELF-EMFs. As powerful electrical motors and other strong magnetic fields generating devices could also be found in many industrial settings, the workers' exposure level in such cases depend on the distance to the magnetic field source. For example, people working with hand-held electrical power tools are having a strong magnetic fields exposure, whereas others further away from even stronger sources, may be exposed at insignificant levels. The design of the instrumentation and the working areas in regard to where the people are located in respect to the appliances, plays a crucial role in determining the resultant exposure level.

Our case-control studies had detailed occupational history including job titles, branch of different occupations, and years for the specific jobs. Thus it was possible to calculate ELF-EMF job exposure for cases and controls using a job-exposure matrix (JEM).

2 | MATERIALS AND METHODS

Similar methods were used in all of our studies. Detailed information on materials and methods has been published previously.[28,29] In short, six administrative regions with oncology centres covering Sweden registered new cancer cases. For 1997-2003, cases and controls covered central Sweden,[29] whereas the 2007-2009 study included the whole country.[28] The oncology centers reported new cases with histopathologically verified brain tumor, either benign or malignant, to us during these periods, although the actual reporting interval varied for center to center. Both men and women were included aged 20-80 years (1997-2003) and 18-75 years (2007-2009) at the time of diagnosis. Only living cases were included after asking the responsible physician for permission before inclusion in the study. Tumor localisation in the brain was based on reports to the cancer registries and medical records, which were obtained after informed consent from the patients.

Controls were ascertained from the Swedish Population Registry. The registry is continuously updated, so that each person could be traced by a unique ID number. It also records the address to each person. For each case, one control subject of the same gender and in the same 5-year group was drawn at random from the Population Registry. They were assigned the same year for cut-off of all exposure as the year of diagnosis of the respective case. All these controls were used in the analysis of risk of glioma.

Exposure was assessed using a mailed questionnaire sent to each person.

The questionnaire contained a number of questions relating to the overall working history, exposure to different chemicals, and other agents, smoking habits, X-ray investigations of the head and neck, and heredity traits for cancer. Regarding use of a mobile phone and cordless phone, time period, average daily use (min per day), use of hands free device, and external antenna in a car were asked for. The ear mostly used during phone calls, or equally both, was also noted. Use of the wireless phone was referred to as ipsilateral (≥50% of the time) or contralateral (<50% of the time) in relation to tumor side. The same method was also applied for the control group; the subjects were assigned the same "tumor" side as the respective case to the matched control.

When questionnaire answers were unclear, they were resolved by phone using trained interviewers. Thereby, a written protocol was used for clarification of each question. The interviewer supplemented the whole questionnaire during the phone call. Each questionnaire had received a unique ID-number that did not disclose whether it was a case or a control; that is the interviewer was unaware of the status during further data processing. All information was coded and entered into a database. Case or control status was not disclosed until statistical analyses were undertaken.

In this study we included only glioma cases. As comparison group all controls were used. This was possible since we adjusted for potential confounding factors such as year of diagnosis (each control had the same year of "diagnosis" as the respective case), age at diagnosis, gender, and socioeconomic index (SEI).

The questions regarding occupations included job title, branch, and first and last year for each job in the work history of each participant. The INTEROCC ELF Magnetic Field Job-Exposure Matrix (ELFJEM) was used for associating occupations with ELF exposure (μT).[26] The JEM used International Standard Classification of Occupations 1988 (ISCO88) four digit codes for most jobs included; ISCO68 five digit codes were used for more specific electrical jobs. The online version of the JEM is available at: http://www.crealradiation.com/index.php/en/databases?id=55. Job codes were coded using the Nordisk Yrkesklassificering (NYK 85; five digit codes) system and their validity was checked before they were translated to the International Standard Classification of Occupations 1988 (ISCO88; four digit codes) using a coding key provided by Dr Erik Bihagen at Stockholm University.[30] For translation to the 1968 ISCO version for specific jobs (ISCO68; five digit codes) we compared with the NYK 85 system manually and selected the most proper codes to be translated. Job exposure the year before diagnosis was excluded. No job was reported for 34 cases and 45 controls, so they were excluded from the analyses.

2.1 | Statistical methods

StataSE 12.1 (Stata/SE 12.1 for Windows; StataCorp., College Station TX) was used for the analyses. Odds ratios (OR) and 95% confidence intervals (CI) were calculated using unconditional logistic regression including the whole control sample (ie, matched to both malignant and benign cases) to increase the power.

Cumulative exposure (μT-years), average exposure (μT), and maximum exposed job (μT) were calculated for the included cases and controls for lifetime work history and in time windows. Two sets of time windows were analyzed, 1-4, 5-9, 10-14, 15-19, and 20+ years before diagnosis and 1-14 and 15+ years before diagnosis. Cut points at the 25th, 50th, 75th, and 90th percentile for controls were used to categorize the exposure variables with the lowest category (<25th percentile) as reference group (OR = 1.0). Tests for linear trends were performed using the Wald test with the median of each category included as an ordinal variable in the analyses. Interaction with use of wireless phones (mobile and/or cordless phone) was investigated on the multiplicative scale counting exposure ≥25th percentile as exposed.

Restricted cubic splines were used to display the relationship between cumulative exposure to ELF-EMF (μT-years) in time windows and glioma. Four knots were used at the 5th, 35th, 65th, and 95th percentiles, as suggested by Harrell.[31]

In all analyses adjustment was made for the matching variables gender, age (as a continuous variable) and year of diagnosis and also for socioeconomic index (SEI) divided into three categories (blue-collar worker, white-collar worker, self-employed).

3 | RESULTS

The results were based on analyses of 1346 glioma cases (86% of included; 11.4% did not answer the questionnaire and 2.4% were excluded since they had no job codes registered) and 3485 controls (86% of included; 12.6% did not answer the questionnaire and 1.1% were excluded since they had no job codes registered). The mean age

TABLE 1 Odds ratio (OR) and 95% confidence interval (CI) for all glioma (*n* = 1346) for occupational exposure to ELF-EMF

	Glioma (*n* = 1346)		
Exposure metric	**Ca/Co**	**OR**	**95%CI**
Cumulative exposure (μT-years)			
<2.33	368/870	1.0	-
2.33 to <3.79	306/872	0.9	0.7-1.1
3.79 to < 5.55	287/869	0.9	0.7-1.1
5.55 to <8.52	219/525	0.9	0.7-1.2
8.52+	166/349	1.0	0.8-1.4
p, linear trend			0.45
Average exposure (μT)			
<0.11	285/830	1.0	-
0.11 to <0.13	330/912	1.1	0.9-1.3
0.13 to < 0.18	316/871	1.0	0.8-1.2
0.18 to <0.27	234/523	1.1	0.9-1.4
0.27+	181/349	1.3	1.003-1.6
p, linear trend			0.04
Maximum exposed job (μT)			
<0.13	284/823	1.0	-
0.13 to <0.16	291/812	1.1	0.9-1.3
0.16 to <0.24	379/968	1.0	0.8-1.2
0.24 to <0.60	234/532	1.1	0.9-1.3
0.60+	158/350	1.1	0.9-1.5
p, linear trend			0.29

Cut points at 25th, 50th, 75th, and 90th percentile for controls.
Unconditional logistic regression, adjusted for age at diagnosis, gender, socio-economic index (SEI), and year of diagnosis. Exposure the year before diagnosis was excluded ("1-year lag").

of the cases was 53 years (median 55, range 19-80) and of the controls 54 years (median 56, range 20-80). Of the glioma cases 803 were men, versus 1472 male controls. The gender difference was explained by the fact that also controls to meningioma cases were used; meningioma is about twice as common in females than in males.

The mean number of jobs for cases were 2.6 (median = 2, min = 1, max = 10) and for controls 2.7 (median = 2, min = 1, max = 12). More than 80% of both cases and controls worked all years in each of the four time windows up to 19 years. Since the last time window, 20+ years, did not have a closed interval such a calculation was not possible. Cumulative lifetime exposure to ELF-EMF varied between 0.05 and 556 µT-years for glioma cases and 0.04 to 468 µT-years for the controls. The main occupations among those with high ELF exposure (≥8.52 µT-years) were machine-tool operators (28 cases, 56 controls) and welders and flame cutters (26 cases, 57 controls). These occupations were also the main ones in all time windows. In Table 1 results for cumulative exposure in µT-years, average exposure in µT, and maximum exposed job (µT) are shown. In the highest average exposure category >0.27 µT an increased risk for glioma of borderline significance was found; OR = 1.3, 95%CI = 1.003-1.6, p linear trend = 0.04.

Table 2 displays the same results as in Table 1 for different types of glioma. For astrocytoma grade I-II no statistically significant risks were found. For astrocytoma grade III an increased risk with linear trend was found in the highest average exposure category ≥ 0.27 µT; OR = 1.5, 95%CI = 0.9-2.7, p linear trend = 0.048. Also in the highest category for maximum exposed job, ≥0.60 µT, an increased risk was seen, OR = 1.6, 95%CI = 0.9-2.8, p linear trend = 0.04. Regarding astrocytoma grade IV (glioblastoma multiforme) an increased risk was found in all cumulative exposure categories, however without a statistically significant trend, p linear trend = 0.12. Average exposure in the two highest exposure categories yielded increased risk of borderline statistical significance, however without a statistically significant trend, p linear trend = 0.07.

Results for cumulative exposure in µT-years for all glioma in different time windows (years before diagnosis) are shown in Table 3. No statistically significant increased risks or linear trends were found.

Cumulative exposure in µT-years in different time windows for different types of glioma is shown in Table 4. Regarding astrocytoma grade I-II and astrocytoma grade III no statistically significant results were obtained. For astrocytoma grade IV increased risks were obtained in the highest exposure categories in the time windows 1-4, 5-9, and 10-14 years whereas no pattern of an association was found in the time windows 15-19 and 20+ years. Thus in the time window 1-4 years and cumulative exposure ≥0.69 µT-years OR = 1.6,

TABLE 2 Odds ratio (OR) and 95% confidence interval (CI) for astrocytoma grade I-II (*n* = 206), astrocytoma grade III (*n* = 157), and astrocytoma grade IV (*n* = 687) for occupational exposure to ELF-EMF

	Astrocytoma, grade I-II (*n* = 206)			Astrocytoma, grade III (*n* = 157)			Astrocytoma, grade IV (*n* = 687)		
Exposure metric	**Ca/Co**	**OR**	**95%CI**	**Ca/Co**	**OR**	**95%CI**	**Ca/Co**	**OR**	**95%CI**
Cumulative exposure (µT-years)									
<2.33	106/870	1.0	-	53/870	1.0	-	92/870	1.0	-
2.33 to <3.79	38/872	0.8	0.5-1.2	39/872	1.1	0.6-1.7	161/872	1.4	1.01-1.8
3.79 to <5.55	31/869	0.8	0.5-1.3	24/869	0.7	0.4-1.2	186/869	1.4	1.01-1.8
5.55 to <8.52	15/525	0.6	0.3-1.2	28/525	1.2	0.6-2.1	142/525	1.4	0.97-1.9
8.52+	16/349	0.9	0.5-1.7	13/349	0.8	0.4-1.7	106/349	1.5	1.05-2.1
p, linear trend			0.74			0.65			0.12
Average exposure (µT)									
<0.11	43/830	1.0	-	35/830	1.0	-	128/830	1.0	-
0.11 to <0.13	56/912	1.2	0.8-1.9	27/912	0.7	0.4-1.2	177/912	1.2	0.97-1.6
0.13 to <0.18	44/871	0.9	0.6-1.4	42/871	1.1	0.7-1.7	167/871	1.2	0.9-1.5
0.18 to <0.27	42/523	1.3	0.8-2.0	27/523	1.1	0.6-1.8	125/523	1.4	1.02-1.8
0.27+	21/349	1.0	0.5-1.8	26/349	1.5	0.9-2.7	90/349	1.4	1.03-2.0
p, linear trend			0.89			0.048			0.07
Maximum exposed job (µT)									
<0.13	46/823	1.0	-	33/823	1.0	-	141/823	1.0	-
0.13 to <0.16	47/812	1.2	0.8-1.9	30/812	0.9	0.6-1.6	142/812	1.0	0.8-1.4
0.16 to <0.24	59/968	1.0	0.7-1.6	43/968	0.9	0.6-1.5	205/968	1.1	0.9-1.4
0.24 to <0.60	33/532	1.1	0.7-1.9	26/532	1.0	0.6-1.7	120/532	1.0	0.8-1.4
0.60+	21/350	1.2	0.7-2.2	25/350	1.6	0.9-2.8	79/350	1.1	0.8-1.5
p, linear trend			0.61			0.04			0.75

Cut points at 25th, 50th, 75th, and 90th percentile for controls.
Unconditional logistic regression, adjusted for age at diagnosis, gender, socio-economic index (SEI), and year of diagnosis. Exposure the year before diagnosis was excluded ("1-year lag").

95%CI = 1.2-2.3, p linear trend = 0.02, time window 5-9 years and cumulative exposure ≥0.92 µT-years OR = 1.9, 95%CI = 1.4-2.6, p linear trend <0.001, and time window 10-14 years and cumulative exposure ≥0.92 µT-years OR = 1.7, 95%CI = 1.3-2.4, p linear trend = 0.003, were obtained. Using the time windows 1-14 and 15+ years strengthened the association of increased risks further for astrocytoma grade IV in the 1-14 year period while no risks were found for 15+ years, Table 5.

Restricted cubic spline plots for astrocytoma grade IV and cumulative exposure to ELF-EMF in µT-years in two time windows (1-14 and 15+ years) are shown in Figures 1 and 2. As indicated in Table 5, the risk increased with increasing cumulative exposure in the 1-14 year time window whereas no statistically significant increased risk was found in the 15+ year group.

We analyzed interaction between exposure to ELF-EMF and use of mobile and/or cordless phones and the risk for all glioma as well as different types without any statistically significant interaction. Results for all glioma and astrocytoma grade IV and use of wireless phones and occupational exposure to ELF-EMF are shown in Table 6. Regarding astrocytoma grade IV somewhat higher ORs were obtained in the categories of use of wireless phones and cumulative exposure ≥2.33 µT-years and also average exposure ≥0.11 µT, respectively, but without a statistically significant interaction.

Since we have consistently found an increased risk for glioma associated with ipsilateral use of mobile or cordless phone[23] we also analyzed such use and occupational ELF-EMF exposure. No statistically significant interaction was found. In fact ORs were of the same magnitude for ipsilateral mobile phone use for those with low (<25th percentile) and high (≥25th percentile) ELF-EMF exposure. The results were similar for glioma in total and astrocytoma grade IV (data not in Table).

TABLE 3 Odds ratio (OR) and 95% confidence interval (CI) for all glioma (*n* = 1346) for occupational exposure to ELF-EMF in time windows; 1-4, 5-9, 10-14, 15-19, and 20+ years before diagnosis

	Glioma (*n* = 1346)		
Cumulative exposure (µT-years)	**Ca/Co**	**OR**	**95%CI**
1-4 years			
<0.27	243/647	1.0	-
0.27 to <0.36	234/646	1.1	0.9-1.3
0.36 to <0.45	257/633	1.1	0.9-1.3
0.45 to <0.69	213/496	1.0	0.8-1.3
0.69+	155/298	1.2	0.9-1.5
p, linear trend			0.31
5-9 years			
<0.36	257/703	1.0	-
0.36 to <0.48	250/754	1.0	0.8-1.2
0.48 to <0.60	262/680	1.0	0.8-1.3
0.60 to <0.92	245/543	1.1	0.9-1.4
0.92+	165/306	1.2	0.97-1.6
p, linear trend			0.06
10-14 years			
<0.36	254/724	1.0	-
0.36 to <0.48	250/675	1.1	0.9-1.4
0.48 to <0.61	327/897	1.0	0.9-1.3
0.61 to <0.92	186/420	1.1	0.9-1.4
0.92+	165/350	1.1	0.9-1.5
p, linear trend			0.35
15-19 years			
<0.40	285/724	1.0	-
0.40 to <0.48	180/598	0.9	0.7-1.1
0.48 to <0.64	315/895	0.9	0.8-1.1
0.64 to <0.96	208/459	1.0	0.8-1.3
0.96+	132/299	1.0	0.8-1.3
p, linear trend			0.77
20+ years			
<1.08	272/733	1.0	-
1.08 to <2.06	243/747	0.8	0.7-1.1
2.06 to <3.51	241/744	0.8	0.6-1.02
3.51 to <5.64	184/445	0.9	0.7-1.2
5.64+	125/297	0.9	0.6-1.2
p, linear trend			0.80

Cut points at 25th, 50th, 75th, and 90th percentile for controls in each time window.
Unconditional logistic regression, adjusted for age at diagnosis, gender, socio-economic index (SEI), and year of diagnosis. Exposure the year before diagnosis was excluded ("1-year lag").

4 | DISCUSSION

This was a large case-control study on brain tumors and occupational exposure to ELF-EMF. All types of brain tumors were included but here results are shown only for glioma. One reason to focus on glioma was that the INTEROCC study showed an association between exposure to ELF-EMF and glioma, but not for meningioma.[26] The INTEROCC results were based on 1939 glioma cases and 5404 controls to be compared with 1346 participating glioma cases and 3485 participating controls in our study. Thus, the results in both studies were based on large numbers of cases and controls. However, in contrast to INTEROCC, we had high participation rate among both cases and controls thus minimizing selection bias. The INTEROCC data were based on results from seven countries of the 13 included in Interphone; Sweden was not included. It is an advantage with a study in only one country, as our investigation, for methodological, and logistic reasons, for example better with one study group instead of multiple as in Interphone (13 countries), differences in response rates in different populations, access to registers, trained interviewers, etc. Furthermore we had a wider age span for included cases and controls, 18-80 years in total, compared to 30-59 years for the majority of included countries in INTEROCC. Thus, we covered the whole lifetime period of occupations in contrast to INTEROCC that did not include occupations in older persons for most countries.

One advantage in our study was that we could make a histopathological classification of the glioma cases. Cumulative

TABLE 4 Odds ratio (OR) and 95% confidence interval (CI) for astrocytoma grade I-II (n = 206), astrocytoma grade III (*n* = 157) and astrocytoma grade IV (n = 687) for occupational exposure to ELF-EMF in time windows; 1-4, 5-9, 10-14, 15-19, and 20+ years before diagnosis

	Astrocytoma, grade I-II (*n* = 206)			Astrocytoma, grade III (*n* = 157)			Astrocytoma, grade IV (*n* = 687)		
Cumulative exposure (µT-years)	Ca/Co	OR	95%CI	Ca/Co	OR	95%CI	Ca/Co	OR	95%CI
1-4 years									
<0.27	41/647	1.0	-	38/647	1.0	-	112/647	1.0	-
0.27 to <0.36	43/646	1.2	0.8-1.9	24/646	0.8	0.5-1.3	114/646	1.4	1.02-1.9
0.36 to <0.45	35/633	1.0	0.6-1.6	34/633	1.0	0.6-1.6	118/633	1.2	0.9-1.6
0.45 to <0.69	45/496	1.3	0.8-2.0	23/496	0.7	0.4-1.3	101/496	1.2	0.9-1.7
0.69+	24/298	1.0	0.6-1.8	19/298	0.9	0.5-1.6	79/298	1.6	1.2-2.3
p, linear trend			0.89			0.74			0.02
5-9 years									
<0.36	44/703	1.0	-	37/703	1.0	-	110/703	1.0	-
0.36 to <0.48	34/754	0.9	0.5-1.4	24/754	0.7	0.4-1.3	132/754	1.4	1.1-1.9
0.48 to <0.60	34/680	1.0	0.6-1.6	31/680	0.9	0.5-1.5	141/680	1.4	1.03-1.8
0.60 to <0.92	47/543	1.3	0.8-2.1	26/543	0.9	0.5-1.5	126/543	1.5	1.1-2.0
0.92+	17/306	0.8	0.4-1.4	20/306	1.1	0.6-1.9	92/306	1.9	1.4-2.6
p, linear trend			0.81			0.68			< 0.001
10-14 years									
<0.36	49/724	1.0	-	30/724	1.0	-	102/724	1.0	-
0.36 to <0.48	27/675	0.8	0.5-1.4	36/675	1.6	0.95-2.6	125/675	1.4	1.1-1.9
0.48 to <0.61	39/897	0.9	0.6-1.4	28/897	0.8	0.5-1.4	201/897	1.5	1.2-2.0
0.61 to <0.92	33/420	1.3	0.8-2.2	20/420	1.1	0.6-2.0	105/420	1.5	1.1-2.1
0.92+	15/350	0.6	0.3-1.1	18/350	1.1	0.6-2.1	99/350	1.7	1.3-2.4
p, linear trend			0.33			0.93			0.003
15-19 years									
<0.40	48/724	1.0	-	30/724	1.0	-	126/724	1.0	-
0.40 to <0.48	21/598	0.7	0.4-1.3	18/598	0.9	0.5-1.7	105/598	1.2	0.9-1.6
0.48 to <0.64	34/895	0.8	0.5-1.2	28/895	0.8	0.5-1.5	199/895	1.2	0.96-1.6
0.64 to <0.96	20/459	0.7	0.4-1.3	25/459	1.3	0.8-2.3	125/459	1.3	1.002-1.8
0.96+	15/299	0.6	0.3-1.2	14/299	1.1	0.5-2.1	77/299	1.3	0.9-1.8
p, linear trend			0.22			0.56			0.19
20+ years									
<1.08	43/733	1.0	-	39/733	1.0	-	117/733	1.0	-
1.08 to <2.06	28/747	0.8	0.5-1.4	18/747	0.5	0.3-0.95	158/747	1.1	0.8-1.5
2.06 to <3.51	19/744	0.7	0.3-1.3	20/744	0.6	0.3-1.2	161/744	1.0	0.7-1.3
3.51 to <5.64	8/445	0.5	0.2-1.2	23/445	1.1	0.5-2.2	120/445	0.9	0.7-1.3
5.64+	13/297	1.0	0.4-2.4	11/297	0.8	0.4-2.0	85/297	0.9	0.6-1.3
p, linear trend			0.85			0.63			0.36

Cut points at 25th, 50th, 75th, and 90th percentile for controls in each time window.
Unconditional logistic regression, adjusted for age at diagnosis, gender, socio-economic index (SEI) and year of diagnosis. Exposure the year before diagnosis was excluded ("1-year lag").

exposure in µT-years or maximum exposed job yielded no statistically significant risk for all glioma, whereas the result for average exposure in µT was of borderline significance, see Table 1.

We analyzed separately low-grade glioma (astrocytoma grade I-II) and high-grade glioma divided into astrocytoma grade III and the most malignant type astrocytoma grade IV (glioblastoma multiforme). For astrocytoma grade I-II and grade III no statistically significant risks were found, see Table 2.

Cumulative exposure in µT-years in different time windows did not give statistically significant risks for glioma overall. Of interest is that dividing glioma in different types yielded only for astrocytoma grade IV statistically significant increased risks in the shortest latency

TABLE 5 Odds ratio (OR) and 95% confidence interval (CI) for all glioma (*n* = 1,346) and astrocytoma grade IV (*n* = 687) for occupational exposure to ELF-EMF in time windows; 1–14 and 15+ years before diagnosis

	Glioma (*n* = 1346)			Astrocytoma, grade IV (*n* = 687)		
Cumulative exposure (µT-years)	Ca/Co	OR	95%CI	Ca/Co	OR	95%CI
1-14 years						
<0.91	260/770	1.0	-	106/770	1.0	-
0.91 to <1.42	311/872	1.1	0.9-1.3	138/872	1.3	0.96-1.7
1.42 to <1.82	317/778	1.2	0.95-1.4	187/778	1.8	1.4-2.3
1.82 to <2.75	240/537	1.2	0.95-1.5	129/537	1.8	1.3-2.4
2.75+	162/329	1.2	0.9-1.5	89/329	1.9	1.4-2.6
p, linear trend			0.12			<0.001
15+ years						
<1.44	319/782	1.0	-	119/782	1.0	-
1.44 to <2.55	257/777	0.8	0.7-0.999	154/777	1.1	0.8-1.4
2.55 to <4.17	264/787	0.8	0.6-1.01	173/787	1.0	0.7-1.3
4.17 to <6.59	190/471	0.9	0.7-1.1	126/471	0.9	0.7-1.3
6.59+	132/313	0.8	0.6-1.1	88/313	0.9	0.6-1.3
p, linear trend			0.71			0.44

Cut points at 25th, 50th, 75th, and 90th percentile for controls in each time window.
Unconditional logistic regression, adjusted for age at diagnosis, gender, socio-economic index (SEI) and year of diagnosis. Exposure the year before diagnosis was excluded ("1-year lag").

periods 1-4, 5-9, and 10-14 years whereas no risk for occupational ELF-EMF was seen for longer latency. This indicates a late carcinogenic effect with tumor promotion/progression. INTEROCC showed an increased risk for all glioma in the 1-4 years latency period but not for longer lag times. The results were similar for low-grade and high-grade glioma. One difference to our results is that some diagnoses in Interphone were histologically confirmed, but some were based on diagnostic imaging.[21] Thus the diagnostic procedure was less stringent than in our study. In fact a number of cases might have been misclassified in Interphone since tumor pathology was not available for all cases. Furthermore no results were given for astrocytoma grade IV separately. Anyhow, the results in both INTEROCC and in our studies are similar with a late carcinogenic effect from occupational ELF-EMF exposure for glioma. These results are supported by laboratory studies showing increasing proliferative activity of neuroderived malignant cells.[32]

Of interest is that we did not find any interaction between occupational ELF-EMF exposure and wireless phone use. Thus exposure to ELF-EMF and RF radiation seem to be independent risk factors for glioma. However, the digital GSM (Global System for Mobile Communication) mobile phone and to a lesser extend the DECT (Digital Enhanced Cordless Communications) phones emit in addition to RF radiation also

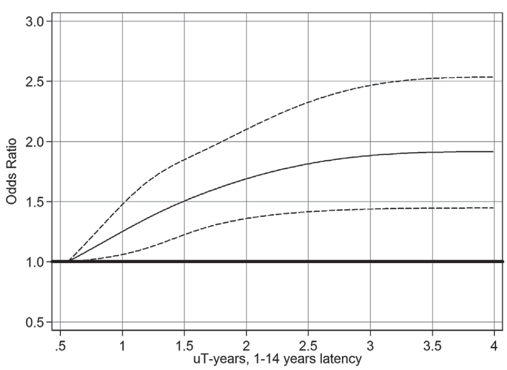

FIGURE 1 Restricted cubic spline plot of the relationship between cumulative exposure to ELF-EMF in µT-years and astrocytoma grade IV in the 1-14 years latency group. The solid line shows the OR estimate and the broken lines represent the 95%CI. Adjustment for age at diagnosis, gender, SEI-code, and year of diagnosis was made. Population based controls were used

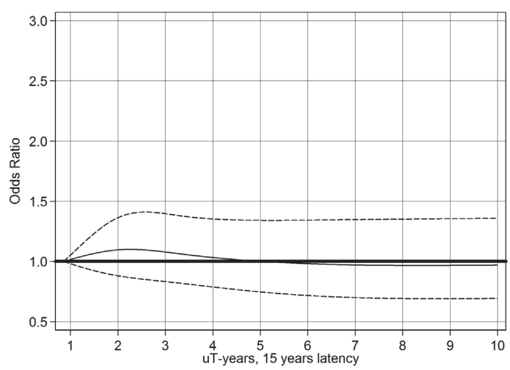

FIGURE 2 Restricted cubic spline plot of the relationship between cumulative exposure to ELF-EMF in µT-years and astrocytoma grade IV in the 15+ years latency group. The solid line shows the OR estimate and the broken lines represent the 95%CI. Adjustment for age at diagnosis, gender, SEI-code, and year of diagnosis was made. Population based controls were used

TABLE 6 Odds ratio (OR) and 95% confidence interval (CI) for all glioma (*n* = 1,346) and astrocytoma grade IV (*n* = 687) for occupational exposure to ELF-EMF and interaction with use of wireless phones (mobile and/or cordless phone)

Exposure metric	Glioma (*n* = 1346)			Astrocytoma, grade IV (*n* = 687)		
Wireless phone	Ca/Co	OR	95%CI	Ca/Co	OR	95%CI
Cumulative exposure (µT-years)						
No use of wireless phone,<2.33	79/261	1.0	-	26/261	1.0	-
Use of wireless phone,<2.33	289/609	1.3	0.99-1.8	66/609	1.2	0.7-2.0
No use of wireless phone, ≥2.33	221/775	0.9	0.7-1.2	145/775	1.2	0.8-2.0
Use of wireless phone, ≥2.33	757/1840	1.2	0.9-1.6	450/1840	1.6	1.04-2.5
p, interaction	0.77			0.75		
Average exposure (µT)						
No use of wireless phone, <0.11	57/232	1.0	-	28/232	1.0	-
Use of wireless phone, <0.11	228/598	1.4	0.99-2.0	100/598	1.5	0.95-2.4
No use of wireless phone, ≥0.11	243/804	1.2	0.8-1.6	143/804	1.4	0.9-2.2
Use of wireless phone, ≥0.11	818/1851	1.5	1.1-2.0	416/1851	1.8	1.2-2.8
p, interaction	0.54			0.50		
Maximum exposed job (µT)						
No use of wireless phone, <0.13	55/222	1.0	-	27/222	1.0	-
Use of wireless phone, <0.13	229/601	1.4	0.96-1.9	114/601	1.7	1.05-2.7
No use of wireless phone, ≥0.13	245/814	1.1	0.8-1.6	144/814	1.3	0.9-2.1
Use of wireless phone, ≥0.13	817/1848	1.4	1.02-1.9	402/1848	1.7	1.1-2.6
p, interaction	0.69			0.26		

Unconditional logistic regression, adjusted for age at diagnosis, gender, socio-economic index (SEI), and year of diagnosis. Exposure the year before diagnosis was excluded ("1-year lag").

ELF-EMF from the battery.[33,34] Analog mobile phones do not create pulsed RF-EMF. Our data suggest that RF radiation is the major risk factor for glioma during mobile phone use since the OR was similar regardless of level of occupational exposure to ELF-EMF and no statistically significant interaction was found. Linde and Hansson Mild reported the highest magnetic flux density for a GSM phone to be 1.8 µT.[33] A single phone transmits one-eighth of the time yielding mean exposure 0.225 µT. In this study 884 cases had used a GSM mobile phone. According to the Linde and Hansson Mild results this yielded cumulative mean battery ELF-EMF exposure = 0.16 µT-years (median = 0.04, range = 0.00013-3.92). The results for the 2014 exposed control subjects were mean = 0.09 µT-years (median = 0.02, range = 0.00013-2.52). Only 4 cases and 2 controls were exposed ≥2.33 µT-years, thus higher level than for the reference category in this study, see Table 1. These results support that RF-EMF from wireless phones is an independent risk factor for glioma.

Occupation may give an indication of the exposure to the ELF magnetic fields, but is nevertheless subject to confounding effects, as people at the same occupation may have different exposure levels due to the type and model of work instrumentation used and the neighbouring electromagnetic sources. By phasing out the cathode-ray tube type visual display units and with the introduction of power saving information technologies, the office workers have commonly quite low exposure to ELF magnetic fields. On the another hand, offices located next to a transformer are likely to have significantly high magnetic field levels, comparable to those found in industrial settings around high power equipment.

Patients in our study with histopathological verification of a malignant brain tumor were reported to us from the cancer registries in Sweden. Controls were selected from the same geographical area as the cases, with matching made on year of diagnosis, gender and age, making the controls comparable with the cases. All the controls could be included in the unconditional logistic regression analysis because adjustment was made for potential confounding factors. In the laterality analysis, the matched control was assigned the same side of localisation as the tumor for the respective case.

One strength of our study was the high percentage of participating cases and controls making it unlikely that selection bias influenced the results. Recall bias might have been an issue, but that seems to be unlikely in relation to reporting different occupations. As JEM is calculated based on samples of same type of occupations, it may not always characterize exposure correctly on an individual level, as workstations and work assignments vary within each job category. However, such differences are likely nondifferential. Furthermore, the level of occupational exposure to ELF-EMF, if any, would in general not have been known for the study subjects, and thus not influence the type of reported occupation. Observational bias might have been introduced by the supplementary phone interviews, but is unlikely as to occupation. The identity of the subjects either as a case or a control was not disclosed during supplementary phone calls and further data processing. A structured protocol was used and the interviewer had to follow that procedure strictly during the interviews. Histopathological classification of the tumor was made without knowledge of exposure. Tumor pathology was coded in a separate data file that was not disclosed before statistical analysis.

Excluding deceased glioma cases from the study might have biased the results towards unity. In total, 1055 cases with malignant brain tumor were omitted from the studies (1997-2003, 2007-2009). Histopathology data were not available for all of these individuals; however the majority would be glioma. Most of these cases would have been diagnosed with astrocytoma grade IV (glioblastoma multiforme) that have a shorter survival than other types of glioma. The results might have been biased if ELF-EMF exposure is associated with decreased survival of patients with glioblastoma multiforme, cf, our findings on RF-EMF exposure and survival of patients with glioblastoma multiforme.[35]

Glioma is the most common malignant brain tumor and represents about 60% of all central nervous system tumors. The most common glioma subtype is astrocytoma. Astrocytic tumors are divided in two groups depending on the malignant potential; low-grade (WHO grades I-II) and high-grade (WHO grades III-IV). Low-grade astrocytoma has a relatively favourable prognosis, whereas survival is shorter for patients with high-grade glioma. Glioblastoma multiforme (WHO grade IV) accounts for 60-75% of all astrocytoma. The peak incidence is between 45 and 75 years of age with median survival less than one year.[36] Thus, one disadvantage of the Interphone study was that only cases aged 30-59 years at the time of diagnosis were included for the majority of included countries[26] in contrast to our range 18-80 years.

We know little about the earliest events in the genesis of glioma in humans for obvious reasons. However, progression of glioma has been studied in a large series of tumors of different malignancy grades. Patients with low-grade glioma have been followed with later progression to high-grade glioma.[37] The natural history of most glioma cases, from earliest events to clinical manifestation, is unknown.

5 | CONCLUSION

In conclusion this study showed an increased risk in late stage (promotion/progression) of astrocytoma grade IV for occupational ELF-EMF exposure.

AUTHORS' CONTRIBUTIONS

Lennart Hardell was the principal investigator and made the draft of the article. Tarmo Koppel and Mikko Ahonen evaluated occupational ELF-EMF exposure and Michael Carlberg made all statistical analyses. All authors participated in writing of the final version of the article, and agree that this version is ready for submission to the American Journal of Industrial Medicine.

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ETHICS APPROVAL AND INFORMED CONSENT

All studies were approved by the Ethical Committee (Örebro County Hospital DNR 351/96, Uppsala University DNR 2005:367) and all study subjects participated after informed consent.

DISCLOSURE (AUTHORS)

The authors report no conflicts of interest.

DISCLOSURE BY AJIM EDITOR OF RECORD

Steven Markowitz declares that he has no competing or conflicts of interest in the review and publication decision regarding this article.

DISCLAIMER

None.

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Article 2

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Radiofrequency radiation at Stockholm Central Railway Station in Sweden and some medical aspects on public exposure to RF fields

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Abstract. The Stockholm Central Railway Station in Sweden was investigated for public radiofrequency (RF) radiation exposure. The exposimeter EME Spy 200 was used to collect the RF exposure data across the railway station. The exposimeter covers 20 different radiofrequency bands from 88 to 5,850 MHz. In total 1,669 data points were recorded. The median value for total exposure was 921 $\mu W/m^2$ (or 0.092 $\mu W/cm^2$; 1 $\mu W/m^2$=0.0001 $\mu W/cm^2$) with some outliers over 95,544 $\mu W/m^2$ (6 V/m, upper detection limit). The mean total RF radiation level varied between 2,817 to 4,891 $\mu W/m^2$ for each walking round. High mean measurements were obtained for GSM + UMTS 900 downlink varying between 1,165 and 2,075 $\mu W/m^2$. High levels were also obtained for UMTS 2100 downlink; 442 to 1,632 $\mu W/m^2$. Also LTE 800 downlink, GSM 1800 downlink, and LTE 2600 downlink were in the higher range of measurements. Hot spots were identified, for example close to a wall mounted base station yielding over 95,544 $\mu W/m^2$ and thus exceeding the exposimeter's detection limit. Almost all of the total measured levels were above the precautionary target level of 3-6 $\mu W/m^2$ as proposed by the BioInitiative Working Group in 2012. That target level was one-tenth of the scientific benchmark providing a safety margin either for children, or chronic exposure conditions. We compare the levels of RF radiation exposures identified in the present study to published scientific results reporting adverse biological effects and health harm at levels equivalent to, or below those measured in this Stockholm Central Railway Station project. It should be noted that these RF radiation levels give transient exposure, since people are generally passing through the areas tested, except for subsets of people who are there for hours each day of work.

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Introduction

On 31 May 2011 the WHO International Agency for Research on Cancer (IARC) categorized the radiation fields from mobile phones, and from other devices that emit similar non-ionizing electromagnetic field (EMF) radiation in the frequency range 30 kHz to 300 GHz, as a Group 2B, i.e. a 'possible', human carcinogen (1,2). Nine years earlier IARC had also classified the electromagnetic fields from overhead electric power lines as a Group 2B carcinogen (3).

The IARC decision on mobile phones was based mainly on two sets of case-control human studies: the Hardell group of studies from Sweden (4-6) and the IARC Interphone study (7-9). Both provided complementary and generally mutually supportive evidence of increased risk for brain tumours, i.e. glioma and acoustic neuroma. Later published studies by us (10-13) and the French CERENAT study on glioma and meningioma published in 2014 (14) supported an increased risk for brain tumours and use of mobile phones. These results were further supported by a study on mice showing tumour-promoting effect from radiofrequency (RF) radiation at low to moderate levels (0.04 and 0.4 W/kg SAR), radiation well below exposure limits for users of mobile phones (15). Thus, implications of the study by Tillman *et al* (16) were successfully tested. It should be added that a long-term animal toxicity study at 900 MHz published in 1997 resulted in statistically significant increased lymphoma risk in mice (17).

Recently, a report was released from The National Toxicology Program (NTP) under the National Institutes of Health (NIH) in USA on the largest ever animal study on cell phone RF radiation and cancer (18). An increased incidence of glioma and malignant Schwannoma in the heart was found. Acoustic neuroma or vestibular Schwannoma is the same type of tumour as the one found in the heart, although benign.

The carcinogenicity findings evaluated by IARC in 2011 were related to personal wireless phone use, including mobile phones and DECT phones. The overall exposure including mobile phone base stations, radio- and TV-transmitters, DECT base stations and wireless local area networks (WLAN) is not very well known. Epidemiological studies of mobile phone base stations indicated health risks for humans, see a review of Khurana *et al* (19), but did not contain enough exposure information.

The exposure guideline by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) was established in 1998 (20) and was based on thermal (heating) effects from RF radiation neglecting non-thermal biological effects. It was updated in 2009 (21) and stated that: 'it is the opinion of ICNIRP that the scientific literature published since the 1998 guidelines has provided no evidence of any adverse effects below the basic restrictions and does not necessitate an immediate revision of its guidance on limiting exposure to high frequency electromagnetic fields. Therefore, ICNIRP reconfirms the 1998 basic restrictions in the frequency range 100 kHz to 300 GHz until further notice'. The guideline provided by ICNIRP still recommends 10 W/m^2 as a reference level for limiting public's exposure to the RF-EMFs (2-300 GHz) (20).

It should be noted that the ICNIRP guideline, although only a recommendation, is nevertheless used in most European countries as well as in many other countries. The guideline is based on short-term (acute) exposures but not chronic, low-intensity cumulative exposures, nor possible health effects. ICNIRP safety limits do not acknowledge effects from long-term exposure and non-thermal biological effects from RF-EMF exposure. According to the philosophy document of ICNIRP (22): 'Some guidelines may still not provide adequate protection for certain sensitive individuals nor for normal individuals exposed concomitantly to other agents'. In practice this means, that if simultaneously exposed to chemicals and RF radiation (15,16), the ICNIRP guideline does not protect. The philosophy document of ICNIRP (22) also states: 'Different groups in a population may have differences in their ability to tolerate a particular NIR (Non-Ionizing Radiation) exposure. For example, children, the elderly, and some chronically ill people might have a lower tolerance for one or more forms of NIR exposure than the rest of the population'. However, this is not considered in existing ICNIRP (1998) guideline document (20) and for example Gandhi *et al* (23) provide a historical overview how ICNIRP and the Federal Communications Commission (FCC) standard setting is based on (adult) military recruit head and body models, not children's.

ICNIRP's goal has been to harmonize guidelines worldwide and most countries have adopted the ICNIRP's guidelines into their national legislation. Using wireless internet access is compatible with ICNIRP's guidelines, but may exceed the BioInitiative Report recommendation (24). There is a vast body of literature that shows non-thermal adverse health effects from RF radiation. These, as well as thermal effects, have been evaluated in several reports, e.g. the BioInitiative report from 2007 (25) and in the 2012 update (26). The 2007 Bioinitiative report suggested a precautionary target level of 1,000 $\mu W/m^2$ for outdoor pulsed RF radiation that could be applied to sources from cell tower antennas, Wi-Fi, WiMAX and other similar sources (25). The BioInitiative 2012 Report defined the scientific benchmark for possible risks as 30-60 $\mu W/m^2$, based in part on post-2007 studies by Thomas *et al* (27,28), Heinrich *et al* (29) and Buchner and Eger (30). Considering also chronic exposure and sensitivity among children the precautionary target level was proposed to one tenth of this, 3-6 $\mu W/m^2$, see Chapter 24 of the BioInitiative Report (26). However, the studies by Thomas *et al* (27,28) and Heinrich *et al* (29) used personal dosimetry without differentiating up-and downlink and without presenting actual measurements, but only percentages of the reference levels. Also shielding by the body may preclude any statement about actual exposure.

The BioInitiative report guideline obviously differs from the one proposed by ICNIRP, largely because ICNIRP protects only against acute, thermal injury while the BioInitiative recommendations address chronic exposures to non-thermal, low-intensity exposures for which mounting evidence shows adverse health effects. The ICNIRP level has been vigorously propagated by that organisation in order to harmonize guidelines worldwide. With few exceptions it has been a successful story and most countries have adopted the ICNIRP guideline. This gives a 'green card' to roll out the technology, for example using wireless internet access in schools (24), since the high exposure level by ICNIRP is rarely compromised.

There are few studies in this area on public exposure, other than for example outdoor exposure in urban and rural areas in Sweden (31), in a workplace (32), the metro in Warsaw (33) and a study with body-worn exposimeters in The Netherlands (34).

The aim of the present study was to assess RF radiation exposure in a public transportation hub, Stockholm Central Railway Station in Sweden. Many shops, restaurants and offices are located within this area. The Central Station contains many people, those working there and those commuting, thus, both short- and long-term exposure occurs. There is a lack of exposure studies in public places in Sweden. The previous measurement studies are outdated due to the rapid technology shift (35,36). We selected a place visited by many persons that are exposed to RF radiation. This was a measurement study with no involvement of test persons. Thus, no ethical permission was needed. We discuss also some laboratory studies on RF-radiation that will help the reader to understand the context of the exposer logger measurements. Especially interesting are non-thermal levels of RF radiation and biological effects.

Materials and methods

EME Spy 200 exposimeter. In the present study an EME Spy 200 exposimeter with a valid calibration was used to collect the exposure data. The 20 predefined measured frequency bands are presented in Table I. They cover the frequencies of most public RF-EMF emitting devices currently used in Sweden. This band selective exposimeter covers 88 to 5,850 MHz. For FM, TV3, TETRA, TV4&5, Wi-Fi and 5G the lower detection limit is 0.01 V/m (0.27 $\mu W/m^2$); for all other exposures the lower detection limit is 0.005 V/m (0.066 $\mu W/m^2$). The upper detection limit is 6 V/m (95,544 $\mu W/m^2$). The sampling time used in this study was 4 sec which is the fastest for the given exposimeter. The exposimeter measures different telecommunication protocols: FM (frequency modulation) radio broadcasting; TV (television) broadcasting; TETRA emergency services (police, rescue, etc.); GSM (global system for mobile communications) second generation mobile communications; UMTS (universal

Table I. Predefined measurement frequency bands of EME Spy 200 exposimeter and frequency ranges.

Frequency band	Frequency Min (MHz)	Frequency Max (MHz)
FM	87	107
TV3	174	223
TETRA I	380	400
TETRA II	410	430
TETRA III	450	470
TV4&5	470	770
LTE 800 (DL[a]), 4G	791	821
LTE 800 (UL[b]), 4G	832	862
GSM 900+ UMTS 900 (UL), 3G	880	915
GSM 900 + UMTS 900 (DL), 3G	925	960
GSM 1800 (UL)	1,710	1,785
GSM 1800 (DL)	1,805	1,880
DECT	1,880	1,900
UMTS 2100 (UL), 3G	1,920	1,980
UMTS 2100 (DL), 3G	2,110	2,170
Wi-Fi, 2G	2,400	2,483.5
LTE 2600 (UL), 4G	2,500	2,570
LTE 2600 (DL), 4G	2,620	2,690
WiMax	3,300	3,900
Wi-Fi 5G	5,150	5,850

[a]DL, down link: transmission from base station to mobile phone; [b]UL, up link: transmission from mobile phone to base station.

Figure 1. Stockholm Central Station main level (ground floor).

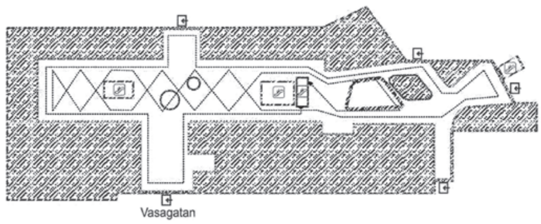

Figure 2. Stockholm Central Station ground floor measurement path.

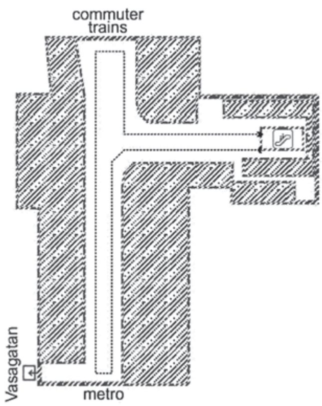

Figure 3. Stockholm Central Station lower level measurement path.

mobile telecommunications systems) third generation mobile communications, 3G; LTE (long-term evolution) fourth generation mobile communications standard, 4G; DECT (digital European cordless telecommunications) cordless telephone systems standard; Wi-Fi wireless local area network protocol; WiMAX (worldwide interoperability for microwave access) wireless communication standard for high speed voice, data and internet.

EME SPY 200 is a sophisticated exposimeter, preferred by the majority of the EMF measurement's community. The unit utilizes 3-axis antennas to capture EMF radiation from all possible directions. The unit reports the exposure in a conservative manner since each reported value is the sampling outcome, where many samples are taken and statistically processed. The amount of the samples is dependent on the measurement band and could reach several hundreds. These samples are analyzed and minimum, mean, median and maximum values are calculated. For each band the sampling period is longer than the pulse length characteristic to that band and signal. This ensures that all the pulses are accounted for in the sampling period. The analysis method of EME SPY 200 allows differentiation of low and high wireless traffic, whereas the peak value might remain the same in both cases. Multiple antennas are of importance to reduce body shielding (37) as well as holding the exposimeter at some distance from the body.

Study design. The present study was performed during daytime November 7, (Saturday; 1 round), November 8 (Sunday; 3 rounds) and November 9, 2015 (Monday; 3 rounds) at the Stockholm Central Station in Sweden. The upper level of the station is displayed in Fig. 1. To the left is the access to the street (Vasagatan) and to the right to commuter trains.

On each measurement round the main and lower floor were walked through with the exposimeter; the same path was always followed. The path was developed to make a clockwise tour of the station's main floor, followed by a zig-zag pattern across the main floor. Due to the narrow area of the lower floor, it was scanned only by a clockwise tour. The walking

Table II. Mean values (μW/m^2) for the seven measurement rounds.

Date	151107 (Saturday)	151108 (Sunday)	151108 (Sunday)	151108 (Sunday)	151109 (Monday)	151109 (Monday)	151109 (Monday)
Time (start)	21:18	11:00	14:45	18:50	9:45	10:50	15:50
No. of readings	195	258	250	235	225	244	262
FM	5.8	9.6	6.7	78.0	10.1	2.0	50.1
TV3	0.0	1.0	0.5	0.3	0.0	0.0	0.1
TETRA I	8.1	2.5	0.4	2.7	1.1	2.7	5.1
TETRA II	0.0	0.0	0.0	0.0	0.0	0.0	1.0
TETRA III	1.3	0.5	0.4	1.3	0.8	1.1	0.8
TV4&5	0.7	0.3	0.2	0.2	0.2	0.3	0.3
LTE 800 (DL[a])	556.8	472.9	421.3	482.9	250.1	363.6	864.4
LTE 800 (UL[b])	0.1	0.7	0.6	0.1	0.3	0.1	0.1
GSM+UMTS 900 (UL)	5.4	4.1	4.3	14.3	8.0	4.8	4.1
GSM+UMTS 900 (DL)	1,561.6	1,453.5	1,409.5	2,074.6	1,337.0	1,165.1	1,314.0
GSM 1800 (UL)	0.4	0.9	1.1	4.1	1.0	0.6	1.1
GSM 1800 (DL)	102.5	354.4	390.0	840.2	495.5	370.5	344.8
DECT	20.8	8.6	19.6	11.2	8.5	12.0	35.4
UMTS 2100 (UL)	0.0	0.1	0.5	0.3	0.5	0.1	0.2
UMTS 2100 (DL)	864.3	964.2	1,631.9	893.3	441.5	557.1	1,239.6
Wi-Fi 2G	1.6	0.9	1.2	2.6	1.2	1.9	2.0
LTE 2600 (UL)	0.1	0.1	0.1	0.2	0.1	0.1	0.1
LTE 2600 (DL)	404.7	309.3	674.5	483.3	372.4	331.0	683.6
WiMax	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wi-Fi 5G	0.7	0.9	1.5	1.6	1.7	3.9	1.4
Total	3,535.0	3,584.4	4,564.2	4,891.2	2,929.9	2,817.0	4,548.1

[a]DL, down link: transmission from base station to mobile phone; [b]UL, up link: transmission from mobile phone to base station.

path is schematically shown in Figs. 2 and 3. The lower level contains businesses and access to the metro, commuter trains and Vasagatan; the main floor has also businesses, access to the trains and exits to the street.

In order to minimize the body's shielding effect to the expositimeter, the unit was held ahead within ~0.4 m from the investigator's body.

Statistical methods. Means in μW/m^2 were calculated for all measured frequency bands and a box plot was constructed to illustrate the distribution of total exposure for all measurement rounds. Values at lower detection limit were treated as no (0) exposure. Total exposure was calculated as the sum of all measured frequency bands. Stata/SE 12.1 (Stata/SE 12.1 for Windows; StataCorp., College Station, TX, USA) was used for all calculations.

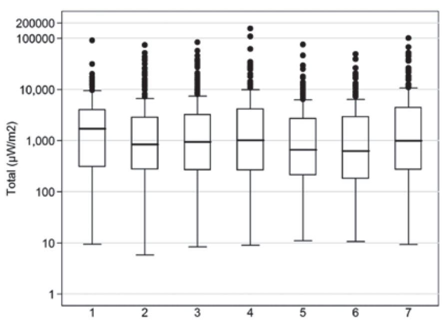

Figure 4. Box plot for total exposure in μW/m^2 for the seven measurement rounds. The median is indicated by a black line inside each box; the bottom and top of the boxes show first and third quartiles; the end of the whiskers are calculated as 1.5xIQR (interquartile range). Points represent outliers.

Results

In total 1,669 readings were collected varying from 195 to 262 during each round (median 244). Thus, the time varied between 13.0 and 17.5 min for different rounds.

The results for each round are displayed in Table II, and for all rounds in Table III. The mean total exposure level varied between 2,817 to 4,891 μW/m^2 (or 0.28 to 0.49 μW/cm^2; 1 μW/m^2=0.0001 μW/cm^2) and the median value for total exposure (all measurement rounds) was 921 μW/m^2. High mean measurements were obtained for GSM and UMTS 900 downlink varying between 1,165 and 2,075 μW/m^2. High mean levels were also obtained for UMTS 2100 downlink; 442 to 1,632 μW/m^2. Also LTE 800 downlink, GSM 1800 downlink, and LTE 2600 downlink were in the higher range of measurements. Notably lower mean levels were seen for DECT varying between 8.5 to 35.4 μW/m^2. The mean level results for FM

Table III. Mean, median, minimum and maximum values (μW/m^2) for all measurement rounds (n=1,669 measurement points).

Frequency band	Mean	Median	Min	Max
FM	23.7	0.0	0.0	9,206.3
TV3	0.3	0.0	0.0	176.6
TETRA I	3.1	0.0	0.0	834.8
TETRA II	0.2	0.0	0.0	78.5
TETRA III	0.9	0.0	0.0	100.9
TV4&5	0.3	0.0	0.0	41.4
LTE 800 (DL[a])	491.8	55.8	0.0	41,281.2
LTE 800 (UL[b])	0.3	0.0	0.0	142.8
GSM+UMTS 900 (UL)	6.3	0.6	0.0	561.3
GSM+UMTS 900 (DL)	1,467.2	254.9	0.0	95,522.5
GSM 1800 (UL)	1.3	0.1	0.0	243.5
GSM 1800 (DL)	418.6	22.9	0.0	58,843.8
DECT	16.7	0.3	0.0	3,637.2
UMTS 2100 (UL)	0.2	0.0	0.0	94.8
UMTS 2100 (DL)	955.8	127.2	0.9	59,847.5
Wi-Fi 2G	1.6	0.2	0.0	186.3
LTE 2600 (UL)	0.1	0.0	0.0	13.4
LTE 2600 (DL)	470.1	64.6	0.0	40,158.8
WiMax	0.0	0.0	0.0	1.3
Wi-Fi 5G	1.7	0.4	0.0	301.2
Total	3,860.2	920.6	5.8	155,263.4

[a]DL, down link: transmission from base station to mobile phone; [b]UL, up link: transmission from mobile phone to base station.

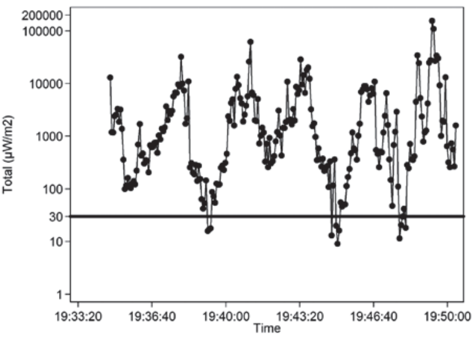

Figure 5. Total radiofrequency field exposure (μW/m^2) of the highest exposure round (151108, 18:50; mean exposure 4,891.2 μW/m^2) by walking across the station. The horizontal line represents the exposure limit of 30 μW/m^2 suggested by the BioInitiative Report (29).

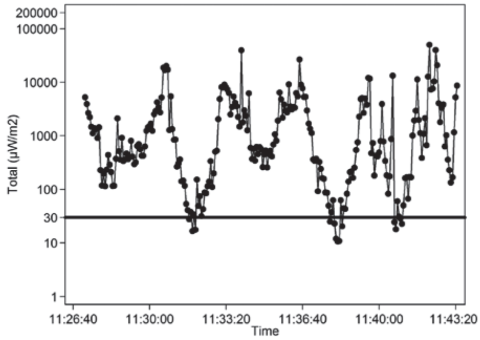

Figure 6. Total radiofrequency field exposure (μW/m^2) of the lowest exposure round (151109, 10:50; mean exposure 2,817.0 μW/m^2) by walking across the station. The horizontal line represents the exposure limit of 30 μW/m^2 suggested by the BioInitiative Report (29).

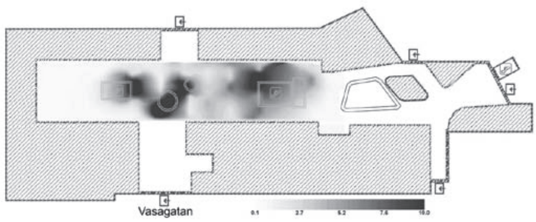

Figure 7. Stockholm Central Station ground floor with total field intensity map (151108, 19:20) scale in mW/m^2.

Figure 8. An example of highest exposure area. A man is standing with his smartphone just a couple of meters below a base station (see arrow). In that area maximum measured power density in the GSM +UMTS 900 downlink band was 95,544 μW/m^2, which is the upper limit of measurement for EME Spy 200.

radio varied between 2.0 to 78.0 μW/m^2. Some of the results showed 0.0 μW/m^2 since readings registered as lower detection limit were considered as 0 in the analysis.

In Fig. 4 the box plot shows total exposure in μW/m^2 for the seven measurement rounds. The overall median value was 921 μW/m^2 with some outliers of >150,000 μW/m^2. Fig. 5 displays the variation over time for the highest exposure round. It should be noted that most measurements were >100 μW/m^2. In Fig. 6 similar results as in Fig. 5 are shown for lowest exposure round.

Fig. 7 shows total field intensity map on the Central Station main level. Clearly there were several hot spots, for example at places where people use to sit or stand waiting for their train or meeting with other persons.

One example of highest exposure area is shown in Fig. 8. In that area maximum measured power density in the GSM + UMTS 900 downlink band was 95,544 μW/m^2, which is the upper limit of measurement in each frequency band for EME Spy 200. Note that the photo was not taken simultaneously with the measurement rounds.

Discussion

EME Spy 200 is a band specific exposimeter and gives the possibility to identify and measure most RF radiation bands currently used in Sweden. We selected Stockholm Central Station in Sweden since it is a place for communication with lots of daily visiting persons. It may be persons that transfer between the metro and train (or opposite), but also people that meet each other or are waiting during a considerable time for a transfer train. There are also lots of shops in that area with employees. We did not make any measurements in shops since the aim was to restrict the study to transfer areas. Anyhow, there is a possibility for many persons to be exposed to high RF radiation for shorter or longer time periods.

Major results. The major finding of the present study was that total RF radiation mean exposure for a walking round, see Figs. 2 and 3, varied between 2,817 to 4,891 μW/m^2. GSM and UMTS 900 downlink contributed to most of the radiation dose. In fact, this together with UMTS 2100 downlink contributed to almost half of total exposure. Other major sources were LTE 800 downlink, GSM 1800 downlink and LTE 2600 downlink. Other sources were comparatively low. According to Table II, the vast majority of the mobile telephone exposure is from the downlink bands, i.e. the sources are the base station antennas placed around the railway station. Exposure from uplink levels was an insignificant percentage of the downlink exposure: LTE 800 0.06%, GSM 900 0.44%, GSM 1800 0.32%, UMTS 2100 0.03% and LTE 2600 0.21%.

All measured mean and median levels were well below ICNIRP's exposure guidelines at 2-10 W/m^2 (see below), but most of the measured levels were above the scientific benchmark of 30-60 μW/m^2 as proposed by the BioInitiative Report (26). Obviously few total measurements were below 30 μW/m^2, see Figs. 5 and 6.

There were also some hot spots for exposure. This is exemplified in Fig. 8 with a man standing close to a base station on the wall just below the roof. The measured exposure was 95,544 μW/m^2, which is the upper detection limit for each frequency band for the exposimeter. Thus, it was not possible to get the exact value. People in general are not aware of this kind of exposure that may be considerable. Moreover, this is an example of an inappropriate placement of a base station with high downlink exposure. Note that the photo was taken separate from measurement rounds.

The exposure guidelines by ICNIRP. The reference values for radiofrequency electromagnetic fields were recommended in 1998 by ICNIRP to 2-10 W/m^2 for frequencies between 10 MHz to 300 GHz. Up to 400 MHz the recommendation is 2 W/m^2. The formula: frequency/(2x10^8) is used for frequencies between 400 and 2,000 MHz. Above 2,000 MHz up to 300 GHz the recommended reference value is 10 W/m^2 (20).

The basic restrictions for time varying electric and magnetic fields for frequencies from 10 MHz up to 10 GHz for the specific energy absorption rate (SAR) is over 10 g of tissue for whole-body average set to 80 mW/kg, for localized head and trunk 2 W/kg and for localized limbs 4 W/kg. FCC/Institute of Electrical and Electronics Engineers (IEEE) public safety limits use a 1 g rather than 10 g volume of tissue and the SAR limit for ICNIRP is 2 W/kg in comparison to the FCC/IEEE 1.6 W/Kg SAR allowance.

These reference values and basic restrictions protect against injuries caused by a heating effect over 1˚C after an exposure of 30 min, and with a safety factor of 50 for general public (20). Injuries caused by other biological mechanisms than heating or from chronic effects are not considered in the above mentioned limit values.

Limitations due to method of measurements. The present study describes measurements mostly from far-field RF radiation. It describes the exposure that the citizen may be exposed to without himself/herself using personal wireless devices. Near-field exposure from people's own mobile phones held near the ear or in the hand when surfing on the internet may be a considerable contribution to the individual's total exposure.

We measured during seven rounds during three days yielding 1,669 readings in total. The exposure levels did somewhat vary between the different walking rounds but did not exceed 2-fold. However, the data does not show that either weekends or weekdays would exhibit higher exposure level. Many people pass through the station in rush hours, but also in weekends when traveling away and into the city. It should be noted that this is a conservative estimate of exposure. The results do not reflect personal wireless devices being carried around or used by individuals, just the 'ambient' RF levels of people not using devices.

The present study used an exposimeter for measurements. Because samples were taken every 4 sec, technologies with large differences between average and peak might not have been exactly evaluated, an inherent limitation of the exposimeter. For example the DECT-base stations and Wi-Fi router exposures may have been undervalued with the used exposimeter. Generally, peak signal level measurement data is interesting when discussing the non-thermal effects of radiofrequency radiation.

The shielding effect from the body of a person carrying an exposimeter can be considerable as shown by Bolte *et al* (38) when comparing a body worn exposimeter with an exposimeter mounted on a car roof. This was partly compensated in the present study by holding the exposimeter at some distance from the body. Bhatt *et al* (37) concluded that using an exposimeter with three antennas, as in the present study, may minimize body shielding.

Laboratory studies and medical aspects. The mean measurements in the Stockholm Central Station showed a total RF radiation between 2,817 to 4,891 μW/m^2. Studies with laboratory animals exposed to RF radiation at or below these levels have shown influence on several physiological parameters in the body of mammals. Influence on the blood-brain barrier, proteins and microRNA in the brain, testicular function, oxidative stress in the cells and DNA damage have been shown. Also neurotransmitters in people living in a village were changed after activation of a GSM mobile phone base station. These are non-thermal effects and are discussed briefly in the following.

The blood brain barrier (BBB) may open by exposure to RF radiation and lead to leakage into the brain of large molecules, like albumin and different toxins. As a result of opening of the protective BBB layer that separates the brain from the blood, this pathological leakage of the BBB has been shown to be toxic to brain tissues and can cause damage to, and death of neurons (39,40). Condensed dark neurons in the rats' brains are a sign of damage, and have been seen after 2 h of exposure to a GSM mobile phone both at 28 and 50 days after exposure (39,40). Several studies on rats have shown opened BBB after RF radiation from a GSM mobile phone with peak power output down to 1,000 μW and with an average whole body SAR-value down to 120 μW/kg (41). A U-shaped response curve has also been seen with stronger health effects by RF radiation at lower exposure levels than at higher exposure (39,41).

Difference between genders after exposure to RF radiation has been found, where male rats got an increased BBB permeability for both GSM 900 and 1,800 MHz pulsed modulated RF radiation while female rats only got increased BBB permeability for the 900 MHz frequency (42).

The hippocampus is a center for memory and learning in the brain, and in particular appears to be a primary target for neuronal damage from RF radiation and opened BBB. Exposure to 900 MHz RF radiation during 3 h per day for 28 days showed extravasation of albumin in the hippocampus and cortex and impaired spatial memory in exposed rats (43). Also exposure for 2 h per day for 55 weeks showed impaired memory in GSM 900 MHz exposed rats, but no statistically significant alterations of histopathological parameters (44,45).

RF radiation has been shown to increase protein synthesis in proliferating human cells after 8 h of exposure, but not in quiescent white blood cells. This indicates a higher sensitivity of growing organisms (46). Also the capacity to repair DNA double-strand breaks was more effected by RF radiation in stem cells compared to differentiated cells like fibroblasts (47).

In a long-term study mice were exposed to a GSM 900 MHz mobile phone at SAR-level 370,000 μW/kg for 3 h a day or to a DECT base station at a SAR-level of 12,000-28,000 μW/kg for 8 h a day. After 8 months of exposure the two exposed groups of mice were compared with a sham exposed control group regarding 432 proteins from the cerebellum, hippocampus and frontal lobes of the brains. Comparative proteomics analyses revealed that 143 of the proteins had a statistically significant downregulation or an overexpression. Several neural function related proteins, like apolipoprotein E, heat shock proteins and cytoskeletal proteins as well as proteins of the brain metabolism were altered (48).

In two long-term studies rats were exposed to RF radiation emitted from a Wi-Fi system of 2.4 GHz for 24 h a day for 12 months. The peak power from the Wi-Fi was 100,000 μW with the antenna 50 cm above the cage. The SAR value over 10 g of brain tissue was 1,030 μW/kg. In one of the studies micro-RNAs (miRNA) in the rat brains were examined. Two of the five examined miRNA, 107 and 106b-5p, decreased 3.3 and 3.6 times, respectively. miRNA plays an important role in the proliferation, differentiation, function and maintenance of neuronal cells. Dysfunction of miRNA pathways may be a potential contribution to pathogenesis of neurodegenerative disorders and also a key indicator of epigenetic changes and cancer risk (49).

In the other study the rat testes and prostate were examined. The SAR value in the exposed rat testes and prostate was 1,020 μW/kg over 10 gram tissue. Compared to the sham exposed rats the Wi-Fi exposed rats showed statistically significant more head defects of the sperms and effects on testicular function and histology (50). Other Wi-Fi exposure studies have indicated damage to DNA in sperms (51-53).

Yakymenko *et al* (54) showed in a review of 100 studies investigating oxidative effects of low-intensity RF radiation in living cells, that exposure down to 2,500 μW/m^2 (55) and with SAR values down to 600 μW/kg (56,57) could increase oxidative stress in the cells. Long-term RF radiation exposure at the frequencies 900, 1,800 and 2,450 MHz for 2 h per day 5 days per week for 30-180 days at SAR 595-667 μW/kg have shown induced oxidative stress, reduced levels of neurotransmitters and downregulation of mRNA, increase in pro-inflammatory cytokines and DNA damage with single strand breaks in the hippocampus in the brain in the exposed rats (57-59). Cognitive impairments in learning and memory were also shown (59). Increase in frequency seems to have more deleterious effect on several of the parameters; 1,800 and 2,450 MHz had a statistically significant effect not only compared to sham exposed animals but also in some cases compared to 900 MHz exposure.

Even lower exposure levels in rats, down to SAR 85 μW/kg, for 900 MHz during 2 h/day, 5 days/week for 30 days showed increase in oxidative stress parameters in lipid peroxidation and protein oxidation. Also cognitive function showed a statistically significant impairment in spatial memory in the rats (60).

Buchner and Eger (30) performed a study with 60 participants out of the 2,000 inhabitants, who lived in the village Rimbach in Germany, when a GSM mobile base station was built in the spring of 2004. The neurotransmitters adrenaline, noradrenaline, dopamine and phenyletylamine (PEA) were measured in second morning urine samples before the base station was activated and 6, 12 and 18 months after. The RF radiation was measured outside each participant's house in peak value of the power density after the activation of the base station. The 60 study participants were divided into three exposure groups, <60, 60-100 and >100 μW/m^2.

After the activation of the GSM base station the levels of the stress hormones adrenaline and noradrenaline showed a statistically significant increase during the first six months and then decreased but were not restored to initial level after 18 months. This was seen especially for the children and the chronically ill adults. A statistically significant decrease was seen for dopamine levels during the first six months ($P<0.0002$), then dopamine levels increased but were not restored to the initial level. These three neurotransmitters showed a dose-response relationship with highest influence for the participants with exposure >100 μW/m^2 at home. PEA levels decreased for the highest exposed group first, but after 18 months all three exposure groups had a statistically significant decrease (P<0.0001). Wireless devices like DECT, Wi-Fi and bluetooth at home seemed to amplify the effect of GSM radiation. Even the lowest exposed group, <60 μW/m^2, had decreased dopamine and PEA levels after 18 months. Chronic dysregulation of the catecholamine system and PEA may contribute to health problems and chronic illnesses (30).

The NTP animal study (18) confirms findings in epidemiological studies of an increased risk for glioma and acoustic neuroma among people that use wireless phones, both mobile phones and cordless phones (DECT). In 2013, accumulating evidence from brain cancer studies resulted in a recommendation to upgrade IARC's 2011 classification of RF from a Group 2B - Possible Human Carcinogen to Group 1 - Known Carcinogen (61). The NTP study has greatly strengthened the evidence of risk, and reaffirms that it is sufficient to reclassify wireless phone radiation as a known cancer causing agent, and confirms the inadequacy of existing public safety limits.

Environmental RF radiation exposure. There are no other published studies in Sweden on RF radiation exposure in public places like this one at the Stockholm Central Station. The study by Hamnerius *et al* (35) from 2000 has merit as an RF radiation baseline, and may establish how much exposure has changed over time. Estenberg and Augustsson (31) measured with a car-mounted device the frequency range 30-3,000 MHz in some public places; rural, urban and city. The arithmetic mean measured exposure was in Stockholm city 6,700 μW/m^2, in urban areas (4 towns) 1,500 μW/m^2, and in rural areas (2 places) 230 μW/m^2. Similarly as in present study the major sources were GSM and UMTS downlinks.

Within one year, from 2011 to 2012, total RF radiation levels in all studied European outdoor city areas in combination increased by 57.1% (62). Over the past decade or so, RF radiation levels have significantly increased in our environment. Frei *et al* (63) estimated that the introduction of mobile phone technology has resulted in a 10-fold increase of RF radiation at outdoor areas compared to the time period before when broadcast transmitting was the most relevant source. Urbinello *et al* (62) measured 3 European cities, including train stations. The RF radiation measurement values in train stations ranged from 0.32 (272 μW/m^2) to 0.57 V/m (862 μW/m^2). Authors comment: 'Interestingly, across all indoor areas in all cities, mobile phone base station exposure showed a stronger temporal increase than mobile phone handset exposure' (62).

In a study by Bolte *et al* (64) 98 persons in The Netherlands carried a body-worn EME-Spy 121 for 24 h. Passing time at a railway station or going by train and metro showed high exposure, mean power density 304-354 μW/m^2, although visiting pubs or cafés showed even higher exposure, mean 526 μW/m^2. These are places where many people gather together and use mobile phones and laptops. During 2010 and 2011 when the study was done exposure from UMTS, both downlink and uplink, was low and few owned and used smartphones.

Grytz and Karpowicz (33) measured RF radiation inside the metro in Warsaw. The major source of exposure was the 900 GSM system. In another publication the mean exposure based on 173,323 measurements in 23 countries worldwide was reported to be 730 μW/m^2 (65). However, these measurements covered a different time period and not the same frequency range as in this study. Furthermore, the study methods were not clearly described. Markakis and Samaras (66) made a measurement campaign in Greece from 2010 to 2012 and concluded that signals from mobile base stations were dominant in workplaces and schools, whereas in home environment the dominant exposure was from wireless phones and computer networks. Viel *et al* (67) used exposimeters to investigate the participants' exposure budget across the week. They concluded the highest exposure to reside during Sundays, with main contributions from UMTS Tx (transmitting, upload) and DECT.

The present study is unique and different from those published previously since it covers 20 different frequency bands including most currently used frequency bands. Thus, in addition to the changing technology, our results are not comparable with previous ones such as the one from 2010 by Joseph *et al* (68) or even the results by Tell and Kavet (69) from 2014 stating that the FM band was a major contributor to overall power density. These results are less reliable comparing with our findings. Mean values for the FM band was orders of magnitude lower than e.g. for GSM+UMTS 900 (DL) and UMTS 2100 (DL) in this study, see Table II.

In conclusion, the aim of the present study was to assess the exposure to RF radiation in a public place in Sweden visited daily by many persons. We compare our results with non-thermal effects in laboratory investigations and also discuss results in animal studies on the carcinogenic risk. In epidemiological studies an increased risk of glioma and acoustic neuroma has been found in persons exposed to RF radiation from wireless phones. In animal studies RF radiation has been shown to promote tumours but also cause glioma and acoustic neuroma. There are also by now mechanistic studies such as oxidative effects from low-intensity RF radiation. We call for upgrading the carcinogenic potential to IARC Group 1, the agent causes cancer in humans.

In this study, real-time band specific exposure measurements at a public place showed comparatively high exposure from all mobile telephone and networking bands. The highest contributors to the exposure were download frequencies from the base stations at GSM+UMTS 900, UMTS 2100, LTE800, LTE 2600 and GSM 1800 bands. However, these RF exposure levels in this study are transient, since people are generally passing through the areas tested, except for subsets of people, i.e., security and police staff, cafe workers, shop workers, janitors, information counter people, who are there for hours each day of work.

Due to the rapid development of the telecommunications technology and the evolution of the wireless infrastructure, it is imperative to measure public's exposure. Yearly monitoring measurements would allow an overview of the public's exposure budget, since nowadays, rapid deployment of new RF radiation sources take place. The information obtained by the exposure studies allows assessing public's exposure to RF radiation today and in the years to come, when future epidemiologic studies seek for information in assessing the historic exposure levels to which the public was commonly exposed. Unfortunately studies on human risk from long-term environmental RF radiation based on personal exposure monitoring do not exist to our knowledge. Given the lack of good historic RF radiation exposure information to date, it is imperative that better efforts be directed to periodic collection of RF radiation exposures in daily life for use in epidemiological studies of cancer as well as of neurological diseases and other adverse health effects attributed to RF radiation exposures.

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Article 3

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RISK MANAGEMENT OF MAGNETIC FIELD FROM INDUSTRIAL INDUCTION HEATER – A CASE STUDY

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Abstract. In the study an industrial occupational setting was investigated in order to determine the workers exposure to the magnetic fields from induction ovens and to develop risk mitigation procedures to lower the exposure. Electromagnetic field measurements were conducted and the workers exposure to the electromagnetic fields was assessed in the framework of the new occupational electromagnetic field legislation. The results show that the exposure could be significantly reduced by implementing relatively easy mitigation measures, including workplace rearrangement, work procedure redesign etc. Time-weighted average exposure to the magnetic field could be lowered from 2.57μT (maximum observed procedure case) to 0.12 μT (recommended procedure scenario after interventions). The investigation also revealed that little attention is paid to training the workers who may be affected by high levels of electromagnetic fields. Considering the requirements of the new European Union and national electromagnetic field legislation, immediate planning of appropriate schooling programs is necessary for all parties involved: employers, workers, work environment specialists.

Keywords: induction, heater, oven, intermediate frequency, electromagnetic fields, occupational exposure, work, risk management.

Introduction

In this study an industrial occupational setting was investigated in order to measure and determine the workers exposure to the magnetic fields (MFs) from an industrial induction heater. Nowadays induction heating is commonly used in the metal-forming industries for welding, annealing, hardening and brazing [1].

The industrial settings may include a variety of electrical instruments and appliances, hence providing countless variations of electromagnetic fields' exposure scenarios. Even if several workstations utilize the equipment of the same make and model, often the layout of the workstation, and peripheral devices may render the risk assessment inadequate based on the equipment alone.

In an ideal laboratory conditions, multiple units of the same equipment of the same make and model may indeed propagate electromagnetic fields (EMFs) with the same characteristics. The characteristics of the radiated EMF include the geometrical radiation pattern, amplitude, mixture of frequencies, waveform etc. Whereas the actual industrial environment is hardly a laboratory setting where other sources are dismissed and the surrounding objects including the building structure and the materials affect the propagation of the electromagnetic wave. In practice, it is important to measure the exposure of workers to the electromagnetic fields in actual work settings, as risk assessment by numerical calculations, simulations or by devices' documentation would leave much room for error and may put workers in risk.

Today, European companies are expected to be in compliance with the new legislation on occupational exposure to the electromagnetic fields. Corresponding EU directive was issued in 2013 and was to be implemented into the national legislation of member states by 2016 July 1st [2; 3].

The legislation is a set of rules, which the employer needs to fulfill, but as with any other legislative document, the rules are general and not scenario or case specific. Induction heating systems are a specific type of industrial appliances that generate high level intermediate frequency electromagnetic fields. Some appliances generate EMFs as a byproduct, but in case of induction heating, the magnetic field is intentional in order to heat up the metal or other electrically conductive objects.

The induction heaters preceded the development of the microwave heating applications. The production of heat by induced currents was recognized already in the early 1880s. First practical induction heaters with the frequencies above the power frequencies were built in the period between the two World Wars [4; 5].

Nowadays, induction heaters operate at frequencies from power frequency to several tens of MHz. Magnetic fields from lower frequency induction heaters are capable of penetrating and heating the

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material more deeply, but are also accompanied by stronger magnetic fields as compared to higher frequency units. The strongest magnetic fields are generated by induction heaters operating below 10 kHz [6-8]. Both electric and magnetic fields are generated by the induction heaters. Mantiply et al. investigated and concluded electric fields from 2 $V \cdot m^{-1}$ to 8.2 $kV \cdot m^{-1}$ and magnetic fields from 0.1 to 21 $A \cdot m^{-1}$ (i.e. 0.12 to 26.4 µT) [8]. Decat et al. (2006) investigated induction heater systems and determined a great variation in the operating time, operator's distance to the unit and exposure to magnetic field (20µT to 0.31 mT) [9].

The magnetic field from the induction heater system is mainly emitted by the coil applicator [10].

With respect to production management, other traditional industrial heating methods (electrical heating, gas heating) have several shortcomings as compared to induction heating. The main advantages are: creating intense heat very quickly and in well-defined locations. This results in shorter process time with reliable quality. Also, induction heating is more energy efficient. The shorter startup and shutdown times lower workers cost [11]. The induction heating has also improved industrial processes as the consistency and repeatability of the heating process improves the quality and increases the productivity; it is a contactless heating process where the target is not affected by being in contact to the heating element [12]. The induction heating is also seen to be more clean and safe as the magnetic field heats directly the target, whereas the temperature of the surrounding area is lower, also avoiding surrounding materials [12].

Workers safety from induction heaters has become more relevant due to recent technological developments and emergence of high temperature superconductor (HTS) based induction heaters. Loss free conduction of current and the HTS capability of carrying high current densities in the temperatures 20-80K are new features compared to the conventional technology [13].

As induction heater operators and any other personnel coming to close range of this system may be exposed to high magnetic fields, these fields need to be measured and the safety of workers assessed in the framework of the relevant national legislation. The aim of this study is to characterize by an example of a typical induction heater unit the magnetic field exposure scenarios and the ways of its mitigation; a variety of options that can be used to reduce the workers exposure are analyzed.

Materials and methods

The subject of this investigation is the induction heater system that is used in production to melt aluminum in otherwise iron containing units. Electromagnetic field measurements were done and the workers exposure to the electromagnetic fields was assessed in the framework of the new occupational electromagnetic field legislation.

Measurements of the electromagnetic fields were conducted across the working area where the induction heater was positioned. The measurements were done by three means.

1. *Spatial measurements.* Spatial measurements of the resultant field, based on the grid pattern were conducted. The grid was marked on the floor by 0.5m steps. The field intensity map was drawn based on the spatial field intensity data. The grid measurement data were also used later to calculate the workers exposure in time series, over several working procedures. The measurements were taken at the height of 1 m, which is the central height of the induction heater coil.
2. *Spectrum measurements.* The spectrum of the induction heater generated field was determined by spectrum analyzer measurements. The spectrum measurements were done in time series. The spectrum measurements provide information on the dynamics of the amplitude and the frequency of the induction heater unit. The spectrum analyzer was at the height of 0.7 m (induction heater work bench level) and at a distance of 0.6 m from the induction heater coil.
3. *Exposimetry measurements.* Personal exposure measurements provided understanding on the actual exposure of the worker. The worker was equipped with the exposimeter in the front abdominal area (at the height of the induction heater coil). The exposimeter logged the resultant field exposure at the worker's position for several consecutive working procedures, demonstrating different work activities encountered during the same process.

Visual observations of the worker's movements were conducted to determine the path of the worker during work procedures. The movements were drawn on the work area plan and spatial analysis was conducted to assess the exposure over the time of the procedures. By videorecordings, the time was measured the worker spends at any of the locations (grid points) at the workstation. The recordings were analyzed in the personal computer using video player software, where accumulating seconds were counted based on the video player timer. The data allowed the assessment of time weighted average exposure of the worker, based on the field intensity map determined earlier.

Also, the visual observations granted the insight to the activities of the worker during the heating process. These activities are directly related to the heating process, but also secondary activities involved with other workers or preparing to the coming tasks were observed.

Workers were questioned about the working methods and the necessity of any of the observed tasks. The questioning also provided information about the companies work arrangement and safety procedures related to the work with induction heaters.

The practical challenge in making measurements at the induction heater worksite is to do with the alternating power level of the induction heater. Consequently, the magnetic field is also changing in time, having stabilized on the maximum level for the brief period at the middle of the heating procedure.

Exposure assessment

Exposure to magnetic field was estimated by time-weighted average (B_{TWA}), in microTeslas (μT) as presented in formula 1. In assessing the time weighted average, the exposure was accounted only when the induction system was active, i.e. activities prior to switching the induction heater system on and after switching it off accounted for null exposure from the induction heater system. Time-weighted average is accounting each time period the worker spends in locations where procedure specific tasks are performed $\{t_1, t_2, \ldots, t_n\}$ complemented by the exposure to the magnetic field (magnetic flux density, B-field)$\{B_1, B_2, \ldots, B_n\}$ at the corresponding locations.

$$B_{TWA} = \frac{\sum_{i=1}^{n} t_i B_i}{\sum_{i=1}^{n} t_i} \text{ (μT)}. \tag{1}$$

In case of measurement devices with a fixed sampling time, the time-weighted average equals the arithmetic means of the measurements [14]. In this study, the latter applies to the exposimeter measurements, which use a predetermined sampling rate.

The exposure during a single work procedure was also assessed by a cumulative exposure index (B_{cum}), expressed in microTesla-seconds (μT-sec). Cumulative exposure for each procedure was obtained by adding up workplace specific exposures $\{B_1, B_2, \ldots, B_n\}$ measured/calculated by one second increments (formula 2) according to the start and end of the work procedure obtained from visual observation records and magnetic field spatial measurements. The cumulative exposure indicator is different from the time-weighted average, since it better characterizes single work procedure accumulated exposure (dosage), since no time averaging is performed. Work procedures differ from each other by the length of time spent on any of the activities resulting in a variation of total work procedure time. In case, more time is spent at the vicinity of the induction heater, and accounting the excess time needed sometimes to complete the task, the summed total exposure is also increased.

$$B_{cum} = \sum_{i=1}^{n} B_i \text{ (μT-sec)}. \tag{2}$$

Based on five consecutive procedures of accumulated exposures, an average exposure was calculated, which characterizes the typical procedure scenario. Exposimeter based measurements were used to calculate means, medians, minimum and maximum values in μT for all measured frequency bands and for total exposure.

Electromagnetic field meters

The meter used for worker's personal exposure measurements and spatial exposure measurements was Gigahertz Solutions NFA400 (Langenzenn, Germany). The meter is capable of simultaneous measurements of 6 frequency bands: 1) 16.7 Hz, 2) 50 Hz, 3) 100 Hz, 4) 150 Hz, 5) <2 kHz excluding the fore mentioned, 6) >2 kHz. The frequency range: 5 Hz to 400 kHz. Measurement range for magnetic flux density 1nanoTesla (nT) to 20 microTesla(μT) and for electrical field strength 0.1-1999 $V \cdot m^{-1}$.Either the magnetic and electric field could be measured by the meter. For magnetic field, the meter is a three-axial meter, capable of measuring all three axes separately and calculating the resultant field. The measurements were taken in tRMS (true Root Mean Square) mode. In worker's personal exposure logging 3D magnetic field was measured at a sampling rate of 0.1 sec.

Spectrum measurements were conducted with a spectrum analyzer AaroniaSpectran NF5035 (Strickscheid, Germany). The spectrum analyzer has an integrated 3D (isotropic) magnetic sensor, with a measuring range of 1picoTesla (pT) to 2milliTesla (mT). The unit is capable also of electric field measurements of 0.1 $V \cdot m^{-1}$ to 20 $kV \cdot m^{-1}$. The frequency range is 1 Hz to 1 MHz. The measurements were taken in RMS mode. The spectrum analyzer was used in conjunction with the laptop computer, which recorded the spectrum at the induction heater in time series.

All the measuring instruments were calibrated.

In the following chapters the measured and visually observed procedures are analyzed. A simulation is performed to recommend an alternative procedure in order to reduce the worker's exposure to the magnetic field. The simulation is based on the field intensity map, i.e. the same data as the exposure in actual conditions.

This study does not address the electromagnetic fields' induced limb currents in the human body.

Results and discussion

The object of the investigation was an induction heating system consisting of the induction heater coil, high current cables and the control unit. The system is complemented by the cooling system, whereas the induction heater coil and the current feeding cables carry a coolant flow to prevent excess heating of the system. The induction heater system was capable of 60 kW maximum power, but it was used at 20 kW due to the production tasks assigned to that heater system; maximum power was never used on that unit. As the strength of the magnetic field depends on the power of the system, i.e. the level of current passing through the cables and the coil, the results characterize the exposure scenarios at the above mentioned typical power level, which is representative exposure to workers of the investigated work station. Figure 1 gives a perspective of the investigated system, whereas red areas designate the magnetic field or its source. The induction heater system generates intermediate frequency high current that is directed by the water-cooled cables to the heater coil. The tense magnetic field emitted by the coil heats up the metallic article placed within the coil. The heating process is regulated by the amount of current fed into the coil and/or the time. The control unit is regulating the current by raising or lowering the voltage. When there is more metal that needs to be heated up, higher currents are fed to the coil, resulting up to 200 Amperes (A) for the investigated unit.

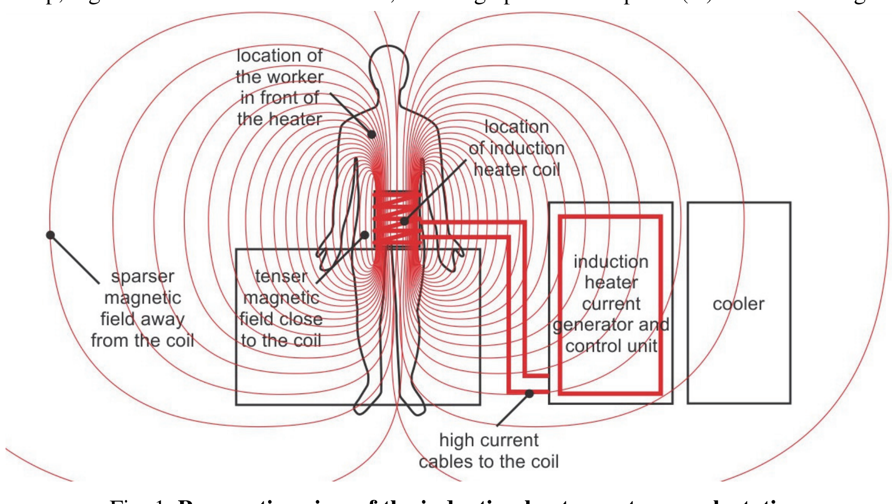

Fig. 1. **Perspective view of the induction heater system work station; magnetic field or its sources are marked in red**

The vertical special distribution of the magnetic field in front of the induction heater coil (Figure 2) indicates the amplitude of the field and is most prominent on the work bench height (0.7 m). Although the central axis of the coil is at 0.9 m, it is likely that the work bench made of iron perturbs the field and is focusing it at the worker's position somewhat lower. 0.7 m height is however the height of the reproductive organs, hence posing a possible health risk.

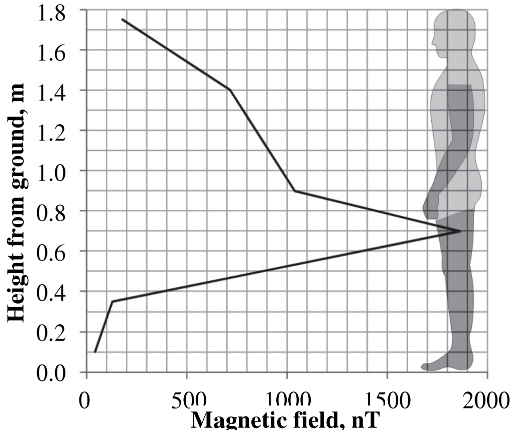

Fig. 2. **Magnetic field vertical spatial distribution in front of the induction heater coil; measurement height corresponds to: 0.1 m and 0.3 m-feet level; 0.7 m – work bench level; 0.9 m - induction coil central height; 1.4 – chest, heart level; 1.75 m – head level**

Strong magnetic field is focused in the immediate vicinity of the induction heating system (Figure 3). All the main components of the system: 1) the induction coil, 2) cables carrying the current and 3) the current generator control unit are the significant sources.

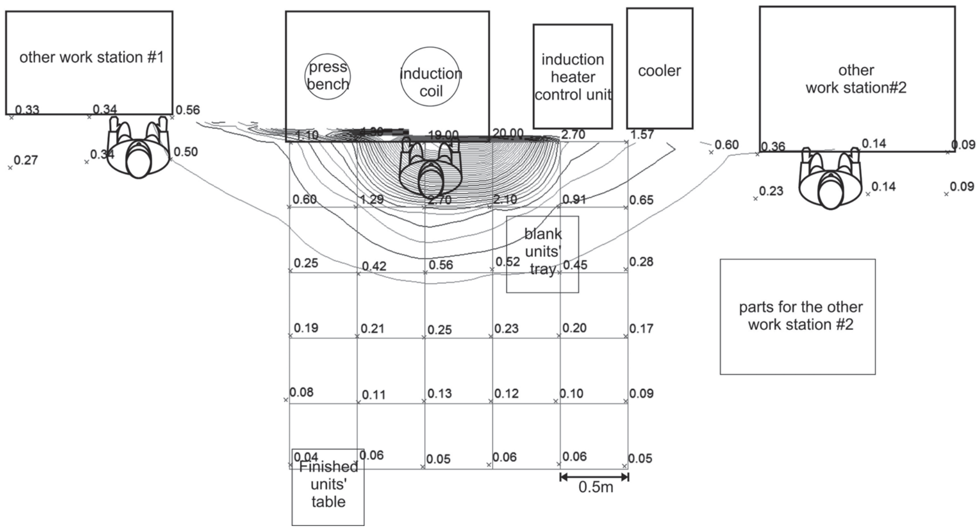

Fig. 3. **Magnetic field spatial distribution (in microTeslas) from the induction heater and the general layout of the work area: induction heater work station in the middle, one other work station to the left (#1) and one to the right (#2)**

Based on the visual observation of working procedures using the induction heater (Figure 5), the nominal work procedure was identified as follows (the movement of the worker is marked with a thick line, whereas the numbered points represent an activity at the corresponding location) (Figure 4):

1. Taking the blank unit from the blank units' tray.
2. Placing the unit under the induction heater table and closing the heater coil on the unit.
3. Switching the heater on from the control unit.
4. Preparing the auxiliary unit to be inserted into the unit in the press bench.
5. Waiting for the heater to complete.
6. Removing the unit, after the heater has automatically switched off.
7. Pressing the unit.
8. Moving the processed unit to the finished units table.

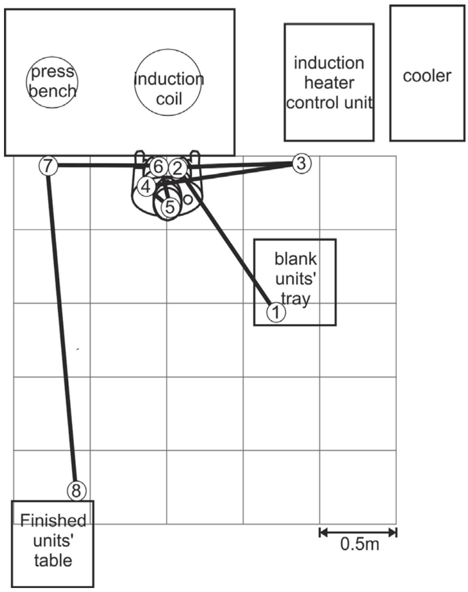

Fig. 4. **Movements of the worker in a nominal work procedure (for activity number see the list below)**

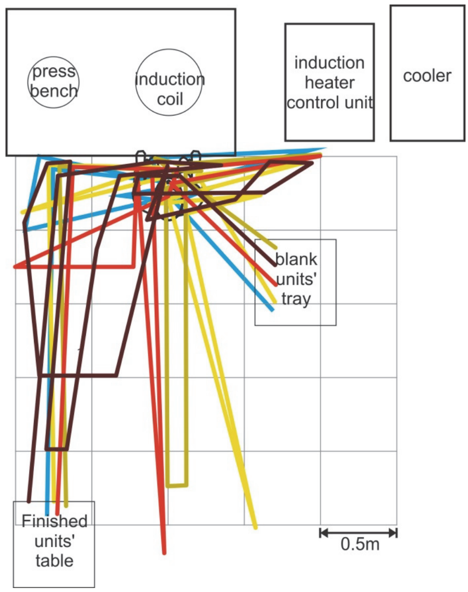

Fig. 5. **Actual movements of the worker in consecutive work procedures; separate colours represent different consecutive procedure rounds**

In the nominal work procedure only the necessary activities are undertaken, i.e. the worker has not left the workstation to go to some other location to wait the ending of the induction heating procedure – the worker remains to wait in front of the induction heater unit. Therefore, the nominal working procedure also describes the worst case exposure scenario under the current work machinery setup and work procedure arrangement.

The nominal procedure represented the typical tasks required to fulfil the work task. However, in many cases the nominal work procedure is deviated by 1) doing secondary tasks with the induction heater, 2) interacting with other workers, 3) changing the place for waiting. Waiting in other locations and interacting or collaborating with other workers take the worker further away from the induction heater, hence also reducing the exposure. Doing technical adjustments on the induction heater system however places the worker's vital body regions (head, torso) closer to the magnetic field source.

Based on the visual observations and interviews with the staff, several high exposure circumstances were identified, many of which could be avoided. Table 1 presents an overview of such scenarios.

In examining the field distribution, we see the magnetic field decreasing at exponential rate and achieving relatively negligent levels at 3-5 m distance. The recommended intervention scenario is simulated based on the field distribution map. Several intervention methods are applied to reduce the induction heater operator's exposure to the excess electromagnetic fields. Minimal exposure policy is followed.

Table 1

High magnetic field exposure circumstances at the induction heating work area

Nr	Case	High exposure circumstances
1	Control unit placed too close to the induction heater	The induction heater system's control unit was placed right next to the induction heater coil. This work layout forces the operator to bare the exposure to the magnetic field in any pattern of movements during the process, as the heating process must be initiated manually from the control unit.
2	Operator waiting too close to the heater	During the induction heating process the operator was waiting right at the induction heating bench for the heating to end, hence being exposed to excess levels of magnetic field.
3	Exposing vital body regions while doing adjustments	During some procedures, the worker was adjusting the heater station benches mechanisms or doing maintenance, while the heater element was active. By doing so, the worker's head was positioned to 0.55 m distance from the heater element, causing a significant exposure to the head.
4	Interaction with other workers	During the operation of the induction heater, other workers came to interact with the operator in the vicinity of the heater. Such interactions included delivering blank units, fetching ready-made units, coordinating about production processes etc. Being close to the active induction heater exposed these workers and the operator of the induction system to excessive magnetic field.
5	Metal objects focus the magnetic field	The heightened exposure was also seen to happen because of metals in the work area. The induction heater bench, being made of iron, focused magnetic field around its edges; the operator's reproductive organs area was in contact with the metal hence exposing these organs to heightened field. Other metal objects that the person is carrying (glasses, zippers etc.) should also be accounted for.
6	Adjacent workstations	Other work stations were positioned close to the induction heater work station, exposing these workers to unnecessary levels of magnetic fields that their work task did not require. The latter could become more relevant with potential pregnant workers at these work stations.
7	Lack of knowledge of magnetic field	The induction heater system's operator was unaware about the field intensity from the heater and the propagation pattern of the field from the heater. Also, other workers coming close to the induction heating system were unaware about the magnetic field.

The main intervention strategy is to increase the distance in between the induction heater set (heating coil and the control unit) and the worker. The worker approaches the heater work bench only when the unit is switched off: at the beginning while placing the raw product in the heating coil and at the end, while removing the heated unit from the coil. For that goal the heater control unit is equipped with an add-on technical solution – a remote control panel, connected to the main control unit via a cable. The remote control panel is placed to 3 m distance from the heater coil, which still allows reasonable operability and fast access to the system. The worker avoids any activities, including interacting with other workers or waiting for the end of the process in the vicinity of the active induction heater. The recommended intervention work procedure results in a significant decrease in the worker's exposure to the magnetic field: the accumulating dosage is only 5.2 % and the time-weighted average exposure is 4.6 % of the actual highest exposure scenario (table 2). Comparing the intervention scenario to the worst case nominal scenario revealed even greater difference, 0.9 % and 0.8 % respectively.

Table 2

Analysis of exposure to the magnetic field from working with an induction heater

Statistics	Duration of the procedure (sec)	Exposure time during the procedure (sec)	Accumulating dosage (μT-sec)	Time weighted average-TWA exposure (μT)
Maximum of exposimeter recorded procedures (N = 5)	137	74	310	2.26
Average of exposimeter recorded procedures (N = 5)	129	74	214	1.64
Maximum of observed procedures (N = 5)	127	NA	296	2.57
Average of observed procedures (N = 5)	121	74	248	2.01
Nominal procedure (worst case scenario)	118	NA	1805	15.30
Recommended procedure (minimal exposure scenario)	130	74[1]	15	0.12

[1]*The exposure time during one procedure interval is the same as statistically established time for an average procedure – this is the time taken by the field to heat the unit to a target temperature and for melting to occur. The exposure time characterizes the period while the induction heater is active, hence generating the magnetic field.*

[NA]*Data not available.*

Figure 6 pictures the worker's actual exposure to the magnetic field from the induction heating system, based on the worker wearing a logging exposimeter. Each procedure round started with the blank unit preparation phase, which took the worker 14 sec in average, followed by a heating phase. After the heater was automatically switched off, the worker conducted a press treatment of the unit and then retired the unit to the finished units tray, which took 35 sec in average. In each round the activation of the induction heater is clearly identifiable by an abrupt rise in the exposure level, briefly after starting the procedure. While the unit was being heated by the magnetic field induction, the worker waited or dealt with secondary activities. Therefore, the exposure dynamics of the magnetic field generated by the induction system is different in all procedure rounds, due to the whereabouts of the worker. In two occasions the exposimeter limit of 20 μT was reached, indicating a field above that level; but the log shows the incidents being very brief.

The difference in between the spatial measurements obtained and exposimeter registered exposure indicators is due to the location of the exposimeter, as the human body intersection width of approximately 0.4m could position the exposimeter further away from the magnetic field source than where the rest of the body's perimeter is located. Also the varying amplitude of the magnetic field during the heating process plays a role, as the spatial grid measurements were taken mostly at the time of peak power, whereas the exposimeter logs the magnetic field level of corresponding amplitude at that moment.

Measurements done by Floderus et al. also concluded that spot measurements at the induction heater units were higher than those recorded by the worker held logging system, except for the brazing machine [15].

The exposimeter based frequency measurements identified the induction heater system to be the main exposure contributor at the frequency band of 2-400 kHz (table 3). Somewhat amplitude was registered also at 50 Hz (mains power) frequency, but the exposure was negligent for an industrial setting. Due to the on and off switching of the induction heater system, there is a great variation in the amplitude of the magnetic field the operator is exposed to due course of the monitoring session. The amplitude variation could also be accounted by the operator moving around at the work area and being closer or further away from the induction heater system.

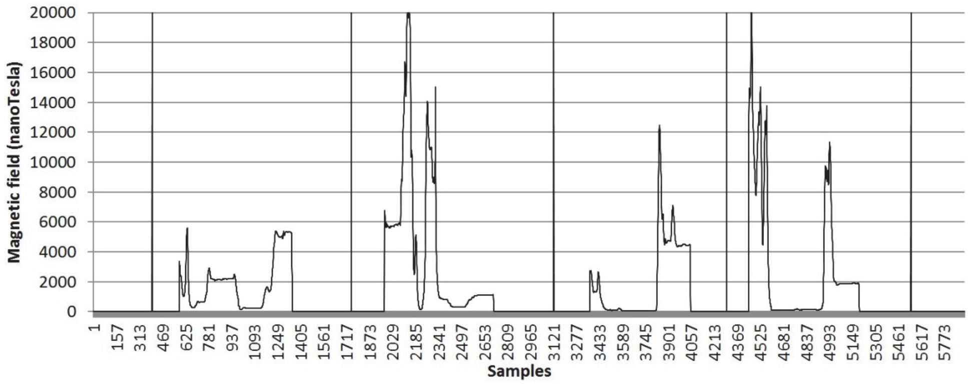

Fig. 6. **Worker's exposure to the magnetic field from the induction heating system; an exposimeter excerpt of four consecutive procedure rounds – vertical bars mark the end/start of the procedure; horizontal bar represents samples taken (10 samples per sec)**

Table 3

Frequency analysis of exposure to the magnetic field from working with an induction heater (in nanoTeslas – nT)

Frequency	Mean	Median	Min	Max	1. quartile	3. quartile
50Hz	229	182	16.4	3208	64.8	314
150Hz	15.2	13.8	0.5	73.7	12.8	16.2
<2kHz	16.8	6.5	0	95.7	2.8	30.1
>2kHz	1659	111	0	20974	0	1862
Total	1796	351	19.9	20976	211	1867

The spectrum measurements identified the operating frequency of the induction heater to be 12.5 kHz (Figure 7), it was also identified that the harmonics extended up to 400 kHz.

For 12.5 kHz the occupational exposure low and high action level for magnetic field is 100 µT [2; 3]. The public exposure limit value for the same frequency is 6.25 µT [16; 17]. It should be emphasized that in case of safety of workers in risk groups the public limits should be followed. Also the public limits become relevant when third parties, e.g., the visitors visit the work area.

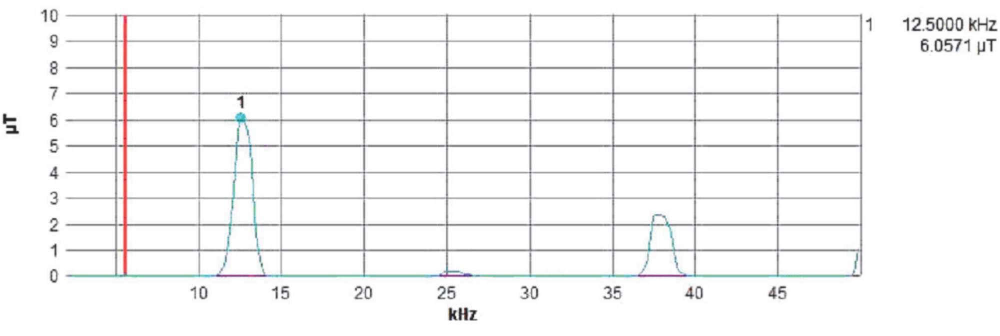

Fig. 7. **Spectrometer excerpt of the frequency distribution of the induction heater, registered 0.6 m from the induction heater coil at 0.7m height**

The magnetic field level from the induction heater coil, as recorded by spectrum measurements at the fixed position of 0.6 m from the induction coil, shows abrupt change in the magnetic field when the unit is switched on/off and slight increase in the magnetic field level during the heating process (Figure 8).

The electric field component at the workplace was relatively low, 3-7 $V \cdot m^{-1}$ at the frequency band of the induction heater system (2-400 kHz) at the worker's position.

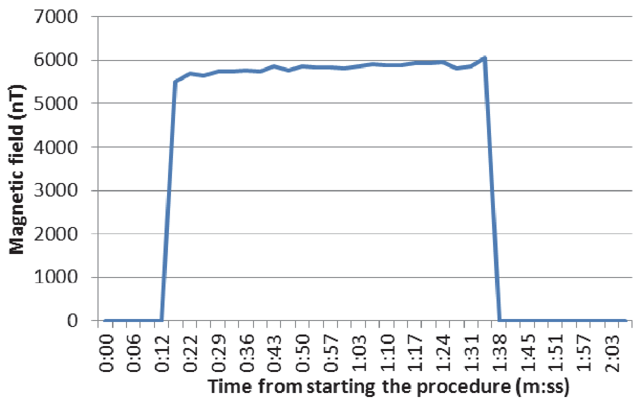

Fig. 8. **Magnetic field level during one heating procedure at the induction heater operating frequency, registered 0.6m from the induction heater coil at 0.7 m height**

Results and conclusions

Visual observations and questionings of workers and their supervisors allowed developing the strategy for managing risks related to the magnetic field from the induction heater system. Technically, the worker is not required to be present, i.e. in close proximity to the induction heater while it is active.

Based on the new legislation on occupational exposure to the electromagnetic fields, the employer is tasked with detailed obligations on worker's safety. In assessing the workers' exposure not only the amplitude and the frequency of the electromagnetic field should be accounted, but special attention needs to be paid also to 1) the duration of the exposure, and 2) the type of exposure, including the distribution over the worker's body and over the volume of the workplace.

The employer is obligated to assess if any alternative technology could reduce the exposure, including technical modifications to the existing equipment or replacement equipment. The employer is also obligated to take into account technical progress and the availability of various measures to control the production of electromagnetic fields at the source and to take actions to reduce the fields.

Special attention needs to be paid to the safety of workers at particular risk (risk groups). These include workers with passive or active medical implant, pregnant workers and adolescents.

All the risk assessment questions should be viewed from the point of view, if the current exposure is really unavoidable, so that the work could not be completed in any other way.

It should be emphasized that the nominal working procedure developed for the heating process using the induction heater exposes the worker to unnecessary levels of the electromagnetic field. The circumstances of the exposure and the work procedure however grant several possibilities for reducing the exposure.

In reducing the workers exposure at the induction heaters work area the employer could undertake mainly technical and organizational safety measures. In Table 4 the safety measures prescribed by the legislation are analyzed in the framework of the current investigation and recommendations are presented. Based on the data gathered at the work area, shortcomings, which prescribe the high exposure of the worker, were identified. Work procedures were analyzed and alternative solutions developed to reduce workers exposure (Table 4). The recommendations were developed based on the new requirements for the occupational safety from the exposure to the electromagnetic fields: the directive 2013/35/EU [3] and the corresponding Estonian national legislation from 1.04.2016 [2].

In considering the sources of the magnetic field, 1) the induction heater coil, 2) cables carrying the current and 3) the current generator control unit, the placement of the equipment should account all of these in creating distance in between the worker and the system. Using alternative technology to reduce worker's exposure could include remote switches, which would not require the worker to be close to the current generating control unit, which is also the source of the magnetic field. The worker does not need to be in the vicinity of the control unit, the task of the worker is to set the right parameters for the heating process and press the button to activate the system - this could also be done from the distance using the remote control.

Table 4

Solutions to reduce the workers exposure to the magnetic field from the induction heater

Nr	Safety measures prescribed by the relevant legislation	Accustomed solutions to reduce exposure at the investigated induction heater workplace
a.	Other working methods that entail less exposure to EMFs	The workers should minimize or completely avoid staying in the vicinity of the MF source. The employer should rearrange work procedures so that the worker does not need to go near the heater, while it is active. The worker should only approach the heater when the unit is switched off. The same principle applies also to the arrangement of work of other workers not attached to this workstation, e.g., workers delivering parts.
b.	Equipment emitting less intense electromagnetic fields, taking account of the work to be done	Since the induction heater system uses the magnetic field to heat up metal, the propagation of the magnetic field might be considered inevitable. Therefore, the choice of alternative models to do the same job would not allow significant reduction in the propagated magnetic field, unless these models are accompanied by the shielding solutions. The heating of the units and melting aluminum may be achieved also by other heating technologies, but for certain products induction heating might be the only option.
c.	Technical measures to reduce the emission of EMFs including interlocks, shielding etc.	A control panel should be positioned separately from the main system, so not to expose the worker while operating the system, e.g., pressing the start button from the distance. An option would be to apply a shield around the induction heater coil.
d.	Delimitation and access measures to limit or control access	Zoning principles should be followed by marking lines on the floor and equipment, indicating both occupational and public safety limits at levels of, e.g., 100 %, 50 % and 10 %. Workers, whose tasks are not related to induction ovens, should be delimited from accessing the high exposure area.
e.	Measures to manage spark discharges and contact currents	Applicable mainly to electric fields.
f.	Maintenance programs	The employer should organize regular maintenance of the induction heater to ensure that malfunction or unauthorized readjustment of the induction heater system would not expose workers to elevated levels of magnetic fields. Also adjustments and maintenance procedures should not be allowed while the heater is active.
g.	The design and layout of workplaces and workstations	Having the control unit close to the heater also prescribes a significant exposure level. Rearrangement of work equipment including repositioning the control unit away from the heater (recommended 5 meters) would decrease the worker's exposure. Blank units and processed units trays should be positioned to the work area considering that there is no exposure from the heater system while the work with blank/ready unit is needed to be fetched. Other work stations should be positioned away from the induction heater system, since exposing these workers is unnecessary.

Table 4 (continued)

Nr	Safety measures prescribed by the relevant legislation	Accustomed solutions to reduce exposure at the investigated induction heater workplace
h.	Limitations of the duration and intensity of the exposure	See point a.
i.	Personal protection equipment	Due to the physical propagation of the magnetic fields (toroidal field lines) there is no practical personal protective equipment suitable for the investigated case. However, metal parts on the body and in garments should be avoided, as these tend to focus the field, hence increasing the worker's exposure.
j	Training of workers	The workers should be trained especially in regard where high field intensities are present, so they could avoid high exposure spots (e.g., avoiding present scenarios where the worker just waits next to the heater for the heating process to end).

The rearrangement of the devices, whereas the control unit is placed further away from the induction heater system and the workers are positioned further away from the magnetic field generating components, would inevitably add distance to the length of the path the worker needs to take to perform each single procedure. The extra time needed to undergo that extra distance is assessed to have relatively little impact on the total procedure time of about 2 min. Only approximately 10 sec would be added to the length of the procedure. Also the placement of the equipment should consider the time when the induction system is actually active, i.e. approaching the induction heater bench would not accompany any exposure when the system is inactive. Therefore, it is reasonable to satisfy with the current setting where the blank units tray is positioned in near proximity of the induction heater coil at a distance of ~1m. The same principle applies for the finished units tray and the postheat processing procedure at the press bench.

It was noted that in several occasions other workers came into the work area of the induction heater system and therefore were also exposed to the high magnetic field. These workers were delivering or retrieving the parts, signing documents, collaborating on work related issues etc. The high exposure of secondary workers could be avoided by moving these activities to outside of the active induction heater system work area. Also, the investigation unveiled the importance of schooling also other workers in the production, as they had no awareness of where and when the strong magnetic fields occur, nor of their risks to their health and safety.

Shielding is an option to be considered in mitigating the exposure to the magnetic field from the induction heater. Both passive and active shielding could be applied. Active shields generate counter fields that cancel or reduce the original field. A set of coils is included in the active shield, positioned in a way to account for the original field, the coils are driven by a control system, that follows the original field by magnetic sensors [18; 19].

In case the passive shield is used, this shield should not be close to the coil, since it would also be heated up. Also, since energy is lost in heating the shield, it would take more time to heat the processed unit. Limited shielding may be offered by one side screens that reduce the magnetic field at the side where the worker is waiting or where other workers are present. However, due to the physical propagation of the magnetic field (toroid field lines), one-sided screens offer comparatively less protection than full envelope shields.

Safety improvements would also include zoning principles, i.e. markings (lines) on the floor for 1) occupational exposure action levels and 2) public safety limits. The line should not be drawn only at 100 % of the corresponding limit, but also 50 % and 10 % line could be considered as to make personnel aware of the risk agent.

Technical measures could also include signalling lamps and sounds, which warn the operator and other personnel when the unit is active: this would allow the personnel to keep proper distance to the source when needed, whereas in other times delivering or fetching parts may be needed to very close proximity of the induction heater system.

Appropriate signs should be attached to the working area including at the immediate work station and also at the entrance to the area. The latter should also be complemented by the instruction sheets for low risk work practices. The above mentioned risk mitigation measures would allow the workers or visitors to be informed of the relevant safety measures.

Training should focus on making workers aware where strong electromagnetic fields are present. The workers should know what the possible health effects from the exposure to these fields are and how to detect them. Indirect effects of the EMFs should also be covered by the EMF training program. Emphasis should be put on how workers could protect themselves, by example adapting new safe work practices. Training workers is also important due to their possible affiliation to the risk group. The safety of workers within the risk groups may be jeopardized, if they get too close to the induction heater system. The latter principle requires careful attention as workers sometimes do not report themselves being attached to the risk groups, e.g., the person carrying active or passive medical implant may be unaware of all the risks associated with their implants. Also, sometimes the workers are unaware that they belong to the risk group, e.g., women not yet knowledgeable about their pregnancy. Therefore, women within their childbearing age, especially the ones who plan to have children, should be encompassed into the training program. Possible damage to the development of the fetus would be most crucial to avoid at the beginning of pregnancy.

The average exposimeter measured exposure level (1.65 μT) was in the same order of magnitude (0.2-1.2 μT) as measured at induction heater workstations by Floderus. Their spot measurements at 0.5 m from the induction heater varied 0.4-20.9μT as compared to 20μT in the current induction heater work station [15].

The measurements and exposure assessment have demonstrated that the worker's exposure to the magnetic field from the induction heating unit is episodic and subject to large variations of amplitude during the heating procedure. The variation is due to the ON/OFF switching of the heating system and due to worker changing position at the work station. This results in short time exposure to relatively strong fields, when the worker has moved closer to the induction heater coil, as reported also in the literature [9; 14; 20].

The results show that exposure during the induction heating procedure could be significantly reduced by implementing relatively easy mitigation measures, including workplace rearrangement, work procedures redesign etc. Time-weighted average exposure to the magnetic field could be lowered from 2.57 μT (maximum observed procedure) to 0.12 μT (recommended procedure after interventions). The investigation also revealed that at present little attention is paid to training the workers who may be affected by high levels of EMFs. Considering the requirements of the new EMF legislation, immediate planning of appropriate schooling programs is necessary for all parties involved: employers, workers, work environment specialists.

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Article 4

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Safety Compliance of Occupational Exposure to Electromagnetic Fields

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Abstract

Consequent to the 2016 legislation, European companies are expected to be in compliance with new legislation about occupational exposure to electromagnetic fields. The aim of this study is to determine the compliance of companies and the respective stakeholders with respect to the new EMF safety legislation. A questionnaire was used to determine the level of electromagnetic safety management (N=190). The stakeholders included working environment specialists, workers, occupational health doctors and labour inspectors. The study found that working environment specialists had assessed the EMF safety in companies to be better managed than did workers and labour inspectors. The key factor influencing EMF safety was training working environment specialists and workers. The shortcomings are characteristic to all companies, but are somewhat less evident in large companies. The study is contributing on how legal aspects of EMF safety are considered at different levels of stakeholders, and also show the need for reducing the exposure resultant from poorly managed safety issues.

Keywords: electromagnetic fields, occupational exposure, workplaces, legislation, European Union, directive.

1. Introduction

The safety of workers is an important factor and one of the key functions of every organisation. The working environment may encompass several risk factors of which electromagnetic fields (EMFs) are one. The relevance of having a good safety understanding of electromagnetic fields in workplaces is because, unlike many other occupational health and safety risk agents, EMFs are invisible, odourless, and cannot be detected by a human being until harm is done and adverse effects occur. An electromagnetic field (EMF) is a physical field that accompanies electricity. All electrical appliances produce this field.

The exposure to electromagnetic fields is a common term, characterising exposure either to electric, magnetic or electromagnetic fields. From the perspective of exposure, EMFs can broadly be divided into four groups, depending on their frequency: static, low frequency, intermediate frequency and radio-frequency electromagnetic fields. In the case of low frequency fields, we are mainly dealing with power frequencies (50 Hz in Europe), i.e. technically extremely low frequencies. Different frequency groups have different mechanisms that affect the human body, but all could induce biological effects. Magnetic and electric fields require differentiation and separate assessment, especially in the case of static, low and intermediate frequency fields. In the case of radio frequency fields, with far field scenarios, the electric and magnetic field are viewed as one and could be assessed as an electromagnetic field.

Occupational exposure to EMFs is a known risk factor. Recently, more attention has been paid to the long-term health effects from electromagnetic field exposure; studies have pointed out the risks related to long-term occupational exposure. (Carlberg, Koppel, Ahonen, & Hardell, 2018; Jalilian, Teshnizi, Röösli, & Neghab, 2017; Huss, Spoerri, Egger, Kromhout, & Vermeulen, 2018; Grundy et al., 2016; Turner et al., 2014). The current safety limits are based on short term health effects (Vabariigi Valitsuse määrus 01.04.2016 nr 44, 2016; The European Parliament and the Council, 2013), which rely on third party guidelines (International Commission on Non-Ionizing Radiation Protection, 1998). Since current safety limits are based on short-term health effects, only a conservative approach to organising safety in working environments and the mitigation of workers exposure could guarantee their safety.

The legislation requires reducing risks, including reducing exposure and implementing other risk mitigation measures in order to guarantee the workers' safety. The employer might not be motivated to raise the safety of workers solely on legislative demands. Productivity and the work environment are important productivity factors for the company.

EMFs are everywhere where electricity is used. Specifically, magnetic field exposure could be problematic where machinery consumes great amounts of current; such processes are native to many industrial technologies. The problem lies within the potential adverse effects on workers' well-being from the exposure to strong electromagnetic fields. The obligation of the employer is to guarantee the workers' safety, hence requiring them to reduce the EMF related risks to as low as possible. It is obvious that there is a variation in exposure to EMFs from different occupations. There are prescriptions set by legislation on how to reduce the exposure to workers.

This study aims to determine the compliance of companies and the stakeholders with respect to the new EMF safety legislation. The study investigates if the corresponding new legislative requirements are implemented in companies. The results would reveal if the new 2016 legislative requirements have had an impact on EMF safety arrangements, especially within companies (Vabariigi Valitsuse määrus 01.04.2016 nr 44, 2016).

The research will address differences in awareness, training levels and the safety compliance of companies, depending on occupational affiliation to EMF related safety issues. The analysis is to determine if the aforementioned stakeholders consider the following factors to affect the EMF safety management:

- Workers EMF safety awareness and training,
- EMF safety management compliance of the company,
- EMF safety arrangement for strong EMF workplaces,
- EMF safety arrangement for risk groups.

The current study is relevant due to the legislative changes in organising workers safety from electromagnetic fields. In recent years the EU has issued a new directive 2013/35/EU (TheEuropean Parliament and the Council, 2013) and the consequent national decree (Vabariigi Valitsuse määrus 01.04.2016 nr 44, 2016). The legislation prescribes new obligations for companies and other stakeholders.

A questionnaire was developed to meet the task. Four target groups were approached: 1) workers, 2) working environment specialists, 3) occupational health doctors and 4) labour inspectors. Accordingly, four variations of the questionnaire were designed to locate the knowledge gaps, how much attention is paid to the issue, and generally how well prepared the stakeholders are to accept the new legislation in occupational exposure to electromagnetic fields.

The current study is relevant for occupational safety specialists, but also workers and other subgroups. The study could be used to argue for the importance of safety training and other employer contributions to safety awareness in regard to EMFs, which would include the means of identifying EMF exposure, and how to reduce exposure to safe levels etc.

The contribution of the study resides in elaborating on how legal aspects of EMF safety are considered in different levels of subgroups, and showing the possible need for reducing the exposure resulting from poorly managed safety issues. Also, the contribution has to establish the link in between the employers' contribution in educating and training specialists and workers, and the resulting safety compliance of both the strong EMF workplaces and the company in general. It may show the possible need of reducing the exposure resultant from poorly managed safety issues or the key factors regulating the EMF safety level in companies.

This paper consists of four chapters, including 1. Introduction, 2. Research background 3. Safety management 4. Data and method, 5. Results, 6. Discussion and conclusions.

2. Research Background

2.1. EU Directive 2013/35/EU

The European Parliament (EP) issued a new directive on occupational exposure to electromagnetic fields on 26.06.2013 (TheEuropean Parliament and the Council, 2013). The directive sets minimum requirements for safety issues in regard to occupational exposure to electromagnetic fields. A three year adoption period was given for the Member States to harmonise their national legislation with the requirements of the directive. The 1 July 2016 is the date by which the directive should be implemented at the national level.

The directive is a legal tool that enables the European Union to enforce common principles across the Member States. The commitment of the European Union (EU) to improve the work environment and to protect workers is written into the Treaty on the Functioning of the European Union (article 153 p.1, a) (European Union, 2012). It also gives the EU the authority to issue directives to that end.

Secondly, the obligation to protect workers is laid down in the article 31(1) of the Charter of the Fundamental Rights of the European Union: "every worker has the right to working conditions which respect his or her health, safety and dignity" (European Commission, 2000).

A framework directive (89/391/EEC) was laid down in 1989 to introduce general prevention principles in the field of occupational health and safety. The directive applies to all fields of activities, except the armed forces, police and civil protection services. It sets principles for the prevention of risks, the assessment of risks, the protection of safety and health, and informing, consultation, training etc. (The Council of the European Communities, 1989a).

The framework directive forms the basis for several other specific directives to be issued. The framework directive provides general principles applicable to all sectors, but where individual directives contain more stringent and specific provisions, the special provisions of specific directives apply. Since the adoption of the framework directive, a number of specific directives setting minimum requirements for the protection of workers have been issued. These directives can be classified as dealing with (The European Agency for Safety and Health at Work, 2014):

- specific tasks (e.g. manual handling of loads),
- specific hazards at work (e.g. exposure to dangerous substances or physical agents),
- specific workplaces and sectors,
- specific groups of workers (e.g. pregnant women, young workers),
- certain work related aspects (e.g. organisation of working time).

Since the framework directive, several other directives on physical hazards have been issued, including vibration – Directive 2002/44/EC(The European Parliament and the Council of the European Union, 2002), noise – Directive 2003/10/EC (The European Parliament and the Council of the European Union, 2003), and artificial optical radiation – Directive 2006/25/EC (The European Parliament and the Council of the European Union, 2006).

From the point of view of occupational health and safety, electromagnetic fields are classified as a physical risk factor. But EMFs are also covered by legislation and standards from the point of view of the operability of electronic apparatuses – electromagnetic compatibility (EMC) and electromagnetic disturbances (EMD). An electromagnetic disturbance is seen as a phenomenon which degrades the performance of the electronic device. This includes radiated emissions, immunity from EMFs, mains disturbances, conducted transients and radio frequency, and electrostatic discharge and lighting surges (Williams, 2016). EMC and EMD are covered with both international standards and European Directives (The Council of the European Communities, 1989; The European Parliament and the Council, 2004a).

Figure 1. Apparati bearing the 'CE' marking and released to general public are in compliance with directive 2004/108/EC and therefore also with the EMF safety limits set for the general public (The European Parliament and the Council, 2004a)

An "apparatus" is considered a finished appliance or a combination of appliances that have been made commercially available as a single functional unit and intended for the end user (The European Parliament and the Council, 2004a). A "CE" (fig.1.) marking is found on an apparatus if it complies with the EMC directive (The European Parliament and the Council, 2004a). Such apparati are also seen to comply with safety limits set to protect the general public from exposure to electromagnetic fields (The Council of the European Communities, 1999). Therefore, if a working environment consists only of electrical appliances also intended for use by the public consumer (e.g. offices), the workplace is automatically conforming to the general public EMF directive 1999/519/EC (The Council of the European Communities, 1999). If a work place includes any industrial electrical appliances or any other devices that are not intended for use by the general public, the compliance with 1999/519/EC is not automatically met.

The general public EMF directive is applied to areas where members of the general public spend significant time, e.g. public places, homes, schools etc. The latter is however not a directive officially, but a recommendation – it does not force the EU Member States to comply with the set rules. However, Member States do follow the same set of safety limits or even stricter ones, as set in the Council's recommendation (The Council of the European Communities, 1999).

But for work places, a specific set of rules has been developed – a directive on the minimum health and safety requirements regarding the exposure of workers to risks arising from physical agents (electromagnetic fields) (The European Parliament and the Council, 2004b, 2008) (The European Parliament and the Council, 2004b, 2008; The European Parliament and the Council, 2013). This occupational EMF directive applies to all work places. Whether the work place is also subject to the EMF directive for the general public is determined if a member of the general public is granted access to the work place in question; for example, customer service areas (i.e. hair salons, bank offices) are subject to both the general public EMF directive and the occupational EMF directive.

The directive is however not a document that enforces companies and other entities to act on its requirements. The directive is a set of rules and minimal requirements that the national legislation of the EU Member States must conform to; that is, the national requirements for safety in electromagnetic fields in working environments cannot be any less than those specified in the directive. Likewise, the directive does not prevent Member States to maintain or introduce more stringent protective measures. In fact, the occupational EMF directive 2013/35/EU states that the implementation of the directive should not serve to justify any regression in relation to the situation already prevailing in the Member States (The European Parliament and the Council, 2004b, 2008; The European Parliament and the Council, 2013). Standards, such as EN 50499, for example, could also be referred to in organising the procedures of EMF risk assessment (CENELEC, 2008). Therefore, the safety regulations across the EU Member States can vary.

2.2. Precursors to the Directive

The preparation for implementing new European Union legislation on protecting workers from electromagnetic fields had been ongoing for more than ten years. A previous directive on the same matter (The European Parliament and the Council, 2004b) had been approved by the European Parliament already on 30 April 2004, and was originally intended to be implemented by the Member States by 30 April 2008. After a lobbying campaign involving patient groups and MEPs (members of the European Parliament), the deadline was subsequently postponed to 30 April 2012 (The European Parliament and the Council, 2008). Some stakeholders expressed discontent with the 2004 version of the directive, namely the Magnetic Resonance Imaging (MRI) sector. They saw that the safety limits proposed by the 2004 directive would limit the use of MRI devices, as workers close to the MRI scanner would be exposed to EMFs (namely in the range of 110 Hz to 5 kHz) above the proposed safety limits (Hill, McLeish, & Keevil, 2005).

Continuing the use of MRI for both research and clinical use was seen to be under threat. The new directive (2004/40/EC) would limit the options for medical staff to take care of patients, like children, the elderly and those anaesthetised, needing help and comfort during MRI scans. In addition, the use of MRI would be hindered in interventional and surgical procedures, and researching new techniques that allow better clinical information and avoid using ionizing radiation (European Science Foundation, 2010; Keevil et al., 2005; Keevil & Krestin, 2010). The postponement and review of the directive was called for.

The dialogue, led by the European legislator, continued amongst stakeholders in order to accustom the directive to new scientific data and the needs of the stakeholders. In addition, the industry was worried about the directive hindering the operability of manufacturing processes and other tasks demanding workers to be exposed to EMFs. A revised proposal of the directive was made public on 14 June 2011 (European Commission, 2011) "title": "Proposal for a directive of the European Parliament and the Council on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields)."

2.3. A Newly Emerging Risk Factor

The relevance of electromagnetic fields as a working environment risk factor is emphasised by the European Union by classifying it amongst the "emerging health risks" (European Commission, 2008). An advisory structure called the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) has been set up since 2004 by the European Commission to provide expert opinions on electromagnetic fields and other emerging or newly identified environmental risks (Commission, 2008). The role of SCENIHR is to provide the European legislators with comprehensive assessments of the risks to the safety of both the public and employees (Scientific Committee on Emerging and Newly Identified Health Risks SCENIHR, 2007, 2009, 2013).

A great portion of the population is interested in and worried by potential exposure to electromagnetic fields. According to the last Eurobarometer poll on electromagnetic fields conducted across the EU Member States, 58 per cent of people do not believe that public authorities protect them from potential health risks related to EMFs. This is a criticism of the public authorities. Half of the respondents (48 per cent) feel that the EU should inform the public of these potential health risks. Only 20 per cent of the respondents said they had received some information on the potential health effects of EMFs (TNS Opinion & Social, 2010).

Both 2007 and 2010 Eurobarometer polls showed that the public is most concerned with high voltage power lines and mobile phone masts affecting their health, while sources of electromagnetic fields were placed in the bottom half of the list that contained several other environmental health risk factors (TNS Opinion & Social, 2007, 2010).

A Eurobarometer poll (April 2014) on working conditions in EU countries revealed that only 24 per cent of the respondents said their workplace have measures to address new emerging risks (TNS Political & Social, 2014).

An electromagnetic field consists of an electric and a magnetic field, which may be of independent strength (at low and intermediate frequencies). Therefore, two sets of safety limits have been produced to cover both electric and magnetic fields. Where the voltage is higher, the accompanying electric field is stronger, whereas electrical appliances that use more power tend to produce stronger magnetic fields. At radio frequencies the electromagnetic field is treated as one field.

Electrical appliances in different working regimes and utilising various technologies may generate a number of electromagnetic frequencies that the worker is exposed to.

2.4. Health Effects and Safety Levels

Health effects are frequency dependent and may occur when the strength of the EMF reaches a certain level. The directive (2013/35/EU) addresses short-term and acute health effects mainly related to thermal effects and the electrical stimulation of tissues. Such effects may include (The European Parliament and the Council, 2013):

- vertigo and other physiological effects related to the disturbance of the human balance organ,
- electric stimulation of peripheral and central nervous system tissues in the body,
- electric field effects on the central nervous system in the head, i.e. retinal phosphenes and minor transient changes in some brain functions
- localised heat stress in the head and trunk or in the limbs,
- whole body heat stress,
- auditory effects caused by exposure of the head.

The process of forming the directive has taken more than ten years. This itself describes the complex set of views related to the issue. A number of stakeholders are affected by the new legislation. Such parties may be viewed as 1) scientists, 2) legislators, 3) employers, 4) employees, 5) work inspectors and 6) occupational health doctors, plus others affected to some extent by the new legislation (Koppel & Kristjuhan, 2013).

The main point of discussion could be viewed as the safety level prescribed by the directive: whether the directive should set a high level or a moderate to low level of protection from EMFs. Some may favour a non-binding and voluntary set of rules, whereas others see obligatory legislation to be the only solution. The confrontation of interests is inevitable, since each party has their own balance sheet of obligations and benefits. Employees are likely to favour strict safety rules and exposure limits as their interest concerns their good health and work ability. Employers on the other hand need to invest into the new safety measures by procuring new equipment, implementing new work procedures and so on. Even though the employers may also see that a healthy worker is a productive worker, payables and receivables need to be summed up. Therefore, employers are likely to favour legislation that would grant them more room to manoeuvre. One example could be brought by the way the European Engineering Industries Association regards the topic, as "irrational public concerns" and "public authorities rushing through legislation" (European Engineering Industries Association, 2014).

Undoubtedly, there are also discussions and contradictory views among stakeholders as well. From within the scientific community we can find parties that would welcome legislation that covers all the biological effects, resulting in quite strict safety limits (Carpenter & Sage, 2007; Group, Sage & Carpenter, 2012). At the same time, scientists following a more conservative approach would like to see a scientific body of research that irrefutably makes a case for the new effects before changing the legislation (European Health Risk Assessment Network on Electromgnetic Fields, 2010; Scientific Committee on Emerging and Newly Identified Health Risks SCENIHR, 2009). The latter approach forms the prevailing view in legislation formulation.

2.5. Implementation

After passing the new EMF legislation, the implementation at Member State level has begun. This process involves the stakeholders presented in Figure 2.

Figure 2. Stakeholders in the implementation of the EMF legislation at national level

Source: compiled by the author

The implementation of the directive is also likely to be impeded by a lack of risk assessment and measurement service providers capable of adequately dealing with exposure scenarios in various workplaces. One shortcoming is certainly the lack of know-how to deal with the full range of electromagnetic fields from static fields to ultra high frequencies. Such service providers should possess the expertise to measure, calculate, and assess the exposure, and the effects of the electromagnetic fields, and to suggest effective mitigation options in the situations encountered. The service providers also need to be equipped with adequate measurement devices such as electromagnetic field meters and spectrum analysers for all frequency ranges (0 Hz to 300 GHz). Specially designed measurement devices may be additionally needed to cover electromagnetic fields with special signal characteristics (e.g. ultra short pulse radars, pulsed signal communications etc.). Such peculiar signals are becoming more common in workplaces and the typical EMF meters are usually not adequate to measure these. Therefore, national regulations in regard to EMF measurement and assessment service providers are likely to be subject to revisions. In Germany, such professionals are assigned the title "EMF Expert" and are required to have a university or college education in the relevant courses, two or three years of professional experience, good knowledge of the measurement and evaluation procedure, and proof of their competence (attendance of special courses) (Institution of Chemical Engineers, 2004).

The new occupational EMF legislation prescribes activities for all stakeholders: renewing or issuing a new national legislative act; training workers in regard to the relevant safety knowledge; training work environment specialists; renewing safety measures in companies; educating occupational health doctors to diagnose EMF related health effects; educating labour inspectors to identify EMF exposure related situations etc.

The European legislators understand that overly strict regulations are not good for business, and that Europe viewed in terms of global competition needs entrepreneur-friendly legislation. In fact, the Treaty on the Functioning of the European Union, which is the legal basis for EU directives, under article 153 p. 2 (b), states that "such directives shall avoid imposing administrative, financial and legal constraints in a way that would hold back the creation and development of small and medium-sized undertakings" (European Union, 2012).

Therefore, the aforementioned prerequisite may, however, be viewed as discrepant to the point of view of the protection of workers (from environmental risk factors). The most significant improvements in the work environment are hardly available without expenditure. When it comes to EMFs, such investments tend to become costly due to the high cost of the shielding materials, acquiring new machinery, the loss of productivity while work procedures are reorganised and so on. There are several industrial processes (e.g. the car industry) and a number of professions that are accompanied by high level exposure to EMFs. Therefore, it is self-evident that the EU will not issue such legislation that would disable these industries to perform their native tasks. In order to understand the European legislation, one should also consider the task the European legislator is confronted with: finding a reasonable and balanced approach that satisfies the safety of the workforce and that companies can endure.

3. Safety Management

Recent global and financial crises in EU Member States may also be seen as one of the causes of deteriorating working conditions in companies, and this is a concern expressed by the European Trade Union Confederation (European Trade Union Confederation, 2013). The issue was also addressed by the European Parliament by issuing a resolution on the European strategy on health and safety at work (2013/2685(RSP)), calling for rapid responses to provide a high level of health and safety at work in response to the impact of economic developments and social crises on the work environment (European Parliament, 2013).

Since electromagnetic fields as a risk factor in the work environment have not gained as much attention as many other occupational health stressors, the literature is missing studies in the field of the safety management of electromagnetic fields. The same also applies to newly emerged technologies that utilise electromagnetic fields. Therefore, in order to learn and plan activities to improve EMF safety in enterprises, one must look at the general studies conducted in the area of occupational health and safety. Next, the implications of the European study of New and Emerging Risks are introduced, as these can be reflected on electromagnetic fields' policy development.

According to the European Survey of Enterprises on New and Emerging Risks, the main occupational health and safety concerns are accidents, musculoskeletal disorders and work-stress. In larger enterprises, more attention is paid to health and safety services, such as safety experts and occupational health doctors (González, Cockburn, Irastorza, Houtman & Bakhuys Roozeboom, 2010). Smaller companies report comparatively fewer occupational health and safety management measures. However, the number of measures decrease with regard to company size at a much faster rate in companies with less than 100 employees. Independent companies reported fewer occupational health and safety management measures than those that are part of a larger entity (Stolk, Staetsky, Hassan & Kim, 2012). Companies fulfilling their legal duties and employee requests appeared to be the main drivers for addressing occupational health and safety issues. According to the study, managers report employee participation to be a key success factor for occupational health and safety management; therefore, the role of social partners remains important in implementing effective measures. Worker participation, whether formally through a works council and shop floor trade union or informally by direct involvement, is associated with better quality management of health and safety (González et al., 2010). Countries with better occupational health and safety management practices tend to have smaller differences in reporting these practices between smaller and larger organisations than countries reporting less occupational health and safety practices, in the overall sample across size ranges (Stolk et al., 2012).

Järvis et al. (2016) examined differences between formal safety and real safety in Estonian small and medium-sized enterprises. Their work revealed key issues in safety culture assessment, finding many organisations with an excellent safety culture and positive safety attitudes. However, their qualitative research approach revealed important safety weaknesses and aspects, and a gap between formal safety and actual safety (Järvis, Virovere & Tint, 2016).

Cooklin et al. (2017) conducted a systematic review (31 studies) on occupational health systems. They concluded that effective interventions were mostly aimed at improving employee physical or mental health, whereas less consistent results were found from integrated interventions targeting occupational health and safety management, injury prevention or organisational cost savings (Cooklin, Joss, Husser & Oldenburg, 2017).

Few studies are available on EMF risk perception among workers. Fatahi et al. (2016) investigated the perception of health risks from electromagnetic fields by MRI radiographers and airport security officers. The findings revealed that MRI radiographers perceive the risk from EMFs less than thought by the general working population, and less than the security officers. Security officers, who felt more positive about EMFs, were determined not to be significantly related to the perceived risk of EMF in general or EMF from other home sources – negative emotions were strongly related to perceived risk. The study concluded that although differences in occupations seem to be reflected in the different perceptions of EMF, the level of occupational EMF exposure does not predict the perceived health risk (Fatahi, Demenescu & Speck, 2016).

4. Data and Method

4.1. Study Design

A questionnaire was developed for four different stakeholder groups. The groups were selected based on the professions most affected by the new legislation. The questionnaire included a common set of questions, and groups also had to answer questions focusing on their role in the new legislation post-implementation (see Table 1).

Table 1. Groups targeted by the questionnaire and the main issues explored

Group	Predictive variables	Response (and predictive) variables (no of items in parentheses)
Workers (W)	age risk group affiliation company size professional tenure workplace type (office, industrial, etc.) workplace EMF level	EMF safety awareness and perception (6) Compliance of company in terms of EMF safety (7) EMF safety arrangement in strong EMF workplaces (8) EMF safety arrangement for risk groups (No. of items in parentheses) (1)
Working environment specialists (S)	age company size company type (office, industrial, etc.) OHS* professional tenure awareness of strong EMFs at workplace	Assessment of workers EMF safety training (5) Compliance of company in terms of EMF safety (10) EMF safety arrangement in strong EMF work-places (9) EMF safety arrangement for the risk groups (6) Knowledge of EMF propagation and safety principles (3)
Occupational health doctors (D)	age OHS* professional tenure awareness of strong EMFs at workplace	Assessment of workers EMF safety training (5) Knowledge of the health effects of EMF (1) Has diagnosed/suspected EMF health effect (1)
Labour in-spectors (I)	age OHS* professional tenure awareness of strong EMFs at workplac-es	Assessment of workers EMF safety training (5) Knowledge of EMF propagation and safety management (4) Compliance of companies in terms of EMF safety (2) EMF safety arrangement in strong EMF companies (12)

Notes: OHS = Occupational Health and Safety.
Source: authors' data

The questionnaire provided the respondents the following number of questions:
- workers – 28,
- work environment specialists – 26,
- occupational health doctors – 21,
- labour inspectors – 22.

The questionnaire focused on the key issues addressed by the new occupational EMF directive (2013/35/EU). The occupational health and safety (OHS) experts (working environment specialists, occupational health doctors, labour inspectors) were asked an expanded set of questions to determine their knowledge about the legislation, EMF induced health effects, risk groups, the obligations of the employer and EMF mitigation options.

The questionnaire aimed to determine whether the respondent's (workers and work environment specialists) company belonged to a high EMF exposure group (i.e. where industrial machinery or installations are present that produce high EMF levels). A list of machinery in specific professions was presented to identify if the company has any of these. If the respondent answered positively, an additional set of questions was given to determine the level of EMF safety management and training. One should know that if the workplace lacks high EMF generating equipment, the company (employer) is not obligated to arrange any EMF specific training or safety management.

Similarly, the same logic was followed in regard to the risk groups. If a worker reported him or herself to be in a risk group (pregnant or wearing medical implants), an additional set of questions was presented to determine the attention paid to his or her condition in the presence of high EMFs. Similar inquiries about the safety arrangement regarding workers in risk groups were addressed to the work environment specialist.

4.2. Data Collection

The questionnaire was published in an online form (Limesurvey server software). The questionnaire was adaptive and presented to the respondents with questions based on their answers in the first sections.

The questionnaire could be filled out anonymously and the respondents were assured that the responses will not be forwarded to anyone outside the research group. An option was also given to relinquish anonymity by leaving an email to receive feedback on the study (N=87).

The questionnaire was published in Estonian, but also in English for those workers or OHS specialists that had immigrated from other countries.

The main method of delivery was by directly emailing the target groups, but other channels of delivery were also used as presented in Table 2. The questionnaire was distributed to companies which are expected to include elevated electromagnetic fields on the basis of their registered field of activity. This included mainly industrial companies, but also enterprises from transportation, communications, power generation and distribution and others. Due to the mixed methods approach, the target population is undetermined. Two rounds of questionnaires were distributed – in April and October of 2017.

Table 2. Channels for approaching the survey target groups and collecting the results

Target group	Target group contacted via
Workers (W)	Companies/institutions directly Companies' work environment specialists OHS thematic internet sites/portals
Working environment specialists (S)	Companies/institutions directly Ministry of Social Affairs OHS thematic internet sites/portals
Occupational health doctors (D)	Occupational health care service providers (clinics, hospitals etc.) The Society of Occupational Health Doctors Ministry of Social Affairs OHS thematic internet sites/portals
Labour inspectors (I)	Labour inspectorate OHS thematic internet sites/portals

Source: authors' data.

Depending on the information sought, the questions were presented either with a Likert scale (1–5) or as general questions (yes/no). The latter was applied where factual information was mostly sought about whether certain safety measures had been implemented in the company. The questions were grouped in categories and analysed by averaging the value given by the respondent. The average values were on the scale of 0–1. Hence, each category represents a variable, the combination of which was used to conduct a bivariate correlation analysis. Workers and work environment specialists were grouped together to reflect the EMF safety situation in the companies.

4.3. Statistical Analysis

The data was assessed using the structured questionnaire approach, and sent to an online depository. Scores as averages for question groups were calculated based on the structure as presented in Table 1. The description of the sample is presented in Table 1. A Pearson product-moment correlation coefficient was conducted to evaluate the relationship between the EMF safety variables using SPSS 21.0. To test the differences of the subgroup means, an independent samples t-test was performed. In addition, the assumption of homogeneity of variances were tested using Levene's *F* test, where $p<0.05$ was considered statistically significant.

4.4. Sample

This questionnaire survey was conducted in Estonia. A total of 190 responses were collected from stakeholders. Table 3 presents basic descriptive statistics on the target groups.

Table 3. Descriptive statistics classified per respondent group

	Stakeholder group				All groups (average)
	Workers (W)	Work environment specialists (S)	Occupational health doctors (D)	Labour inspectors (I)	
Number of respondents	113	39	21	17	190
Age average/min/max age (y)	43/18/78	41/27/70	56/38/77	48/24/69	45/15/78
Professional tenure average/ min/max (y)	15/1/45	8/1/28	14/2/45	11/1/25	18/1/45
Gender male/female/unknown	41/46/26	15/24/0	5/16/0	6/11/0	67/97/26

Source: authors' calculations

5. Results

EMF safety component scores are presented in Table 4. Safety training for workers was assessed by all stakeholders, whereas workers themselves also assessed their EMF safety awareness and perception.

Table 4. Assessed score (0–1) of EMF safety management components as assessed by the stakeholder subgroups (mean values of subgroups)

code	Variable	Stakeholder group			
		Workers (W)	Work environment specialists (S)	Occupational health doctors (D)	Labour inspectors (I)
A	Workers EMF safety awareness and training	0.42	0.45	0.50	0.38
B	Compliance of companies in terms of EMF safety	0.09	0.33	NA	0.20
C	EMF safety arrangement of strong EMF workplaces	0.19	0.45	NA	0.21
E	Knowledge of EMF propagation and safety principles (health effects)	NA	0.44	0.63	0.57
D	EMF safety arrangement for risk groups	0.50	0.65	NA	NA

Notes: NA – not asked; Source: authors' calculations.

The assessment of (A) Workers EMF safety awareness and training by all subgroups, including the workers themselves, showed no statistical significance between the workers with respect to work environment specialists $t(104) = -.72$, $p = .472$, occupational health doctors $t(88) = -1.78$, $p = .079$ and labour inspectors $t(83) = -.98$, $p = .328$.

A large discrepancy can be seen between workers and work environment specialists assessing (B) Compliance of the companies in terms of EMF safety. The independent samples t-test was associated with a statistically significant effect, $t(44) = -3.20$, $p = .003$. This could indicate that workers do not perceive the EMF safety as the work environment specialists claim or intend. However, the mean scores for EMF safety compliance of the companies was not statistically significantly different between the working environment specialists and the labour inspectors, $t(42) = 1.75$, $p = .088$.

(C) Workplaces with high exposure to EMFs were addressed with a dedicated set of questions. The same discrepancy is also detected here, where work environment specialists report the safety arrangement to be more than twice as good as that perceived by the workers. The independent samples t-test was associated with a statistically significant effect, $t(49) = 2.44$, $p = .018$. The score given by labour inspectors supports the workers point of view by being statistically significantly different from the work environment specialists' mean score, $t(24) = 2.38$, $p = .026$.

(E) Knowledge of EMF propagation and safety principles was explored among the work environment specialists and labour inspectors, while a similar question about EMF health effects was asked of the occupational health doctors. The mean scores for the work inspectors and occupational health doctors were relatively high – this can be explained as both groups had EMF safety training organised by the government. As these subgroups were measured using a different set of questions corresponding to their specialist field, the statistical significance is not tested here.

(D) Meeting the needs of the risk groups was reported by the work environment specialists as being higher than the workers. However, the mean scores of these two subgroups are not statistically significantly different, $t(41) = 1.14$, $p = .261$.

Only 8 per cent of the workers reported themselves as belonging to one (or several) risk groups. Five per cent of the workers belonged both to a risk group and those who reported having high EMF workplaces at their company. Only a third of these workers reported having had attention paid to their condition in regard to the high EMFs present at the company. In addition, workers belonging to the risk groups did not exhibit any better knowledge in regard to EMF knowledge (score 0.30 out of 1) (Workers EMF safety awareness and training) than the rest of the sample. Although the size (N=9) of the subsample (workers affiliated with risk groups) is small, this may indicate that little attention is paid to training members of this group about electromagnetic fields and safe work practices at such workplaces.

A correlation analysis is presented in Table 5, to describe EMF safety management in companies, based on the workers and work environment specialists subgroup.

Table 5. Correlations between EMF safety variables: subgroup, workers and work environment specialists (N=152).

	AG	PT	CS	AW	A	B	C	D	E
AG	1								
PT	.671**	1							
CS	-.072	-.258**	1						
AW	.049	-.025	-.043	1					
A	.036	-.009	.054	.692**	1				
B	-.021	-.210	.220	.661**	.493**	1			
C	.057	-.142	.341*	.142	.381**	.824**	1		
D	.023	-.229	.007	.084	.270	.479**	.541**	1	
E	-.142	-.233	.023	.646**	.869**	.702**	.472	.409	1

Notes: * Correlation is significant at the 0.05 level; ** Correlation is significant at the 0.01 level;
Source: authors' calculations.
AG – age; PT – professional tenure; CS – company size; AW – awareness of strong EMFs at the company's workplace; A – workers EMF safety training; B – company's EMF safety compliance: C – EMF safety arrangement of strong EMF workplaces; D – EMF safety arrangement for the risk groups; E – Knowledge of EMF propagation and safety principles.

The analysis reveals the key factors influencing EMF safety management in companies. First, the awareness of work environment specialists (AW) about whether their company has strong EMF producing equipment is strongly positively correlated with (B) Compliance of the company in terms of EMF safety, and (E) Knowledge of EMF propagation and safety principles. Hence, the training of work environment specialists; that is, in terms of (E) Knowledge of EMF propagation and safety principles, also correlates strongly with (B) Compliance of the company in terms of EMF safety.

A weak positive correlation was found with (CS) Company size and (C) EMF safety arrangement of strong EMF workplaces, possibly indicating that larger companies manage EMF safety issues better.

No significant correlation was found between (PT) professional tenure and the relevant EMF safety variables. The same applied to respondent's age. This could indicate that neither age nor professional tenure play a role in managing EMF safety in companies. In the example of work environment specialists, neither professional tenure or age determine (E) Knowledge of EMF propagation and safety principles. In addition, neither age or professional tenure was a predictor for being aware of strong EMF workplaces in the company (AW).

The respondent companies (responses from workers and work environment specialists) were gathered from different size companies, based on the European Commission's classification of micro, small, medium and large companies (Centre for Strategy & Evaluation Services, 2012; European Commission, 2009). The size of the company/institution and respondents affiliation:

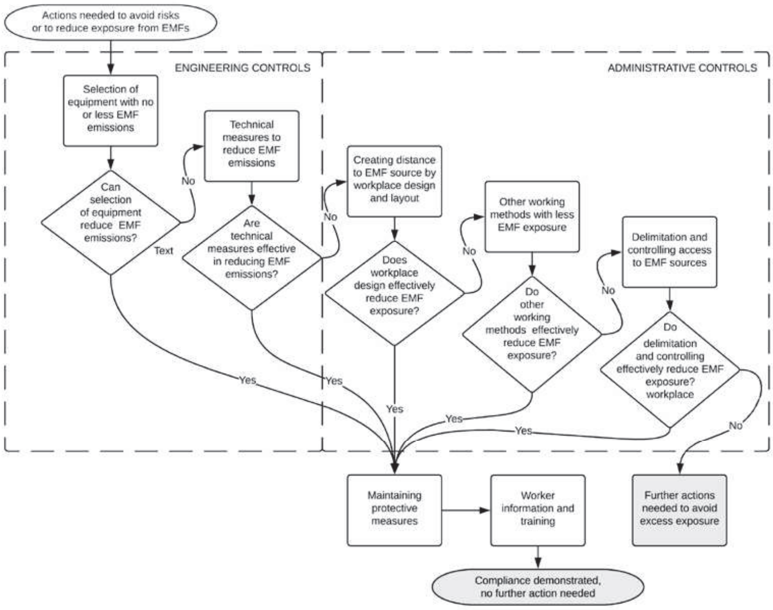
- micro (up to 9 employees) 14%,
- small (10–49 employees) 27%,
- medium (50–249 employees) 32%,
- large (over 249 employees) 27%.

In conclusion, the results of the analysis presented above showed that little attention is paid to EMF safety arrangements, and the awareness of safe practices in work concerning EMFs varies among stakeholder groups.

Following the EMF risk management guidelines set in the directive (The European Parliament and the Council, 2013) and the consequent national legislation (Vabariigi Valitsuse määrus 01.04.2016 nr 44, 2016), the author proposes an operational model of measures to reduce EMFs (figure 3). The model depicts hierarchically the activities presented in order of preferred implementation. The philosophy of the model follows general occupational safety principles, collective protection, where measures that benefit most of the workers should be preferred, such as established in the EU occupational health and safety framework directive, by which collective protective measures should be given priority over individual protective measures (Article 6, p.1) (The Council of the European Communities, 1989a). This prescribes trying first to eliminate the risk at the source. General measures should be preferred to localized measures. The aim of the process is to achieve a proper level of safety and to demonstrate compliance with the legislative requirements and good practice.

The model prescribes first selecting equipment that radiates less EMFs. Alternative technologies and equipment that produce less EMFs could solve this issue. However, changing equipment may not always be practicable. Sometimes this requires replacing the entire process and results in significant investments in new technical machinery.

Figure 3. Operational model of measures to reduce EMFs



In cases where emissions from the equipment are a necessary part of the work process, other technical measures should be implemented that reduce EMF emissions at the source. Shielding is most often used to control emissions from the equipment. A shield could be included by the manufacturer of the equipment or devised later by the employer. Shielding requires a frequency dependent approach and may not always achieve acceptable results, especially at low frequencies. Technical measures could include guarding. This could include interlocks and other automated technical means to cut the power from radiating equipment which otherwise would expose the worker to high levels of EMF in close proximity. Other technical measures could include human presence detection systems, such as light curtains, pressure mats etc. Two hand control devices and emergency stop buttons could be implemented where applicable. Technical measures should be preferred to administrative measures, as these could potentially remove the high exposure risk and in general provide a higher level of safety to all workers. The employer should employ specialists, as technical measures require an in-depth understanding of EMF propagation principles.

If the aforementioned engineering controls are inefficient or not applicable, the employer should turn to administrative control measures. To control employee exposure, first, creating distance in between the worker and the radiating equipment should be tried. The exposure levels decrease drastically when moving away from the source. If distancing does not produce satisfactory results or is not applicable, other working measures should be implemented. This could mean reducing the time the worker spends next to the radiating equipment, hence lowering the high exposure time. Rearrangement of work procedures, repositioning equipment, redesigning the work environment could all be done to remove the worker from highly exposed areas. The last administrative measure is to limit worker access to the highly exposed work areas. The employer could also close access to rooms and areas where high exposure conditions occur. The risk assessment should critically evaluate the workers' access to EMF high exposure areas – is there an immediate need for human presence in the area during the operation of the equipment. All unnecessary personnel should be removed from access and hence grant them protection.

The employer should pay attention to documenting administrative measures and providing proper supervision over the implementation of the measures. The workers should be trained on the implemented measures, including both the intermediate staff at the site, but also other workers and groups that could enter the high exposure areas. These groups could involve firefighting personnel, premises maintenance crews, security personnel etc.

EMF reduction measures are more easily implemented in designing the workstation and work areas. The cost could be significantly higher in subsequent stages of business operations. The elimination of EMF high exposure should be the employer's goal. The EMF safety management system should encompass EMF reduction principles that involve more than one measure, covering technology, work procedures and human factors.

6. Discussion and Conclusions

A questionnaire-based study was conducted that indicated the perception of EMF safety, depending on the position of various stakeholders. The results show that contributing to safety education for both workers and work environment specialists has a positive effect on safety compliance and other related safety issues within the company; thereby, helping the organisation to demonstrate fulfilment of legislative requirements.

Despite some exceptions, the overall results indicate that compared to legislative expectations, little attention is still paid to training workers about electromagnetic fields as a work environment risk factor in terms of: how these fields are created; how to identify overexposure to EMFs; what are the safe practices when working near high EMFs, and so on. Work environment specialists exhibited better knowledge of EMF safety arrangements compared to workers, but the overall result is still too poor to bring the legislation into practice.

The shortcomings are characteristic of all companies, but are somewhat less evident in large companies. Considering the requirements of the new EMF legislation, in order for companies to achieve and demonstrate their compliance, we suggest that appropriate training programmes for work environment specialists and workers be implemented.

A discrepancy could be found in several issues according to responses from workers or work environment specialists. For example, work environment specialists reported better management of risks (than did workers) at high EMF workplaces and also in reckoning the needs of workers in risk groups. This inconsistency could be explained by a failure in the safety management procedures and training programmes; in other words, what is written on paper does not necessarily exist in practice.

According to a recent database search, there seems to be no similar research regarding EMFs, and therefore the results cannot be compared to previous relevant literature. Although there were no specific EMF safety studies that could be compared to the results of the current study, such findings might be in line with other occupational health and safety studies, where an association between worker representation and good practice is made. The European study of worker representation and consultation on health and safety found that worker representation in developing safe working methods was more present in larger organisations, the public sector, organisations with older workers, and in workplaces where health and safety and the views of workers are seen as a priority (Stolk et al., 2012). The primary finding of the mentioned study was that the involvement of workers indeed plays a significant role in ensuring that new occupational health and safety policies and action plans are successfully implemented in practice. The same study from a period two years earlier had similar findings (González et al., 2010).

The crucial factor in implementing new occupational health and safety rules is the use of worker representatives. Additional occupational health and safety tasks, next to their regular work, require them to work extra hours. The European Trade Union Confederation sees the issue as a priority, so that the worker representatives get the needed support not only from the employers, but also other workers and trade unions (European Agency for Safety and Health at Work, 2012).

The findings of this study are in line with Järvis et al. (2016), who examined the differences between formal safety and real safety. Like Järvis et al., who determined shortcomings in real safety compared to formal safety, the current study has also indicated a discrepancy in the EMF safety score between responses from the work environment specialists and workers (Järvis et al., 2016).

The implication in light of the current study may be expressed formally that safety is organised and safety management systems include the risks from EMFs; however, as pointed out by Cooklin et al. (2017), effective work interventions are mostly those aimed at improving employee physical or mental health, whereas integrated interventions targeting occupational health and safety management with injury prevention or organisational cost savings are less effective (Cooklin et al., 2017).

An important factor in assessing worker exposure to EMFs is the availability of relevant exposure data, corresponding to the workplace and the job. Stam (2014) investigated the exposure levels at different workplaces with respect to the new EU directive (2013/35/EU). She found measures set by the directive could be complicated, as there is a scarcity of different workplace scenarios with EMF exposure and guidance on good practices (Stam, 2014).

One limitation of this study could be in regard to whether the sample is representative according to occupational exposure. Typically, there is considerable variation in exposure between companies, but also from workplace to workplace within the same company. Similar large-scale studies in the future should combine in-situ measurements with the same questionnaire design, shedding more light on the mechanisms of EMF safety management in strong EMF workplaces, and also companies in general.

Due to subgroup-specific means of delivering the invitations to participate in the study and anonymous participation, the authors could not send reminders to the subgroups or ask for additional information if needed. Due to the selected method of distributing the questionnaire, the response rate could not be determined in a valid manner. There was no list of people affiliated with subgroups (i.e. workers, work environment specialists); therefore, the overall number of these subgroups could not have been determined and the response rate assessed. The subgroups had to be reached by different means; the information on how representative the subgroups turned out to be is not available. However, it is less likely that the results are biased according to non-representative groups because there is a clear difference between the scores of different subgroups.

The findings of this study highlight relevant EMF safety components in the process of adapting to the new EMF safety requirements. Similarly, new EMF guidelines could be better implemented in construction, mining, health and social work industries, as occupational health and safety arrangements are already best in these domains compared to others, according to the European Survey of Enterprises on New and Emerging Risks (Stolk et al., 2012). In implementing the new requirements, the EMF safety system should be integrated into the general safety management system of each company. By doing so the companies would be able to benefit from a fully functioning EMF safety system, within the meaning of the new EMF legislation.

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Reducing exposure to extremely low frequency electromagnetic fields from portable computers

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Abstract. The relevance of this article can be described by the rapid development in computer technology which has resulted in widespread use of laptop computers. Consequently the population is now more exposed to the electromagnetic fields, emanating from such devices. The aim of this article is to test various intervention measures which would help to reduce the exposure. The authors focus only on the measures easily applicable by the general public. The effectiveness of the interventions is measured by reduced electric and magnetic field. This study focuses on the electromagnetic fields in the range of 50Hz to 400kHz. The importance of minimizing exposure to the electromagnetic fields is also stressed by the high level European bodies. Reduction of environmental risk factors, where possible, is in fact the corner stone of European occupational health legislation. The measurements are conducted using a novel 14-point model, covering the entire body of the user. Measurements from 46 laptop computer workplaces provided data about 156 unique exposure instances. The measurement results show that the least exposure scenario comprises of a laptop computer working on battery, having external input devices and display, the casing of the computer being properly grounded and power wires and adapters are positioned away from the user's body.

Keywords: electromagnetic fields, ELF, extremely low frequency, computer, laptop

INTRODUCTION

In this study, laptop personal computers (PCs) are in the focus from the aspect of electromagnetic fields (EMFs). Laptop computers produce a wide range of electromagnetic fields. The main source for EMFs from laptop PC's are 1) low and intermediate frequencies from power processing both inside (mainboard) and outside (power adapter) and 2) radio frequencies from wireless data transmission. This study deals with electromagnetic fields at the lower end of the spectrum, within a range from 50Hz to 400kHz. This encompasses extremely low frequencies (ELF), ultra-low frequencies (ULF), very low frequencies (VLF), low frequencies (LF) and some of medium frequencies as classified by the International Telecommunications Union (ITU)(ITU, 2005). This bandwidth was selected as, with the exception of radiofrequency fields, most all other electromagnetic emissions from mobile PC lay within that range. This study does not deal with EMF radiation utilized by PCs for wireless data transmissions (WLAN, 3G/4G etc.).

In this study different exposure scenarios were investigated, intervention measures applied and their efficiency measured. The selection criteria for intervention measures was based on easy applicability by PC users.

The relevance of the subject is prescribed firstly by the exponentially increased use of mobile computing devices in the past years, which in turn have increased the levels of EMFs in the working and learning environments.

The relevance can also be described, as the public is increasingly interested in reducing their exposure to the EMFs in everyday life. The danger from EMFs below the currently effective safety limits still remains debatable. The general precautionary principle, used in occupational and public health, however requires to reduce environmental risk factors to as low as possible. Therefore this study provides solutions on how to reduce electromagnetic fields from laptop computer use, and at the same time retain the functionality of a PC as a working and learning device.

Laptop computers, like any other electrical consumer products, must comply with the standards of electromagnetic compatibility which in turn would automatically ensure the compliance with the legal safety limits for the EMFs. Therefore it is highly unlikely that a modern PC would produce levels above of such safety limits.

However, as new data from dosimetric and clinical studies suggests, there may be other biological mechanisms induced by the electromagnetic fields that are currently unaccounted for in the safety limits (Bioinitiative report, 2007 and 2012).

Although these newly proposed health implications cannot be unnoticed, a great uncertainty still exists amongst the scientific community. New biological effects are yet not well known and therefore there is a problem with replicating many of such studies. Also, it remains unclear, if the mentioned biological effects also have health consequences. Reports ordered by the EU have concluded: there is limited or inadequate evidence for such new effects (EFHRAN, 2010). The main aim of the legally established safety limits is to protect the public and workforce from levels of electromagnetic fields that are known to cause adverse health effects (EP, 1999; EP&EC, 2004 and 2013; ICNIRP, 1998).

Therefore, the lawmakers have not yet hastened to lower the safety limits but suggested the public and working people to follow a precautionary approach, until the science has made it more clear, what levels can be considered as harmful (EEA, 2007). The precautionary principle is voluntary in nature and prescribes that electromagnetic fields should be reduced to as low as reasonably possible. Also the current safety guidelines refer that the obligation of the employer is not only to assure the workplace's compliance with the limits but also to ensure that EMFs are reduced to the minimum. Special risk groups should also be considered – pregnant women and people wearing passive or active medical implants (EP&EC, 2013).

Whereas this study mainly deals with laptop PCs in office workplaces, there are many other places where people in work or in public are exposed to the EMFs. An international study done in several European countries, monitored peoples overall exposure to the EMFs, and it was found that the highest exposures were encountered in transportation vehicles (e.g. people using mobile devices simultaneously in a closed metal casket), followed by exposure in outdoor urban environments (wireless transmission antennas), and then in offices, followed by urban homes (Wout et al, 2010).

Modern office environment consists of a many EMF propagating appliances: some produce EMFs as a by-product (e.g. ELF EMFs from a PC); others use EMFs intentionally (e.g. wireless data link). Many of such types of products are new and not fully covered by compliance standards, therefore may create exposures to the EMFs that are currently unaccounted for in the guidelines (Kühn et al, 2007).

In the area of ELF and VLF EMFs, less research has been done in regard to mobile computers than in the domain of radiofrequencies. Whereas radiofrequencies in the portable PCs are created intentionally – to establish wireless data transmission link, low frequency EMFs can be considered as a side product of the operation of the PC. Computer components such as power supply modules, mainboard, video card, display, etc. all process signals and consume power which also generate electric and magnetic fields (MF) in the ELF and VLF range. Whereas the emanating magnetic field mostly depends on the processed electrical current, the strength of the electric field radiation is determined by the design and application of the portable PC. If the circuits and wires are enclosed in a shield and the casing is grounded, then the electric field values may be very low. Therefore, given that the laptop computers are with proper metal casing, the main factor determining the strength of the electric fields should be whether the casing is grounded or not (figure 1).

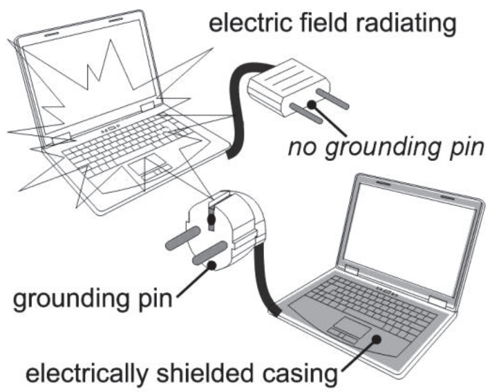

Figure 1. Plug type CEE 7/16 (left) is lack of the grounding pin, whereas plug type CEE 7/7 can ground the PC casing. Source: authors' drawing.

Frequencies of the electromagnetic fields produced by the laptop computers also vary from model to model. Besides typical sinusoidal waveforms, the EMFs have also an impulsive nature forming a complex waveform (Zopetti et al, 2011). Switching mode power supplies should be considered as main contributors to the impulse EMFs in the PC usage. A study by Zopetti et al (2011) concluded that power supply units are the main source of high EMFs (Zopetti et al, 2011).

Bellieni et al (2012) reported that next to the power supply unit, also the laptop PC's body itself (being in contact with a human body) gives off nearly the same levels of EMFs, and these can be higher than these found in the proximity of high tension power lines, transformers and domestic video screens (Bellieni, 2012).

The authors utilize a recently developed 14-point measurement protocol and a format of graphical representation, allowing easy understanding of the measurement results, by those not accustomed to the EMF issues. Unlike in some measurement protocols, where only one (maximum) reading is recorded from the worker's body position, this newly developed protocol provides better exposure assessment, picturing a detailed view of exposure levels in different body regions.

The aim of the paper is to identify high and low exposure scenarios, where various set ups of laptop computers, (including wiring) produce different exposure levels to the electromagnetic fields. This study is set to test the effectiveness of several intervention measures in actual office work environments. The results provide recommendations on how to use mobile computing devices by minimizing user's exposure to the EMFs.

A long term perspective of this study is to produce results that can be utilized in drawing up PC usage exposure assessment model. Such model is to use self-reported data (a questionnaire) of usage of electrical appliances and assess the exposure to various ranges of EMFs.

MATERIALS AND METHODS

In the ELF and VLF range of the electromagnetic spectrum, field strength measurements were conducted for both electric and magnetic fields. We investigated four factors that typically affect the exposure levels from laptop PC use in office environments: 1) battery or external power, 2) internal or external keyboard/mouse, 3) internal or external display 4) grounded or ungrounded casing and 5) distance to peripheral electrical wires and power adapter. Based on the combination of these determinants, tens of practically possible exposure scenarios could be deduced. Most common scenarios were selected for this study, as presented in table 1.

Each of the exposure scenarios required a separate EMF measurement run. Scenario A, i.e. a PC setup without any intervention was studied first. A special wall socket plug was used to connect the laptop PC to external power without establishing a grounding connection for the PC casing. This would ensure comparable results for all PCs under testing, since some establish grounding via power supply unit. Secondly, intervention measures were tested independently from each other – only one determinant was changed (scenarios AG, AK, AW). Then, different combinations of interventions were tested. The authors selected the combinations that were most often used in practice.

Table 1. EMF exposure and intervention scenarios investigated in this study.

Power source	Casing grounded	Ext.keyboard, mouse	Ext. monitor	Peripheral wiring, adapter
A	-	-	-	-
A	G	-	-	-
A	-	K	-	-
A	-	-	-	W
B	-	-	-	W
A	G	K	-	W
B	G	K	-	W
B	G	K	M	W

Abbreviations: A on external power source; B on battery power; K on external keyboard (otherwise on internal keyboard); M on external monitor (otherwise on internal monitor); G casing grounded (otherwise ungrounded); W wires routed away from body; (-) no intervention, which in case of 'peripheral wiring' means that power wires and/or adapters are right next to the body.

This study was set to investigate above mentioned exposure scenarios in actual work environments. Each workplace is unique by its laptop, peripheral devices and other inventory that makes up the overall electromagnetic field that the user is exposed to. While lab measurements are useful in determining the absolute exposure values and intervention effectiveness, the aim of the authors was to provide an overview of actual EMF levels present at places where office staff work daily. This allows encompassing also ambient EMFs, which are necessary to take into account when assessing the end result of an intervention. Perfect application of interventions can be achieved in the lab, but actual office environments are often confined by neighboring desks, preset wiring etc. that are likely to hinder the intervention outcome.

Figure 2 describes exposure scenario A – laptop powered from a wall socket. This occurs most often when working with laptop PCs. Intervention BW would mean switching from external power (wall socket) to battery power. This would also remove the power adapter from the scene and create distance to any power wires.

Another intervention scenario, where external power is retained, would remove the power adapter and wires from beneath and next to the worker's feet (scenario AW). This means rerouting the adapter and wires to create maximum distance to them (usually 0.7 to 1.5m).

Another intervention to increase user's distance to the EMF source (the PC), is using external keyboard and mouse (K). Also, connecting an external display unit to the laptop PC could result in additional distance (M). However, since external displays are also powered from the wall socket, secondary EMF source will be introduced into the scene.

Another way to reduce electric fields from the laptop PC, is to see that the casing is properly shielded and grounded (G). To make sure the shielding is adequate, in this study grounding was applied by two means: 1) connecting a grounding cable into laptop's USB-port's (Universal Serial Bus) grounding pin and 2) connecting power adapter's wall plug's third pin to ground (if applicable).

A new 14-point model of a human body (developed by Koppel) was used to conduct the measurements – altogether 14 points, distributed across the body, were measured for both electric and magnetic field (Fig.2)(Koppel & Tasa, 2013). Unlike most workplace exposure measurements, where often only one reading is produced, encompassing 14 points, allows recording detailed readings. This in turn gives an overview of the exposure situation and to determine, which body regions are most exposed to the EMFs. Therefore intervention measures can be directed more efficiently.

The 14p model is based on a sitting PC user, since the office personnel mostly spend their day behind the desk. On each of the 14 points, EMF meter was directed into different directions to obtain the strongest field reading. By going through the 14−point model, the whole body area was scanned The PC was set into operating mode, without any active software operations. The portable computers were on a chipboard office table. In case of power adapter and wires being positioned right at the worker's feet, point no 9 reading was taken right at the adapter/wires. Similarly point no 14 (the palms) reading was taken by scanning the PC casing for the highest field value. Therefore points no 9 and 14 represent the highest possible exposure point for the palms and the feet.

An average exposure was calculated based on the 14 points for each intervention. The results were grouped based on intervention scenarios. For each group average, maximum and minimum sets were determined, e.g. maximum of group A would indicate a PC that produced a highest average exposure across 14 points, in that group.

The equipment used for conducting the measurements, consisted of a low-medium frequency analyser ME3951A from Gigahertz Solutions, with a frequency span from 5Hz to 400kHz. Readings were taken in RMS (root mean square) values.

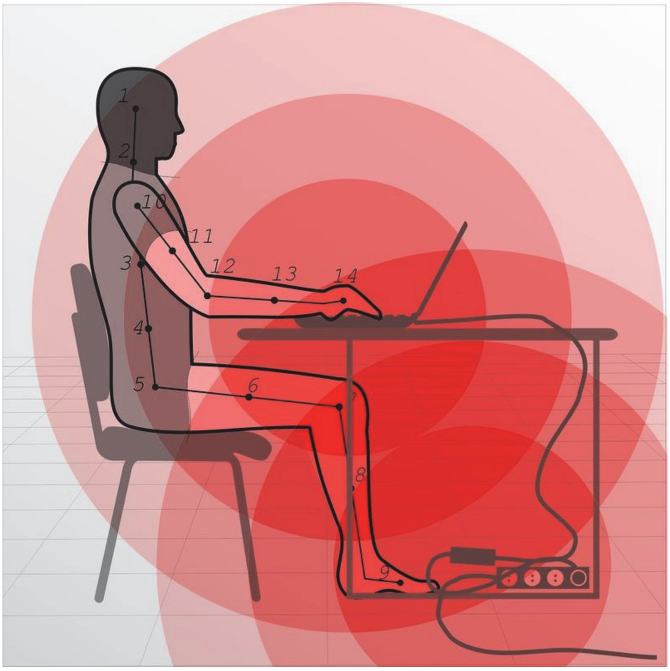

Figure 2. 14-point measurement model used in this study (Koppel), with exposure scenario A.

RESULTS

Altogether 156 unique exposure instances were investigated, each resulting in 14 readings for both electric and magnetic field (the entire sample consisted of 4368 manually taken readings). Measurements were taken in office environments from 46 laptop PC setups.

Figure 3 presents average, minimum and maximum values, classified per exposure scenario across the sample.

As this study conducted measurements for both electric and magnetic field, different propagation ways for these separate aspects of the electromagnetic field must also be taken into account when analyzing the results.

The highest exposure levels were characteristic to scenario A where no intervention was applied: 1) the laptop PC was connected to the wall socket, 2) using internal input devices (keyboard and mouse), 3) using internal monitor, 4) having an ungrounded casing and 5) with wires and power supply unit loosely positioned next to the user's body. For illustration purposes a PC was selected from the sample, that produced average field levels as compared to the rest of the sample, both in pre and post intervention measurements. Figure 4 pictures a scenario A (no intervention) measurement for that PC.

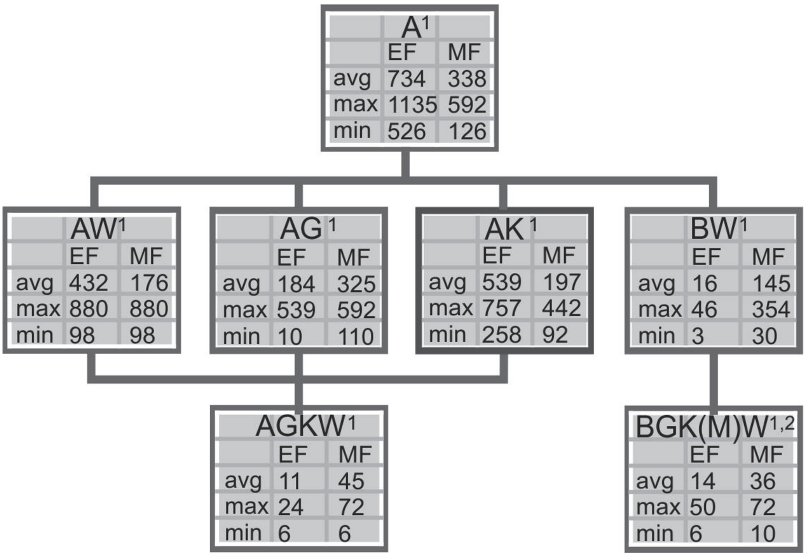

Figure 3. The effectiveness of various intervention scenarios, expressed as average (avg), maximum (max) and minimum (min) values for each intervention group's electric field (EF; V/m) and magnetic field (MF; nT); 1 see table 1 for scenario descriptions; 2 scenarios BGKW and BGKMW presented as one group due to their similarity in results.

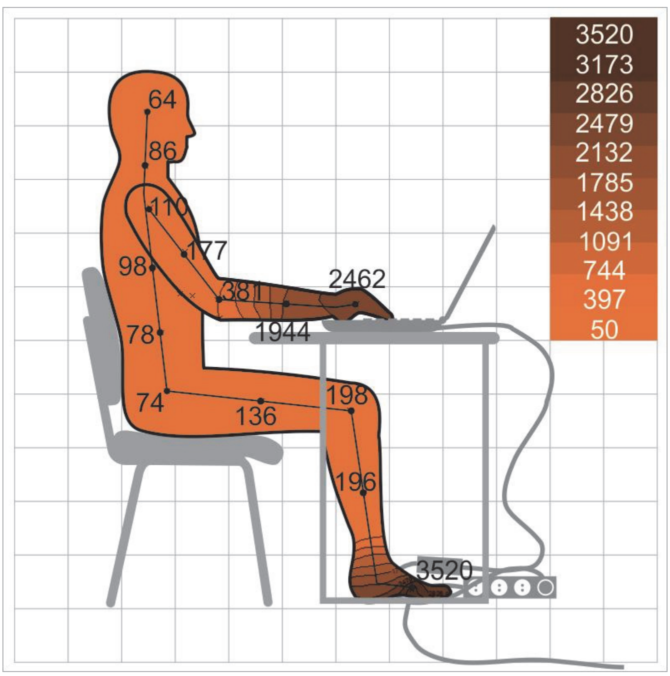

Figure 4. Scenario A for a selected PC, which represents typical field strength values for a computer without any intervention. Electric field values in V/m.

Figure 5 represents field strength values for the same PC when intervention scenario AGKW was implemented. The electric field strength as averaged over the body had decreased from 680V/m (scenario A) to 9V/m (scenario AGKV).

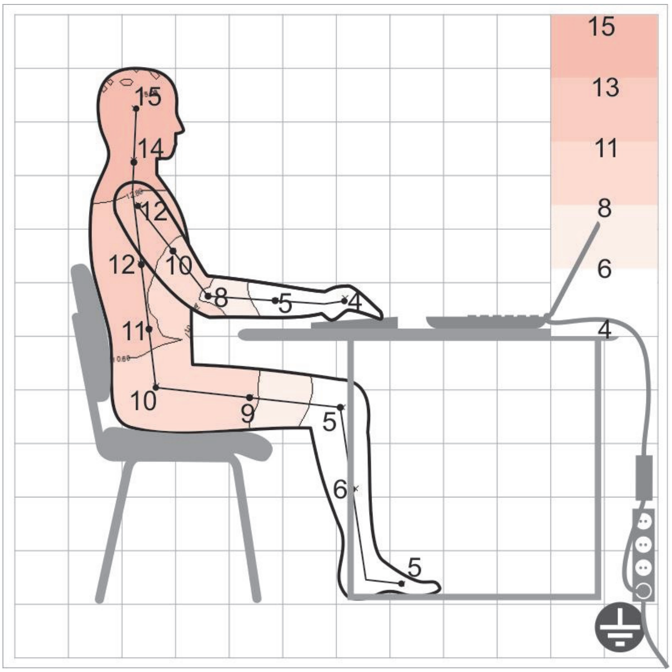

Figure 5. Scenario AGKV for the same selected PC, with typical field strength values for that intervention class. Electric field in V/m.

The first level intervention included testing each intervention measure separately (AW, AG and AK). Measurements indicated large variations in exposure levels across the sample. Any of the investigated four factors was seen to have a significant impact on overall exposure formation, but eventually did not produce satisfactory results alone itself.

Grounding the computer (AG) would somewhat reduce the electric field, but magnetic field remains unaffected due to the differences in propagation of these two fields.

Weakest electric fields we measured at the business class laptop PC's with an extra outer metal casing and with PC's casing properly connected to ground. Contrariwise, high E-filed levels were detected where the PC was lacking ground connection for casing. Such exposure scenarios are encountered in daily life where power plug lacks the third (casing grounding) connector (see figure 1) and if ground also cannot be established via external display unit or other peripheral device connected to ground.

Positioning of the PC's power adapter (AW) was also seen to largely increase the exposure levels. Often the adapters together with the wires were lying loosely on the floor, right next to or below the user's feet. Other peripheral wires, such as extension cords, while placed in close proximity of the user's body, were also measured to abruptly raise the exposure levels.

The usage of external keyboard and mouse (AK), was also seen to greatly affect the maximum exposure level. This can be explained by the user's increased distance to the PC if external input devices are used.

First significant reduction in electric field was noticed, when the laptop PC was on battery power and peripheral wires positioned away from the user's body (BW). Some PC models were seen to be unaffected irrespectively whether the PC was powered from the wall socket or from the battery. Whereas other models produced many folds greater exposure in electric field when connected to external power (AC). This is mainly to do with the PC mainboard's power module design, but also to do with the quality of switching power supply unit – whether the power adapter was equipped with adequate noise suppression filters or not.

Significant reduction of both electric and magnetic field could only be seen when multiple interventions were implemented simultaneously i.e. scenarios AGKW and BGK(M)W. Although BGK(M)W has a slightly lower magnetic field and AGKW with a bit lower electric field (see Fig.3), the difference is marginal. Both scenarios produced satisfactory results and could be therefore recommended to the general public.

Involvement of external display unit, did not allow any significant change in EMF exposure, than using laptop PC's internal display. Although using an external display would allow placing the PC unit further away from the body, the external display unit also contains a live circuit itself which radiates EMFs.

The most exposed body parts were the user's hands and feet. Almost in all cases significant reduction in exposure could be achieved by utilizing external input devices (keyboard and mouse), since using the PC's internal input devices, places the user in close contact with the PC mainboard. Elevated exposure of the feet was encountered every time when the PC's power supply unit and/or peripheral power wires were arranged loosely, close to the user's body (most often the feet). The weakest exposure levels were detected in points 1 and 2 representing the head and neck.

CONCLUSIONS

This study has indicated that the user of a mobile PC can extensively control his/her exposure to the EMFs, without any significant extra effort or investment. Simple rearrangement of devices and adoption of new usage habits can reduce exposure to the EMFs even by factors of scale. Interventions, applied by this study, can broadly be divided to measures that reduce exposure by 1) increasing the distance to the EMF source, 2) shielding the EMF source and 3) using alternative power supply modes.

It was found that not all laptop PCs submit to interventions similarly. This is due to the PC design e.g. casing. Exposure levels are also dependent on the quality of accompanying power supply units. Some, cheap looking power adapters were seen to produce elevated levels of EMFs, both from the adapter itself, the power cable and consequently the PC unit. Few, good quality power adapters were equipped with a third wire for a casing ground – this effectively shielded the adapter, the power wire and the PC casing. Quality and design of a PC casing was also seen to be a determinant in how much electrical field was propagated out from the enclosure. The design of the PC also determines which parts of the PC radiate the most EMFs and whether the user is to be in close contact with these.

The overall conclusion - in order to effectively reduce the exposure levels, one should apply a combination of various intervention measures. Applying just one, may reduce some aspects of EMFs and/or reduce exposure only from a certain body area. The best reduction of EMFs was achieved when at least three intervention measures were applied: the whole body average exposure to the magnetic field was lowered by 89% (scenario BGKMW) and to the electric field by 99% (scenario AGKW).

As a general rule, the more distance were created between the user and the portable PC, the weaker the EMFs got. External input devices (mouse, keyboard) and output devices (monitor), together with rearrangement of power cords, can be viewed as means to create greater distance to the PC. The usage of such peripheral devices at the same time retains the full functionality of the PC or even improves it: 1) utilizing ergonomic mouse and keyboard alleviates ergonomic issues and allows better control of the cursor, 2) larger display reduces eye strain while images become larger and text more clear to read.

The results of this article are applicable for the general public, where users of mobile PC's seek to reduce the exposure to the EMFs. This study provides several ways, on how to reduce the EMF levels and to avoid excess exposure. However, the effectiveness of intervention measures should always be tested. As found in some instances in this study, some USB-sockets' grounding pin did not produce an effective grounding effect, whereas using other USB-port on the same computer achieved a good result. Also the power adapters may lack the third (grounding) pin or be of faulty design or working order.

DISCUSSION

The results of this study are in line with the work of Ekman et al (2012), who also concluded a wide variation in the strengths of the electric field: the mean electric field of a PC was measured to lie between 10 and 678 V/m, with the maximum detected field of 1050 V/m. For the PCs with high electric field, the underlying cause was the lack of grounding for the PCs casing (Ekman et al, 2012). The PCs with proper grounding were having electrical field strength tens of times lower. The main determinant was seen to be the power adapter unit, where some models were lacking a third pin for casing ground (Ekman et al, 2012).

This study found the strongest exposure to the MF to occur in point no 14 (the palms) and in point no 9 (the feet). Similar results were measured by Zopetti et al (2011) and their follow up study by Bellieni et al (2012), where magnetic field right at the power supply units was measured to be the strongest of the setup (from .28 to 4.7 μT RMS) (Zopetti et al 2012, and Bellieni et al 2012). The authors of this study measured magnetic field at the same place (point 9 in scenario A) ranging from .30 to 3.6 μT. When analyzing the magnetic fields right at the laptop PC, Zopetti et al (2011) recorded lower values (from .55 to 1.1 μT RMS) than this study (from .2 to 5.4, averaging at 2.7 μT for scenario A at point no 14) (Zopetti et al 2012). This can be understood, as a difference in measurement setup - the height of the sensor from the object being measured. While this study scanned the computer at the height of ~1cm, Bellieni et al (2012) from a height of 5cm. Also, this study used point no 14 to measure the EMFs from on top of the laptop PC i.e. palms, Zopetti et al (2011) and Bellieni et al (2012) measured from beneath the laptop PC, where they reported getting the highest readings. Therefore, considering the difference in measurement protocols, and acknowledging the concurrence of power supply unit measurements, the results of this study provide a good representation of the EMF levels produced by modern laptop computers.

Comparing our results from laptop PCs to desktop PCs, we would conclude that there is no difference in electric field. In this study points 3 and 4 from scenario AGKW averaged in 12V/m, whereas Baltrenas et al (2011) measured at the same relative body position 12V/m in average for the desktop computers with LCD monitors and 15V/m with CRT monitors (Christiane, 2011).

Measurements of magnetic field conducted in this study, were subject to fluctuations, due to variations in electrical power demand in neighboring facilities. Ambient magnetic field also varied from site to site. Since this study was conducted in actual work environments, such influences are inevitable even during the period when one laptop PC was investigated under various interventions. Per authors' evaluation, such variations in magnetic field remained mostly within the range of 40nT and therefore do not pose a role in comparing the exposure scenarios, except the multiple intervention scenarios AGKV and BGK(M)V. With the last two scenarios the magnetic field reaching the user's body from the PC was so low that remained below the ambient magnetic field level. Meanwhile, electric field, that is mostly shielded by walls, remained constant, unaffected by neighboring activities.

In order to completely control the workers' exposure to the EMFs, attention must also be paid to the elements of the work desk and any accompanying furniture. The focus should be on the arrangement of power cables and position of metal parts of the furniture. An ordinary power cable below the desk plate (at a distance of 3mm from the worker's thigh) can produce an electric field of 40kV/m on the surface of the skin (if the person is grounded) (Van Loock, 2007). Therefore, to minimize discomfort at the office desk, one should keep away from metal parts and electric wires (Van Loock, 2007). Van Loock recommends keeping a distance of at least 30cm from the metal frame.

Complemented by authors' earlier work in the high frequency range of the EMFs (Koppel & Ahonen, 2013), the results of this study can be utilized in drawing up an exposure assessment model based on users' self-reported data (an online questionnaire). Although methodically questionnaire assessment is not as accurate as on-site measurements, a great number of people can be reached, who are interested in reducing their exposure to the EMFs. Such online-assessment model also serves as an educational tool since a vast portion of public are unaware of how the electromagnetic fields are propagated – a conclusion made by the authors after talking with the people from the workplaces. This finding is also supported by public studies which show that precaution as a way to manage EMFs has not been seen relevant for the majority of the public: they don't think about the measures (only 15% think) and they do not implement any measures (only 7% implement) (Christiane, 2011). Therefore, the authors emphasize the need to educate the public about electromagnetic fields as environmental risk factors.

With a diverse range of electrical office appliances and advancements in computer technologies, new methods of work have emerged e.g. working at distance via laptop. These developments have also brought along elevated levels of EMFs the worker today is exposed to. This paper has offered solutions on how to greatly reduce such exposure. The measures pointed out are both easy to implement and effective.

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Appendix 2

Article IV questionnaire

QUESTIONNAIRE Risk management of electromagnetic fields (combined translation from Estonian of 4 subgroups)

Thank you for coming here!

As from July 2016 a new occupational electromagnetic fields decree became into effect, which the companies are expected to comply with. How the safety actually is managed – is revealed by this questionnaire. The electromagnetic fields are propagated by all electric devices and in some instances may pose a health risk. Filling out the questionnaire, provides an overview of 1) what is expected from the safety management of electromagnetic fields and 2) what are means of reducing electromagnetic fields exposure at workplaces. The questionnaire is part of a doctoral work in order to find out how Estonian stakeholders have managed the implementation of the new decree. The questionnaire can be filled out anonymously. Your responses are only used to draw generalization and will not be forwarded to anyone outside the research group.

I'm thankful if you spend about 5 min to fill out this questionnaire. From my behalf I'm ready to answer your possible questions in this area of expertise.

Tarmo Koppel
Tallinn University of Technology
<E-mail>
<Telephone>

Notes	
	if-questions are asked only from respondents who answered Y to a specific question
1option	select 1 answer from a list e.g. (A/B/NS) select one option from two or NS-Not Sure option
checkboxes	select 1 or more answers from a list
text	text input
matrix1...5	continuous scale answer, e.g.: not at all 1 2 3 4 5 a great deal
w s d i	workers version working environments specialist version occupational health doctor version labor inspector version

(Role selection) Topic	**Questions**
OHS expert?	
Respondent classification	010 Is any of these duties applicable to you? (1option) 011 work environment specialist, occupational health and safety hygienist 012 occupational health doctor 013 work inspector 014 all others* (also workers)
1. Personal and professional background	
Sex	
(all)	101 Sex: (1option) Male, Female
Age	
(all)	102 Age: (text)
Employment mode	
(if014Y)	110 Employment (select the one where you are most likely to have occupational exposure to the electromagnetic fields) Part-time work Full time work Self-employed Homemaker Unable to work Unemployed Student Retired * you are not required to fill out the questionnaire since you have no employment status
profession	
(if014Y)	111 What is your main profession/occupation (text) (main profession means the main percentage of your time is spent in this job over the last 10 years)
professional tenure	
(if014Y)	112 How many years have you worked in that profession (question 111)? (text)
OHS prof. tenure	
(if011Yor012Y or013Y)	113 Altogether, how many years of tenure do you have in the field of occupational health and safety? (text)
affiliation to risk group	
(if014Y)	120 Are you now or have been during the time at that workplace (question 111): (checkboxes) 111 Pregnant 112 Carrying a metallic medical implant (including metallic prostheses, plates etc., but excluding dental and other smaller implants) 113 Carrying an active medical implant (defibrillator, pacemaker, nerve stimulator, insulin pump, cochlear implant etc.) 114 None of the above
2. Workplace and work operations	
(if011Yor012Yor014Y)	201 How many organizations are you employed at / provide services for
number of employees in the company	
(if011Yor014Y)	202 How many workers are there in your company/institution where you spend most of your work time? (checkboxes) up to 9

	10-49 50-249 over 249 Remark
Workplace type	
(if014Y)	203 Your workplace is mainly (select max 3) 2031 office 2032 industrial facilities 2033 servicing facilities 2034 outdoor work 2035 moving from place to place 2036 home 2037 car or other vehicle autos 2038 other
workplace type	
(if011Y)	204 Your company/institution is mainly (1option) 2041 office 2042 industry 2043 servicing 2044 other
(if011Yor012Y or013Y)	209 How well are you informed, if there are strong electromagnetic fields in the workplace(s) where you work or which you service? 2091…2095 (not aware at all 1…5 I'm well aware)
High EMF exposure company/ workplace?	
(if011Y)	210 Are any of the strong EMFs creating devices/processes utilized in your company/institution Y/N 2101 Yes 2102 No 2103 Don't know --- Strong EMF sources are found at (shortened list from Estonian version): Industry: microwave heating and drying, industrial microwave ovens, use of open magnetron, dielectric heaters, plastic sealers, induction heating, wood gluing equipment, electrolysis hall, large furnaces, aluminum production, arc welding, spot and induction welding, electrical melting, radiofrequency plasma devices, non-destructive magnetic testing, industrial magnetizers/demagnetizers, proximity of rectifiers in electrochemical processes, Medicine/Therapy: MRI, shortwave or microwave diathermy treatment, surgical diathermy, all other medical equipment using intentional radiation with EMF exposure or application of currents Communications: radio/TV broadcasting equipment, transmitters, base stations, (e.g. rooftop workers near base stations antennas), Power generation and distribution: power stations, power transformers, high voltage power lines, air cooled coils in capacitor banks, current supply systems (bus bars), Transportation: electrically driven transport: trains, trams Other: radars, radiofrequency and microwave lighting, other strong EMFs producing equipment.
High EMF exposure company/ workplace?	

(if014Y)	211 Are any of the strong EMFs creating devices utilized at … Yes No Don't know 2111 at your workstation 2112 at your workplace (company) --- Strong EMF sources are found at (shortened list from Estonian version):: Industry: microwave heating and drying, industrial microwave ovens, use of open magnetron, dielectric heaters, plastic sealers, induction heating, wood gluing equipment, electrolysis hall, large furnaces, aluminum production, arc welding, spot and induction welding, electrical melting, radiofrequency plasma devices, non-destructive magnetic testing, industrial magnetizers/demagnetizers, proximity of rectifiers in electrochemical processes, Medicine/Therapy: MRI, shortwave or microwave diathermy treatment, surgical diathermy, all other medical equipment using intentional radiation with EMF exposure or application of currents Communications: radio/TV broadcasting equipment, transmitters, base stations, (e.g. rooftop workers near base stations antennas), Power generation and distribution: power stations, power transformers, high voltage power lines, air cooled coils in capacitor banks, current supply systems (bus bars), Transportation: electrically driven transport: trains, trams Other: radars, radiofrequency and microwave lighting, other strong EMFs producing equipment.
(if014Y)	220 You can specify what type of strong EMF devices or installations you have 2201 at the vicinity of your workplace 2202 your company/institution (text)
3. EMF safety awareness and perceptions	
Danger perception	
(if014Y)	301 Do you believe that EMFs at your workplace have an adverse effect on your health (1…5)
EMF training	
(if014Y)	310 Assess the following statements (matrix1…5) 311 I'm familiar how to detect adverse health effects from the EMFs 312 I know how to report these adverse health effects 313 I know how to protect myself from the EMFs related risks 314 I'm satisfied with the EMF safety know-how, provided by the employer
EMF training	
(if011Yor012Y or013Y)	340 Assess the following statements. (matrix1…5) 341 Workers in general are familiar how to detect adverse health effects from the EMFs 342 Workers in general know how to report these adverse health effects

	343 Workers in general know how to protect themselves from the EMFs related risks 344 Workers in general are well informed and trained by the employer in regard to the EMF safety 345 Workers in general are aware if they belong to any of the electromagnetic fields' risk groups
(if 012Y)	350 Do you consider yourself to be well educated about how to detect and diagnose electromagnetic fields' induced health effects (1…5)
(if 011Y or 013Y)	351 Do you consider yourself to be well enough educated for your job about (matrix1…5) 3511 how to assess the safety of workers with regard to electromagnetic fields 3512 how to guarantee the safety of workers who belong to electromagnetic fields risk groups 3513 what type of electromagnetic fields (frequency, level, duration) are present in workplaces that I administer or assess 3514 who of the workers belong to electromagnetic fields risk groups in workplaces that I administer or assess
4. Electromagnetic fields' safety arrangement at the company/institution	
all	401 Have you heard about the new decree of 2016 set to regulate occupational exposure to the EMFs (matrix1…5)
(if011Yor014Y)	403 Have the workplaces at your company/institution been assessed based on the new 2016.y national decree on occupational exposure to the electromagnetic fields?
(if013Y)	405 By your assessment, how many of enterprises, where there are strong electromagnetic fields generating equipment ... (0…100% Likerts-10) 4051 have heard about the new decree of 2016 set to regulate occupational exposure to the electromagnetic fields 4052 have the workplaces been assessed based on the new 2016.y national decree on occupational exposure to the electromagnetic fields (LIST STRONG EMFs SOURCES)
Workers training	
(if011Yor014Y)	410 Assess the following (1option) 411 The employer has organized occupational health and safety education and training 412 EMF topics have been involved in these educations more often than once in a year once in a year less than once in a year that's not done don't know
(if014Y)and(if Y 2111)	420 Has the employer briefed you about (Y/N) 421 the risks involved with strong electromagnetic fields at your workplace? 422 safety measures on how to reduce the risks arising from strong electromagnetic fields at your workplace?
(if011Y) and(if Y 210)	425 Has the employer briefed workers that are likely to be exposed to strong EMFs about (Y/N/NS) 426 the risks involved with strong electromagnetic fields 427 safety measures on how to reduce the risks arising from strong electromagnetic fields
EMF safety measures	

(ifr014Y)	430 Have the following safety measures been implemented to reduce the exposure to the electromagnetic fields at your workplace (Y/N/NS) 431 redesigning work procedures which result in less electromagnetic fields exposure 432 rearranging workplace setup to increase distance to electromagnetic fields sources 433 Replacing work equipment which such ones that produce less electromagnetic fields 434 reducing exposure time to electromagnetic fields 435 every EMF safety issue has received proper attention
(if011Y)	440 Have the following safety measures been implemented to reduce the workers exposure to the electromagnetic fields (Y/N/NS) 441 redesigning work procedures which result in less electromagnetic fields exposure 442 rearranging workplace setup to increase distance to electromagnetic fields sources 443 Replacing work equipment which such ones that produce less electromagnetic fields 444 reducing exposure time to electromagnetic fields 445 every electromagnetic fields safety issue has received proper attention
(if014Y) and (if Y 2111)	450 Have the following safety measures been implemented to reduce the exposure to electromagnetic fields at your workplace (Y/N/NS) 451 limiting the intensity of the exposure 452 using safety locks and other technical solutions to prevent accidental exposure 453 use of shielding solutions to reduce the exposure 454 using shift work to reduce the exposure time 455 use of personal protective equipment 456 signals, labels, floor markings to control access to high electromagnetic fields exposure area 457 prevented unauthorized workers to access places with high electromagnetic fields levels
(if011Y) and (if Y 210 or Y2112)	460 Have the following safety measures been implemented to reduce the workers exposure to electromagnetic fields (Y/N/NS) 461 limiting the intensity of the exposure 462 using safety locks and other technical solutions to prevent accidental exposure 463 use of shielding solutions to reduce the exposure 464 using shift work to reduce the exposure time 465 use of personal protective equipment 466 signals, labels, floor markings to control access to high electromagnetic fields exposure area 467 prevented unauthorized workers to access places with high electromagnetic fields levels
(if013Y)	469 By your assessment, how many of enterprises, where there are strong electromagnetic fields generating equipment, have the following safety measures been implemented to reduce the workers exposure to electromagnetic fields... (0...100% Likerts-10) 4691 redesigning work procedures which result in less electromagnetic fields exposure 4692 rearranging workplace setup to increase distance to electromagnetic fields sources 4693 Replacing work equipment which such ones that produce less electromagnetic fields 4694 reducing exposure time to electromagnetic fields, e.g. using shift work

	4695 using safety locks, barriers and other technical solutions to prevent accidental exposure 4696 shielding electromagnetic fields' sources 4697 use of personal protective equipment 4698 signals, labels, floor markings to control access to high electromagnetic fields exposure area 4699 prevented unauthorized workers to access places with high electromagnetic fields levels 4701 employer has organized the work so that workers within the risk group wouldn't get into the area with strong electromagnetic fields 4702 pregnant workers have been granted the possibility to change their work into such with less electromagnetic fields HELP: Risk groups - pregnant workers, workers with medical implants e.g. pacemakers, metal plates
Consideration of EMF risk groups	
(if011Yor014Y) and (if Y 210 or Y2111 or Y2112)	471 Have the pregnant workers granted the possibility to change their work into such with less electromagnetic fields (1...5)
(if014Y)and (if Y2111 or Y2112)	472 Has the employer organized the work so that you wouldn't get into the area with strong electromagnetic fields? (Y/N/NS)
(if011Y)and (if Y 210 or Y2111 or Y2112)	473 Has the employer organized the work so that workers within the risk group wouldn't get into the area with strong electromagnetic fields? (risk groups - pregnant workers, workers with medical implants e.g. pacemakers, metal plates etc.) (Y/N/NS)
(if011Y)	474 Please assess the following (Y/N/NS) 4741 Have electromagnetic fields been addressed in company's risk assessment 4742 Have measurements of electromagnetic fields been performed as part of risk assessment 4743 Have manufacturer documentation e.g. instruction manuals used in conducting risk assessment
Inspecting	
(if013Y)	475 During your inspections, how often have you considered electromagnetic fields (not at all 1...5 very often)
(if013Y)	476 By your assessment, how many of enterprises, where there are strong electromagnetic fields generating equipment... (0...100% Likerts-10) 4761 have electromagnetic fields been addressed in company's risk assessment 4762 have measurements of electromagnetic fields been performed as part of risk assessment 4763 have manufacturer documentation e.g. instruction manuals used in conducting risk assessment
(if 012Y)	480 By your assessment, (0...100% Likerts-10) 4801 how many enterprises pay attention to electromagnetic fields' risk management 4802 how many enterprises have presented a list to the health surveillance provider of workers who are exposed to strong electromagnetic fields 4803 how many enterprises, whose workers are exposed to strong electromagnetic fields, have presented to the health surveillance provider, a data about the electromagnetic fields' characteristics from the equipment that produces such fields comment

	HELP: (list strong EMF sources)
(if 012Y)	481 Have you ever suspected or identified that a health effect on the worker could be caused by exposure to strong electromagnetic field (text)

Appendix 3

Summary of the Original Articles

Original articles	Objective	Methodology and data	Results and contribution
I Case-control study on occupational exposure to extremely low-frequency electromagnetic fields and glioma risk.	The aim was to investigate occupational exposure to the magnetic field with respect to long term health effects (brain tumors).	The exposure was assessed using a mailed questionnaire sent to each person. The questionnaire contained a number of questions relating to the overall working history, exposure to different chemicals, and other agents, smoking habits, X-ray investigations of the head and neck and heredity traits of cancer exposure was assessed by Job Exposure Matrix (JEM).	The results were based on 1346 glioma cases. The mean age of the persons was 53 years. Cumulative exposure for astrocytoma grade IV in the time window 1-14 years had an odds ratio (OR) = 1.9, 95% CI = 1.4-2.6, linear trend $p < 0.001$, and in the time window 15+ years the OR = 0.9, 95% CI=0.6-1.3, linear trend $p = 0.44$ in the highest exposure categories 2.75+ and 6.59+ µT years, respectively. **Contribution:** the article confirms an increased risk in late stage (promotion/progression) of astrocytoma grade IV for occupational ELF-EMF exposure.
II Radiofrequency radiation at Stockholm Central railway Station in Sweden and some medical aspects on public exposure to RF fields.	The aim of the study was to assess RF radiation exposure in a public transportation hub, Stockholm central railway station Sweden.	Quantitative study with in-situ measurements using the exposimeter. Spatial measurements, including mapping was performed.	In total, 1,669 readings were collected varying from 195 to 262 during each round (median 244). Total RF radiation mean exposure for a measurement round (Fig.2 and 3, article II) varied between 2,817 to 4,891 µW/m². GSM and UMTS 900 downlink contributed to most of the radiation dose. **Contribution:** the information obtained by the exposure studies allows assessing public's exposure to RF radiation and points out elevated exposure scenarios.

III Risk management of magnetic field from industrial induction heater- A case study.	The subject of this investigation is the measurement of EMF possibly launched by the production of aluminum with the induction heater system. The workers' exposure to the electro-magnetic fields was assessed by the Directive 2013/35/EU.	In this quantitative study. Several types of EMF measurements were conducted, including spatial measurements; spectrum measurements, exposimetry measurements and logging in time series.	Strong magnetic field is focused in the immediate vicinity of the induction heating system (Figure 3, article III). The main intervention strategy is to increase the distance between the induction heater set (heating coil and the control unit) and the worker. A significant decrease in the worker's exposure to the magnetic field is achieved: the accumulating dosage is only 5.2% and the time-weighted average exposure is 4.6 % of the highest exposure scenario (Table 2, article III). **Contribution:** The article provides a model for a hierarchical approach and recommendations for reducing workers' exposure to the electromagnetic field. These guidelines can also be used in training workers.
IV Safety compliance of occupational exposure to electromagnetic fields.	The study aims to determine the compliance of companies and the respective stakeholders with respect to the new EMF safety legislation. The study investigates if the corresponding new legislative requirements are	A questionnaire targeted occupational EMF stakeholders including workers, working environment specialists, occupational health doctors, and labor inspectors. A total of 190 responses were collected from stakeholders. Average scores for questions groups were calculated. A Pearson product-moment correlation coefficients were computed to evaluate the relationships between the EMF safety variables.	The results show that contributing to safety education of both the workers and the working environment specialists has positive effect of safety compliance and other related safety issues within the company. The overall results indicate that as compared to the legislative expectations, still little attention is paid on training workers about the electromagnetic fields as work environment risk factor. **Contribution:** The findings point out relevant EMF safety components in adapting to the new EMF safety requirements. The author recommends that implementation of an EMF safety system should be integrated into the general safety management system of the company.

	implemented in companies.		
A1 Reducing exposure to extremely low frequency electromagnetic fields from portable computers	The purpose of the study is to identify high and low exposure scenarios, where various set ups of laptop computers, (including wiring) produce different exposure levels to the electromagnetic fields.	Altogether 156 unique exposure instances were investigated, each resulting in 14 readings for both electric and magnetic field (the entire sample consisted of 4368 manually taken readings). Measurements were taken in office environments from 46 laptop PC setups.	The highest exposure levels were characteristic to scenario A where no intervention was applied: 1) the laptop PC was connected to the wall socket, 2) using internal input devices (keyboard and mouse), 3) using internal monitor, 4) having an ungrounded casing and 5) with wires and power supply unit loosely positioned next to the user's body. For purposes of illustration, a PC was selected from the sample which produced average field levels as compared to the rest of the sample, both in pre- and post-intervention measurements. Figure 4 pictures a Scenario A (no intervention) measurement for that PC. **Contribution**: Development of a model for reducing EMF exposure from portable computers

Curriculum vitae

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Education

Educational institution	Graduation year	Education (field of study, degree)
Tallinn University of Technology	2017	Healthcare technologies, Master of Science in Engineering,
Tallinn University of Technology	2012	Academic studies of working environment specialist
Tallinn University of Technology	2004	Master of economic sciences
Tallinn University of Technology	2000	Bachelor of social sciences

Language skills

Language	Level
Estonian	Native
English	Upper
Finnish	Upper-Intermediate
Russian	Upper-Intermediate

Professional employment

Period	Organization
2016–...	Tallinn University of Technology, School of Business and Governance, Department of Business Administration
2010–2014	Tallinn University of Technology, School of Business and Governance, Department of Business Administration
2009–2016	Institute of Environmental Health and Safety
…–2016	Renolin OÜ

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Hariduskäik

Õppeasutus	Lõpetamise aeg	Haridus
Tallinna Tehnikaülikool	2017	Tehnikateaduste magister
Tallinna Tehnikaülikool	2012	Töökeskkonna spetsialisti akadeemiline koolitus
Tallinna Tehnikaülikool	2004	Majandusteaduste magister
Tallinna Tehnikaülikool	2000	Sotsiaalteaduste bakalaureus

Keelteoskus

Keel	Tase
Eesti	Emakeel
Inglise	Kõrgem
Soome	Kõrgem-kesktase
Vene	Kõrgem-kesktase

Teenistuskäik

Periood	Organisatsioon
2016–...	Tallinna Tehnikaülikool, Majandusteaduskond, Ärikorralduse Instituut
2010–2014	Tallinna Tehnikaülikool, Majandusteaduskond, Ärikorralduse Instituut
2009–2016	Keskkonnatervise ja Ohutuse Instituut
…–2016	Renolin OÜ