OCCUPATIONAL EXPOSURE TO ELECTROMAGNETIC FIELDS IN THE HEAVY ENGINEERING CO_2 WELDING INDUSTRY IN THE MANGAUNG METROPOLITAN MUNICIPALITY

by

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DECLARATION BY CANDIDATE

I **Selepeng France Raphela** declare that this thesis submitted to the Central University of Technology, Free State for the degree Doctor Technologiae: Environmental Health is my own independent work and that it has not been submitted at any other university for examination.

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SUMMARY

Some epidemiological studies suggest that exposure to high levels of electromagnetic fields (EMFs) may be linked with the development of adverse health effects. However there is still controversy on this matter. Due to rapid technological growth in the modern society, employees in the welding and electrical industries are highly exposed to electromagnetic fields and may be at a high risk for developing occupational diseases. The health effects which may result from exposure to electromagnetic fields are related to the strength and frequency of the fields.

This study was conducted to (i) assess the exposure levels to EMFs in the welding industry, (ii) determine the possible health risks associated with exposure levels, and (iii) develop a health and safety model to guide the industry on how to reduce exposure to EMFs. The study was conducted in one mega welding company in the Mangaung Metropolitan Municipality. Welders, fitters and office workers (88 in total) gave consent to participate in the study and completed questionnaires (ethical clearance attached). Measurements of extremely low frequency EMFs were taken in workshop A, workshop B and working offices. Measurements for magnetic fields were taken at distances of 1, 2 and 3 meters (m) from the EMFs sources.

The exposure levels of magnetic fields were very high in the workshops, with welders and fitters exposed to about 7.6 microtesla (µT). Electric fields were relatively low in all workstations. Participants in the study were experiencing symptoms of ill health such as headaches, sleep disorders, fatigue and distress. The symptoms reported by the workers were similar in the both groups (exposed and control). There is no clear relationship between recorded exposure levels and the development of the reported symptoms. The health and safety model was developed to guide the industry to reduce exposure to electromagnetic fields. The model describes the implementation of engineering and administrative control measures in an effort to reduce exposure to EMFs. The model also highlights the importance of wearing personal protective equipment to shield against EMFs amongst others.

This study suggests that occupational exposure to high levels of extremely low frequency EMFs may increase the risk for development of chronic diseases such as leukaemia, brain and breast cancer and other diseases among highly exposed employees. Implementation of safety measures is necessary to reduce exposure to EMFs.

Keywords: electromagnetic fields, occupational diseases, health risks

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CHAPTER 1

1 OVERVIEW

1.1 Introduction

Electromagnetic fields, which are produced by power lines, electrical wiring and electrical equipment, are present in most environments. Different types of electromagnetic energy include X-rays, visible light, microwaves and electromagnetic fields. Electromagnetic fields differ in strength according to their frequencies which are expressed in Hertz. In the welding industry for instance, the electromagnetic energy produced ranges from ultraviolet, infrared, and visible light to radio frequency and power frequency electromagnetic fields.[1]

Evidence exists that there may be an increased risk of leukaemia among people employed in electrical occupations, compared to people who work in other occupations.[2] People working in electrical occupations include electrical engineers, phone line workers, television and radio repairers, power station operators, electricians and welders amongst others. There is a high rate of mortality from leukaemia among electrical workers.[2] There has also been an increase in exposure to electromagnetic fields due to recent technological developments. These technological developments are common in industries, power transmission, transport, high energy physics research and medicine.[2] The mandate of the World Health Organisation (WHO) is to enhance the awareness of the health impacts of electromagnetic fields. The aim is to maintain and sustain safe and health-enhancing human environments, which are protected from biological, chemical and physical hazards.[2]

1.2 Problem statement

Guidelines concerning the protection of the general public from exposure to electromagnetic fields have been developed by the WHO. From these guidelines there are three monographs[3,4,5] on electromagnetic fields which address possible health effects from exposure to extremely low frequency (ELF) fields, static and ELF magnetic and radiofrequency fields respectively. The monograph on extremely low frequency focuses on the exposure to electric and magnetic fields with frequencies ranging from >0 to 100 kHz.[6] The monograph on static fields is based on the fields generated by a permanent magnet that do not vary over time, and their frequency is 0Hz.[6] The monograph on radiofrequency fields is based on the fields with radio frequencies ranging from 100 kHz to 300 GHz.[6] The development of these monographs occurred through the collaboration of the United Nations Environment Programme (UNEP), the International Labour Office and the International Non-ionizing Radiation Committee (INIRC) of the International Radiation Protection Association (IRPA) and the International Commission on Non-ionizing Radiation Protection (ICNIRP). The fundamental aspect about these monographs is the Environmental Health Criteria (EHC) which address possible health effects of exposure to very low frequency (up to 100 kHz) electric and magnetic fields.[6] Possible health effects resulting from exposure to power frequency (50-60 Hz) magnetic fields were highlighted in the monograph as well as the effects of exposure to the very low frequency electric fields were indicated.[6] Welders, for example, are exposed to extremely low frequency fields (<300 Hz). Literature has reported that there is an association between occupational exposure to extremely low frequency fields and certain cancers, such as leukaemia and cancer of the nervous system.[7]

There is an increase in exposure to electromagnetic fields (EMFs) in modern day world, particularly in the welding and electrical industries, due to the growth in electrical power generation, use, transmission and repairing of equipment. Employees in industries related to this are at high risk of exposure to EMFs,[2] and failure to comply with the safety standards worsens the situation. There is a need to investigate the exposure levels of employees to electromagnetic fields and to develop a model to guide the welding industries to improve health and safety standards within the working environment.

1.3 Aim and objectives of the study

Exposure to time-varying extremely low frequency electromagnetic fields results from natural sources, such as the sun, the earth and fields emitted by our own bodies. Apart from natural sources, residential and industrial use of electricity for power, heating and lighting has added greater exposure. This study aims mainly to develop a safety model to help the welding industries to protect employees from exposure to electromagnetic fields in the workplace.

The objectives of the study were:

- to measure the time-weighted average environmental exposure levels in the workplace;
- to determine the risk associated with exposure to electromagnetic fields in these industries;
- to assess the risk of exposure to electromagnetic fields through the questionnaires;
- to investigate whether the industry complies with safety standards and applicable legislation; and
- to develop a health and safety model for the welding industries as a guide for the protection of employees from exposure to electromagnetic fields.

1.4 Possible health effects related to EMF exposure

1.4.1 Introduction

Electromagnetic fields contain both electric and magnetic fields. Electric fields are found everywhere, including in the body cells. Magnetic fields are similar but are produced by an electric current. Electromagnetic fields are produced when electrical and magnetic fields are in motion.[8]

1.4.2 Types of electromagnetic fields and background information on the welding industry

Electromagnetic fields are categorised according to frequency (Hz) and wavelength. According to the electromagnetic field spectrum, Gamma rays and x-rays are both forms of ionizing radiation with a very high frequency.[1] X-rays are about 1 billion Hz and are able to penetrate the body and damage the internal organs and tissues. Other forms of electromagnetic fields such as visible light, microwaves, ultraviolet and infrared radiation form part of the non-ionizing radiation. Microwaves produce several billion Hz and as a result produce thermal or heating effects on the body.[1] A microwave oven, for example, produces microwave energy inside the appliance that is very high (about 2.45 billion Hz), while cellphones, cellphone masts and cellphone towers produce radiowaves with a frequency range of 800-900 MHz. In the welding industry, the welding equipment produces extremely low frequency fields with power frequency fields of about 50 or 60 Hz. Low energy levels are transmitted by extremely low frequency fields in such a way that they contain no thermal or ionizing effects and are associated with a very weak electric current flow in the body.[1] Another aspect is resistance welding which refers to welding by pressure, and in this instance welders are exposed to extremely high levels of extremely low frequency electromagnetic fields. There are five types of resistance welding namely spot welding, flash welding, butt welding, projection welding and seam welding. These welding techniques are commonly used in various types of operations such as manufacturing of cars, radios, television transmitters and metal equipment.[7]

1.4.3 Cancer-related effects

Studies concerning the association between the risk of cancer among electrical workers and exposure to electromagnetic fields were conducted worldwide. The first study[9] was done by using a death certificate database based on both titles and information on cancer mortality as sources of information. Employees were classified according to presumed magnetic field exposure. The study indicated that there was an increased risk of leukaemia among electrical workers. Increased risk of various types of leukaemia and nervous tissue tumours and in a few instances of both male and female breast cancer were reported.[10] In one study ELF exposure was measured at the workplace by taking the duration of work into consideration.[11] From this study it was evident that there was an elevated cancer risk among exposed employees.

According to the National Institute of Environmental Health Sciences and the United States Department of Energy (1995), exposure to electric and magnetic fields exists in households due to the frequent use of electrical appliances and exposure to electrical wires; however this exposure is linked to production of weak currents between cells.[8] Exposure to low frequency (60Hz) EMFs is associated with changes in functions of cells and tissues. A decrease in the levels of the hormone melatonin and alteration of tumour growth are also linked to exposure to low frequency EMFs. A link between the central nervous system cancers and exposure to low frequency EMFs was also reported.[8]

1.4.4 Electromagnetic fields and leukaemia

A longitudinal study was conducted for 21 years to investigate the mortality rate among Swiss railway workers as a result of leukaemia. Employees who were exposed to extremely low frequency magnetic fields were found to have a high rate of mortality as a result of leukaemia.[8] Evidence exists that there is an association between heavy exposure to low frequency electromagnetic fields and the risk of leukaemia. The cancer incidence in workers exposed to high levels of magnetic fields was investigated. Workers who worked during 1985-1994 in the engineering industries that use resistance welding were selected. The results of the study show an elevated risk of brain tumours and leukaemia among women.[7]

1.4.5 Electromagnetic fields and death rate

A study on electromagnetic fields and the death rate was conducted in the United States by reviewing all death records of women who died from 1985 to 1989 as a result of breast cancer. Among the women who had worked as electrical engineers, 68 were identified to have died of breast cancer, with 199 having died of other causes.[12] Employees included in the review were electrical engineers, electricians, telephone repairers and power line workers. According to the study women who were employed in electrical occupations had a higher death rate as a result of breast cancer than other employees not in the electrical industry.[12] Evidence exists from the review that women who were electrical engineers had a 73% higher risk of dying from breast cancer than their peers who were not employed as electrical engineers. In the case of telephone repairers and line workers the risk was exceedingly high at about 200%.[12] From the above-mentioned studies there is evidence that employees in electrical occupations face a higher risk of death resulting from cancer.

1.4.6 Effects of occupational exposure to EMFs on heart rate and blood pressure

A study was conducted to determine the occupational exposure to electromagnetic fields among workers at amplitude modulation (AM) broadcast stations. From the results of the study, it is clear that a majority of workers had more abnormalities in electrocardiogram (ECG) readings when compared with workers at radio-link stations (who were presumed to have low electromagnetic field exposure).[13] Another study[14] indicated that there were no changes in mean, systolic and diastolic blood pressure or in heart rates among employees who were exposed to radio-frequency energy (RFE). An increase in blood pressure and cholesterol blood levels was reported in a study among broadcast and television-station operators with a high RFE exposure as compared to radio-relay station operators with low exposure.[15]

1.4.7 The effects of EMF exposure on the female reproductive system

There are some reports on low birth weight among female physiotherapists who were exposed to short waves (typically 27.12 MHz).[16] One study[17] indicated that there were lower incidences of congenital malformations and miscarriage in physiotherapists than in the general community. Another study[18] indicated that in terms of biological effects, exposure to low-level electromagnetic fields has less potential to produce reproductive effects than other factors. The possible effects of occupational exposure to EMF were reviewed by associating maternal video display units (VDU) or microwave-oven exposure during pregnancy and adverse reproductive effects. The results indicate that there was no association between maternal video display units (VDU) or microwave-oven exposure during pregnancy and adverse reproductive effects.[19] Therefore there is a lack of evidence to indicate a strong association between maternal VDU use by women and foetal loss.

1.4.8 The effects of EMF exposure on the male reproductive system

A study was conducted among Danish military personnel operating RFE systems by comparing them with other occupational groups. The results indicate that there were no significant differences in semen volume, sperm density and morphology, or immotile spermatozoa among the military personnel as compared to other occupational groups.[20] A study on the effects of mobile phones on sperm motility was conducted. The results of the study indicate that men who carry their mobile phones in their hip pocket or on their belt had lower sperm motility than men who carried them elsewhere on their body.[21]

Another study was conducted among men who had a history of being exposed to computers. The results obtained from the study indicate that there were no significant differences in sperm viability, sperm density, percentage of normally formed sperm, percentage of progressive sperm or semen volume.[22] From the above studies it is evident that there is no significant impact on the male reproductive system due to exposure to radio frequency energy.

1.4.9 The effects of EMF exposure on the immune system

An increase in immunoglobulins G and A concentrations, increased lymphocytes and lower T-helper/T-suppressor cells was reported among workers at television transmission and satellite communication centres.[23] In a follow-up study, in which the subjects were radar operators, the results indicate increased levels of immunoglobulin M and decreased total T8 lymphocytes. An assumption made about the study was that the effect of microwave radiation on the immune system depends on the nature of the exposure. There were no clinical implications related to the changes. A study was conducted in which medical personnel were exposed to operating radio frequency energy units. Medical personnel were exposed to radiation levels at the recommended exposure limits. The results indicate that there was no significant difference between the small groups of control and exposed group in terms of total leucocytes counts, total lymphocytes counts, leukocyte subpopulations and lymphocyte proliferation.[24]

More natural killer cells were found among workers operating induction heaters with a very low frequency range of three to 30 KHz compared to those found in the control group.[24] In the study, 18 different immunological parameters were measured and compared with each other. The results show a decrease in monocyte phagocytic activity in these workers. Countering to that was an increase in the number of active cells, indicating normal non-specific immunity. In another study parameters of immune function were studied in women living in a geographical area containing a large number of radio/television transmitters. The parameters of these women were compared with those of female white collar staff and doctors at a university in an adjacent geographical area. The results indicate that the women in the geographical area containing a large number of radio/television transmitters had lower levels of interferon-y produced by peripheral blood mononuclear cells, compared with the women at the university in the adjacent area. The subgroup of women in the geographical area containing a large number of radio/television transmitters had higher serum IgE levels.[25]

1.4.10 Effects of exposure to EMFs on the endocrine system

Certain studies were done based on the effects of the EMFs on the endocrine system. In one study, the subjects were exposed to 900 MHz RFE emitted by cellular phone for two hours per day, five days per week and for one month.[26] The results of the study indicate that there were no significant differences with regard to serum adrenocorticotropin and growth hormone concentrations. A decrease in the concentration of thyrotropin during exposure weeks was observed and increased to baseline levels thereafter. Another study[27] indicated that technicians working in radio-broadcasting, radio-link or television-transmitter stations experienced increased blood levels of triiodothyronine, tetraiodothyronine and thyroid-stimulating hormones. Control subjects were not occupationally exposed to RFE. Some of the RFE-exposed technicians had to climb television towers as part of their daily work, however, and there is a possibility that exertion could lead to an increase in blood levels of triiodothyronine and tetraiodothyronine and thyroid stimulating hormone. A study was conducted among satellite-station operators. The results indicate changes in the circadian rhythm of 11 oxycorticosteroids and an increased variability of catecholamine secretion.[28] One study reported that broadcasting operators exposed to high levels of RFE experienced an increase in excretion rates of cortisol, epinephrine and norepinephrine. A control group of the study consisted of satellite-station operators who were exposed to low levels of RFE.[29]

1.4.11 The effects of EMFs on haematological changes

The results of a study among employees who were exposed to RFEs showed peripheral blood changes with regard to cytopenia, a decrease in haemoglobin, red blood cells and white blood cells counts. An increase in red blood cells with basophilic granularity, altered white blood cells metabolism, disordered lymphocytes subunits (T helper and suppressor cells) ratio and T- and B-cells numbers were also reported in the study.[30]

1.4.12 The effects of EMFs on blood levels of free radicals

The effects were investigated whereby subjects were exposed to EMFs by keeping cellular phones in their pockets in a standby position with the keypad facing the body for 4 hours. The results showed that there was a generation of free radicals, which led to an increase in the peroxidation in the blood plasma when subjects were exposed to EMFs.[31] In addition, a decrease in the activities of superoxide dismutase and glutathione peroxidase in erythrocyte was found.

A case report about a man who was exposed to 10 GHz EMFs indicated that he experienced mild erythema and a burning sensation within 1 and 3 months respectively after exposure.[32] The symptoms disappeared shortly afterwards. A case of dermatitis was reported in a study in which a patient had an implanted neurostimulator.[33] The reaction was related to electrical current being passed through the skin of the patient during transcutaneous nerve stimulation. In this study dermatitis was caused by electromagnetic radiation due to direct contact with the electrical current.

1.4.13 Effects on hearing and vestibular system

A higher incidence of hearing loss among 31 employees and family members residing in quarters near a radio-broadcasting station was found, compared to a control group that consisted of 30 subjects.[34] The effect was related to a microwave auditory phenomenon. In another study, 30 volunteers with normal hearing were exposed to cell phones for 10 minutes. The results indicate that there were no changes in measurable otoacoutic emissions and that none of the subjects experienced deterioration in hearing level.[35]

1.4.14 Health risks associated with exposure to EMFs in the welding industry

In general welders are exposed to extremely low frequency fields. Evidence exists that exposure to extremely low frequency fields in welding occupations is associated with increased risk of tumours of the kidneys, the biliary passages, the liver and the pituitary gland.[7] The results indicate that those men who were employed as resistance welders have a higher risk of developing tumours of the kidneys, the liver, the biliary system and the pituitary gland. In women there was a high risk of breast cancer. In addition, an increased risk of tumours of the liver and pituitary gland were observed in women who were exposed to extremely low frequency fields in welding occupations. There is an association between occupational exposure to extremely low frequency fields and certain cancers such as leukaemia and cancer of the nervous system. An increase risk of brain tumours was reported among Swedish welders.[36]

1.4.15 Guidelines for protection against EMFs

A working group on non-ionizing radiation (NIR) was formed by the International Radiation Protection Association (IRPA) in 1974. The aim of the working group was to examine the problems arising in the field of protection against various types of NIR. A number of health criteria documents on NIR as part of the World Health Organisation's (WHO) Environmental Health Criteria Programme were developed by the Environmental Health Division of the World Health Organisation, the International Radiation Protection Association and the International Non-Ionizing Radiation Committee. The restrictions provided in these guidelines focused on scientific data alone. These restrictions provide an adequate level of protection from exposure to time-varying EMFs. Based on the restrictions, two classes of guidance are provided, namely:

- **basic restrictions**: refer to restrictions about exposure to time-varying electric, magnetic and electromagnetic fields. These restrictions are based directly on established health effects. Current density, specific energy absorption rates and power density are the physical quantities used to specify these restrictions. Measurements of power density in air among exposed individuals outside their bodies only can be done.[37]
- **reference levels**: refers to levels provided for practical exposure assessment purposes to determine whether the basic restrictions levels are exceeded or not.

Electric field strength, magnetic field strength, magnetic flux density, power density, and current flowing through the limbs are the derived quantities based on these levels. For safety purposes, adherence to the reference levels will ensure adherence to the relevant basic restriction.[37]

In these guidelines, the following quantities are used based on different waveforms, namely:

- current density in the frequency range of up to 10 MHz;
- current in the frequency range up to 110 MHz;
- specific energy absorption for pulsed fields in the frequency range 300 MHz-10GHz; and
- power density in the frequency range 10-300 GHz.[37]

Negligible energy absorption and no measurable temperature rise in the body result when individuals are exposed to low frequency electric and magnetic fields. A significant energy absorption and an increase in body temperature result when individuals are exposed to electromagnetic fields at frequencies above 100 kHz. A highly non-uniform deposition and distribution of energy in the body result when individuals are exposed to uniform electromagnetic fields.[37]

1.4.16 Conclusion

Three factors in the workplace that determine personal exposure to electromagnetic fields in the workplace are: the strength of the electric or magnetic field sources, the distance from the sources and the time spent in the magnetic field. Biological effects have been reported as a result of exposure to time-varying, static and extremely low frequency electric and magnetic fields. The following measures can be taken to reduce exposure to EMFs in the workplace, namely:

- limiting the time spent near EMFs sources;
- informing employers and employees about the possibility of risk from EMF exposure, increasing the distance between the workers and the EMF source; and
- using equipment that is designed to emit low EMFs.[1]

1.5 Methodology

1.5.1 Background

The methodology of the study included the obtaining of environmental exposure measurements. Questionnaires were used to gather information on the health and safety risks of exposure to EMFs. Compliance with safety standards by the companies was investigated. A health and safety model was developed to guide the welding industry to reduce occupational exposure to EMFs.

1.5.2 Subjects

The workers in a heavy engineering CO_2 welding industry in the Mangaung Metropolitan Municipality, Free State Province, South Africa. A sample of 58 subjects (exposed group) and 30 subjects (control group) participated in the study and the total number of subjects was 88. The exposed group consisted of welders (n=37) and fitters (n=21) while the control group (n=30) consisted of employees who work in offices and were not exposed to electromagnetic fields from welding. Subjects were randomly selected from various workstations. Full-time permanent welders and fitters who had worked for a period of 3 or more months were included in the study. Both male and female subjects of different races from within the country (South Africa) and other foreign countries were included.

1.5.3 Measurement of extremely low frequency EMFs in the workshops

Different sampling techniques were used to take the measurements. Measurements were taken in welding workshops and offices. Time-weighted average exposure levels were measured. Measurements were taken in the workshops while welding was taking place. Measurements were taken near the sources of EMFs such as photocopy machines, computers and electrical wires in offices. Measurements for magnetic fields were taken at different distances[38] (1m, 2m and 3m) from the welding tip. The following dosimetric quantities of the EMFs were measured, namely electric and magnetic field strengths. Measurements were taken for extremely low frequency electromagnetic fields at the frequency of 50 Hz. The data was recorded on a data collection sheet (see Appendix 3).

1.5.4 Investigation of whether the welding industry complies with safety standards

The measured personal and environmental exposure levels to EMFs were compared to the recommended safety exposure levels of the international standards to determine whether companies comply with the safety standards.

1.5.5 Questionnaires and confidentiality

Questionnaires (see Appendix 1) were compiled based on risk factors (e.g. duration and frequency of exposure, type of equipment used, occurrence of signs and symptoms among employees related to exposure to EMFs, etc.) associated with exposure to EMFs in these industries. Employees completed the consent forms (see Appendix 2) to participate in the study. Employees also completed the sections in the questionnaires on general and work-related information. Information provided in the questionnaires was used to evaluate the exposure of employees to electromagnetic fields. The information in the questionnaires was treated with confidentiality and the subjects remained anonymous.

1.5.6 Evaluation of the measured exposure levels to EMFs

The measured exposure levels were used to evaluate the exposure of employees to electromagnetic fields. The information obtained from the subjects through completion of questionnaires was also used to evaluate the extent to which employees were exposed to EMFs. The information obtained from the exposed group by means of the completion of questionnaires and measured exposure levels was compared to the information obtained from the control group, also by means of the completion of questionnaires and measured exposure levels. The prevalence of symptoms associated with exposure to EMFs among employees was used to evaluate the exposure. The type of equipment used was also taken into consideration when evaluating the exposure of employees.

1.5.7 Development of a safety model

A safety model based on the guidelines for protection against EMF exposure was developed. According to the ICNIRP guidelines, there are two classes of guidelines, namely basic restrictions and reference levels. Based on these guidelines a model was developed. The model guides the welding industries on how to reduce occupational exposure to EMFs by adhering to safety standards. Recommendations were made to assist the industries to improve their safety standards and protection of employees from exposure to EMFs.

1.5.8 Data analysis

Data gathered from the questionnaires and the EMFs in the workplace and offices were captured electronically in Microsoft Excel 2007. Any further analysis was done using SAS Version 9.2. Descriptive statistics, namely frequencies and percentages, were calculated for categorical data. Medians and percentiles were calculated for numerical data. Analytical statistics namely the Kruskal-Wallis test was used to compare the mean (or median) values obtained from the groups (i.e. workshops1 and 2, control group and workshop 1 as well as control group and workshop 2). The median values from the three groups were also compared (i.e. control group, workshop 1 and workshop 2) by using the Chi Square Statistics and Fisher’s Exact test.

1.5.9 Site inspection and safety standards

The health and safety standards in the workplaces were inspected. General housekeeping and safety precautions in the workplace were examined. Protective clothing and equipment used by employees was examined to determine any risks associated with them. A walkthrough survey was conducted to identify potential risks in the workplace related to EMF exposure.

1.6 Ethical aspects and good clinical practice

1.6.1 Ethical clearance (170/2011)

Ethical clearance (see Appendix 4) for the study was obtained in order to ensure good research practice and conduct. The clearance included aspects such as accuracy, fairness, intellectual honesty and protection of the subjects involved.

1.6.2 Project safety

An induction was conducted before the commencement of the project with all the participants involved to explain the safety procedures. All participants were supplied with protective equipment to be used for the entire duration of the project.

1.6.3 Good clinical practice (GCP) / Quality assurance

To ensure the quality and high standard of the research the following issues were taken into consideration:

- record keeping of the maintenance of equipment;
- taking of many measurements per day at different intervals;
- training by experts with regard to utilisation of equipment used;
- correct handling of samples and materials; and
- verification of data collected from existing records.

1.6.4 Financial implications for participants

Participation in the study was voluntary and subjects did not receive any remuneration.

1.6.5 Subject information and informed consent

All workers received the subject information about the research and the consent forms (see Appendix 2). The subjects gave their consent regarding participation in the study by completing and signing the consent form.

1.6.6 Confidentiality

All data collected was treated as confidential. The names of the company and the subjects remained anonymous throughout the entire duration of the research after the research was conducted. Other aspects related to ethics in health sciences were taken into consideration. These aspects include analysis of risks and benefits associated with the study especially in relation to chronic life threatening diseases. Participants were well informed about the risks and benefits of the study their rights of privacy were protected.

1.7 Hypothesis

Employees in the welding industries in the Mangaung Metropolitan Municipality are exposed to high electromagnetic field levels.

1.8 Contents and planning

In this study, a review of studies on possible health effects of exposure to electromagnetic fields is presented in Chapter 2. The results in regard to the measurements of electromagnetic fields measured in the workshops and offices are provided in Chapter 3. In Chapter 4, the results in regard to the data obtained from questionnaires are explained. The safety model is presented in Chapter 5, and recommendations are provided in Chapter 6. The referencing style for the *Journal of Occupational Health Southern Africa* was used in all the chapters. An article from Chapter 3 was published in the *Journal of Occupational Health Southern Africa*. In addition an article from Chapter 4 was published in the same journal. The article for Chapter 5 has been submitted for publication to the Interim journal.

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CHAPTER 2

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2 A review of studies on the possible health effects associated with exposure to electromagnetic fields

2.1 Abstract

Several studies have raised concern about the adverse health impacts of exposure to electromagnetic fields (EMFs) in various occupations. The majority of the studies have focused on the adverse health impacts caused by exposure to electromagnetic fields from power lines, electrical and wireless devices commonly found in homes, workplaces and schools. Epidemiological research suggests a considerable health risk as a result of exposure to electromagnetic fields. Some clinicians are not aware of the adverse health impacts emanating from electromagnetic fields due to the fact that environmental health aspects have not been fully emphasised in medical education. The manifestations of electromagnetic fields on human beings are misdiagnosed and ineffectively managed. It is important for health care workers to be aware of the clinical implications of EMF exposure. A review of scientific literature concerning the health effects of exposure to EMFs is presented.

Keywords: adverse health impacts, electromagnetic fields, health risk, environmental health, clinical implications

2.2 Introduction

Electromagnetic fields (EMFs) are invisible waves generated by power lines, electrical wiring and electrical equipment. Types of electromagnetic energy include X-rays, visible light, microwaves and electromagnetic fields. Electromagnetic fields that originate from power lines, mobile phones, common electrical devices and some types of machinery have been regarded as potential health hazards.[1] Various international organisations such as the World Health Organisation (WHO) have initiated intense investigations concerning the impact of non-ionizing radiation (NIR) on human health. This was in response to the research reports that reported a link between exposure to electromagnetic fields and adverse health impacts such as reproductive dysfunction, cancer and central nervous system disorders. In the electromagnetic spectrum, electromagnetic fields are classified according to frequency and wavelength. Non-ionizing radiation (NIR) refers to radiation with lower frequencies. The studies were conducted to investigate the health effects of NIR. Various studies focused on extremely low frequency (ELF) electromagnetic fields generated by power stations, power lines and some electrical equipment.[2,3]

Some studies focused on the adverse health impacts related to radio and microwave frequencies generated by wireless communication technologies, cordless and cellular phones and some electrical materials.[4,5] An investigation regarding the health effects associated with intense exposure to NIR due to high voltage from electricity was also conducted.[2,3] As water becomes polluted when it travels through a contaminated environment, so electricity becomes “polluted” when it comes in contact with electronic devices. When electricity comes in contact with equipment such as computers it becomes hazardous and develops into scattered higher frequency signals. Electricity generates NIR which radiates to the adjacent environment and is regarded as a potential health hazard.[6]

2.3 Problem statement

Conflicting information about the health effects resulting from exposure to electromagnetic fields is found in medical and occupational health and safety literature. The WHO called for an intense investigation to assess the health risks associated with exposure to electromagnetic fields. The objective of the study was to review literature with more emphasis on studies that investigated the health effects associated with exposure to electromagnetic fields.

2.4 Sources, measurements and exposures of EMFs

Whenever electricity is generated, transmitted or distributed in power lines or cables, electric and magnetic fields exist. The use of electricity is of critical importance to modern society: such fields are therefore found everywhere in the environment. The units for electric and magnetic field strengths are volt per meter (v/m) and microtesla (µT) respectively. The geometric mean for residential exposure ranges between 0.025 and 0.07 µT in Europe and 0.055 and 0.11 µT in the United States of America.[7] The mean values for electric fields in homes are around several tens of volts per meter. The magnetic field values may be as much as few hundred microtesla in the vicinity of certain appliances. The electric fields measured close to power lines may be up to several thousand volts per meter while magnetic fields can be around 20 µT.[7,8]

Residential exposure to electromagnetic fields of 50 or 60 Hz among children was linked to an increased incidence of childhood leukaemia.[7,8] Approximately 1 to 4% of children have a mean exposure above 0.3 µT while around 1 to 2% have a median exposure in excess of 0.4 µT.[7] The time-weighted average exposure level to electromagnetic fields in certain occupations (e.g. welding) has been found to be higher than others (e.g. office work).[7] The exposure levels to magnetic fields in offices range between 0.4 to 0.6 µT. The highest exposure levels, those above 3 µT, are commonly found among welders, railway engine drivers and sewing machine operators.[9] Employees in the electrical supply industry may be exposed to electric fields of up to the value of 30 kV/m.[7,8]

2.5 The concept of electric and magnetic fields

Electric charges produce electric fields irrespective of the state of motion.[7,9] Power lines produce electric fields in a pattern of cylindrical symmetry. An electric field is produced by a single charge in all directions in a pattern with spherical symmetry and infinite dimension. The distribution of charges and objects in the vicinity determines the overall shape of the pattern of the electric field experienced at any point. There is a relationship between electric charges and voltages, but not between electric charges and currents or power.[7,8] Charges that are in motion produce magnetic fields. Magnetic fields are proportional to the electric currents in a system irrespective of the usage of voltage.[9] The coupling of electric and magnetic fields becomes stronger with increasing frequency. This is as a result of time-varying charge distributions. Maxwell's equation is used to describe the characteristics and interactions of electric and magnetic fields.[7] The accelerating charges produce a radiation component. Radiation is absolutely negligible in the ELF range according to practical exposure situations. The distance between two successive cycles of the wave is called the wavelength.[7,8,9] The wavelength is related to frequency according to the following formula:

- Wavelength = speed of light / frequency

The wavelength is very long at the frequency of 50 Hz (i.e. 6000 km).[7,9]

2.6 Electric and magnetic fields inside the human body

Electric fields and currents inside the body are induced when exposure to external electric and magnetic fields at extremely low frequency occurs.[7] The relationship between the external fields and induced electric and current density inside the body or other parameters associated with exposure to these fields is described by dosimetry. Excitable tissue such as nerve and muscle tissue are stimulated by the induced electric and current density. The distribution of ELF electric fields is disturbed by the human body. Electric fields are shielded by electrically grounded objects, trees and buildings.[8]

The human body is a good conductor at low frequency and as such the disturbed field lines are perpendicular to the body surface.[7,9] The currents inside are induced by oscillating charges on the surface of the exposed body. The key features of dosimetry for human exposures to ELF electric fields are as follows:

- The magnitude of the electric field inside the human body is normally smaller than the external electric field.
- The predominant direction of the induced fields is vertical when the exposure is mostly to the vertical field.
- With regard to the external electric field, the strongest induced fields are experienced by the human body which is in perfect contact with the ground. The

weakest induced fields are experienced by the body which is insulated from the ground (for example a person wearing shoes).

- The body size and shape, rather than the tissue conductivity, determine the total current flowing in a body in contact with the ground.
- The induction of electromagnetic fields occurs in critical organs or target sites which then affects the entire body.[9]
- The conductivity also affects the distribution of the induced electric field, but less so than the induced current.
- A separate phenomenon states that contact with the conductive object located in the electric field can result in the production of current in the body.[7]

The permeability of tissues is the same as that of air in the case of magnetic fields.[9] The fields are not disturbed by human bodies. The Faraday induction of electric fields and associated current densities in the conductive tissues describe the main interaction of magnetic fields.[7] The key features for human exposures to magnetic fields are as follows:

- The orientation of the external fields determines the induced electric fields and current. When the external field is aligned from the front to the back of the body, the induced fields become high. The induced fields can also be high for certain organs in cases where external fields are aligned from side to side.
- The magnetic fields orientated along the vertical body axis induce the weakest electric fields.
- Higher electric fields are induced in larger bodies for a given magnetic fields' strength and orientation.[9]
- The conductivity of various organs and tissues affects the distribution of induced electric field strengths.[7,8]

2.7 Biophysical mechanism of electromagnetic fields

Numerous mechanisms for the interaction of fields with the human body have been proposed. Three of them operate at lower levels than the others and these include induced electric fields in neural networks, radical pairs and magnetite. The myelinated nerve fibres will be stimulated by the electric fields induced in tissue by exposure to ELF electric or magnetic fields. The synaptic transmission in neural networks as opposed to single cells can be affected by the weaker fields. Multi-cellular organisms use signal processing by the nervous system to detect weak environmental signals.[7,9]

The acceptable way in which magnetic fields affect the specific types of chemical reactions is the radical pair mechanism.[7] This mechanism is related to an increase in the concentration of reactive free radicals in low fields and a decrease in high fields. Human and animal tissues contain various forms of iron oxide in trace amounts. These include magnetite crystals and small ferromagnetic crystals. The magnetite in the human brain does not have an ability to detect weak geomagnetic fields.[7] The human body can be influenced by certain critical frequencies that may exist for certain organs like the brain or specific cell structures.[9] The surface charge induced by electric fields can be perceived with regard to the indirect effects. This can lead to painful micro-shocks when a conductive object is touched.[7]

2.8 Neuro-behaviour associated with exposure to EMFs

Biological responses ranging from perception to annoyance through surface charge effects are caused by exposure to power frequency electric fields.[7] The field strength, ambient environmental conditions and individual sensitivity determine these responses.[9] The level of perception was observed among 10% of subjects who were exposed to electric field strength ranging between 2 and 20 kV/m.[7] About five percent of the subjects experienced annoyance when they were exposed to electric field strengths of between 15 and 20 kV/m. The size of the object determines the thresholds for the discharge from the charged object through a grounded person.[7,8]

The cells of the central nervous system are considered to be highly sensitive to induced electric fields as a result of exposure to ELF magnetic fields below the threshold for nerve stimulation.[10,11] Peripheral or central nerve tissue can be stimulated by high field strength and rapidly pulsed magnetic fields. Direct nerve stimulation by the threshold-induced electric field could have as low as a few volts per meter. Induced ELF electric fields in the central nervous system increase the susceptibility of people suffering from epilepsy.[7] The central nervous system is sensitive to electrical stimulation.[8] A family history of seizures and use of tricyclic antidepressants, neuroleptic agents and other drugs that lower seizure threshold are associated with sensitivity to electrical stimulation. Exposure to weaker ELF magnetic fields can affect the functioning of the retina of the eye. The interaction of the induced electric field strengths in the extracellular fluid of the retina results in flickering light sensation called magnetic phosphenes or magnetophosphenes. The extracellular fluid of the retina has a threshold-induced electric field strength that lies between 10 and 100 mV/m at a frequency of 20 Hz. Other neurological effects such as brain electrical activity, cognition, sleep, hypersensitivity and mood remain unclear. Some people are highly sensitive to electromagnetic fields in general.[7]

2.9 Cancer-related effects

The possibility that cancer may be linked to exposure to low frequency EMFs has been investigated over the last two decades and reviewed by both national and international experts.[12] Cancer is characterised by uncontrolled abnormal growth of cells.[8] The growth of cells may disrupt surrounding tissues and move to other parts of the body through blood and lymphatic vessels. Carcinogenesis refers to the process of cancer formation with two different developmental stages, namely initiation and promotion. During the initiation stage, irreversible changes that include mutation of genes occur.[7] The stage of promotion is reversible and sustained when the stimulus is repeatedly applied to the initiated cell. During promotion further development of a tumour is stimulated. The extremely low frequency EMFs have low energy levels in molecular interaction. It is therefore suggested that these low frequency EMFs can lead to DNA damage.[7,8] Low frequency EMFs can induce these changes through other sources such as endogenous radicals. Cancer formation may be enhanced by non-genotoxic interferences in signal transduction.[8] The progression of the disease may be influenced by other factors such as immune surveillance and hormonal dependency once the full malignancy has been established in a primary tumour.[7,9] It is hypothesised that extremely low frequency EMFs can interfere with these factors and lead to tumour development in a later stage.[7,9] An analysis based on nine well-conducted studies indicated an incidence of cancer among subjects who were exposed to ELF magnetic fields above 0.4 µT. The occurrence of cancer was not observed in studies where subjects were exposed to magnetic fields below 0.4 µT.[13]

2.9.1 Electromagnetic fields and breast cancer

A case-control study[14] was conducted among African Americans, Latinos and Caucasians in Los Angeles. The subjects were all aged between 45 and 74 years, and were selected and recruited from a file of licensed drivers. The incidence of breast cancer between 1993 to 1999 was linked to the tumour register of the state. The control group was selected based on ethnicity and comprised of subjects who were not suffering from cancer. An EDMEX II meter was used to measure the magnetic fields for seven days. The measurements were taken in the bedrooms of the subjects and included both the broadband (40-80 Hz) and harmonic (100-800Hz) magnetic fields, sampled at 120s interval. The night-time mean was determined for each subject based on the information obtained from the questionnaires; this mean was used to assess the exposure levels of the two groups of subjects. The following variables in the magnetic field were measured, namely (1) mean night-time bedroom magnetic field; (2) proportion of night-time bedroom magnetic field measurements ≥ 0.4 µT; and (3) short-term variability in the night-time bedroom magnetic field. A mean night-time broadband magnetic field level of less than 0.2 µT was found in the homes of subjects with cancer (91%), as well as in the control group (92%). On average about 86% of both groups had no measurements above 0.4 µT. From the study it could be concluded that there was no association between mean night-time magnetic field exposure and the occurrence of breast cancer.[14]

To investigate the association between the risk of breast cancer and EMF exposure, a case-control study[15] was conducted, through the Long Island Study Project (LIBCSP), among women under the age of 75 years. Between August 1996 and June 1997, subjects were identified who had been living in the Long Island homes for a period of at least 15 years. The experimental group comprised 576 cases of individuals while the control group comprised 585 individuals. An EMDEX II meter programmed to measure both broadband (40-80 Hz) and harmonic (100-800 Hz) magnetic fields was used to measure both spot and twenty-four-hour measurements in the homes of the participants. The spot measurements were taken at the front doors, bedrooms and most lived-in rooms of the subjects, whereas the twenty-four-hour measurements were taken in the bedrooms and most lived-in rooms. The intervals for spot and twenty-four-hour measurements were three seconds and 15 seconds respectively. Questionnaires were used to collect data on the usage of electrical appliances. The results indicated that the means for 24-hour broadband magnetic fields in bedrooms were 0.16 µT for the experimental group and 0.14 µT for the control group. The exposure levels were not associated with the occurrence of breast cancer.[15]

In Norway, a case-control study[16] investigated whether residential and occupational exposure to magnetic fields increases the risk of female breast cancer. The study population included women aged 16 years and above who were living in a residence near high voltage power lines between 1986 and 1996. The distances from corridors to power lines ranged from 40 m (33 kV lines) to 300 m (420 kV lines). There were about 1830 cases of breast cancer, with two control groups per case (3658 in total). The control group was selected based on the following criteria: the subject was (1) born within 5 years of those in the case study; (2) free from breast cancer and alive at the time of diagnosis, and (3) residing in the same municipality as those in the case study. The distances from the houses to the power lines were measured and the time weighted average residential exposure to magnetic fields was estimated for the last five years before the case was diagnosed. Occupational exposure levels were estimated by using a scale that ranged from one (<4h exposure at 0.1 µT per week) to three (≥ 24 h exposure at > 0.1 µT per week).The combined residential and occupational exposures were calculated based for 1296 cases and 2597 controls. Women were considered to be exposed when the time-weighted average residential exposure was 0.05 µT and there was an occupational exposure of more than 30 years. According to the findings of the study, there was an association between exposure to magnetic fields and the occurrence of breast cancer.[16]

Research conducted previously indicates inconsistent association between usage of electric blankets and breast cancer.[17] A case-control study[17] was conducted among breast cancer patients aged 50-70 years. The cancer cases were identified from the state-wide tumour registries in Wisconsin, Massachusetts and New Hampshire. About 5683 cases of breast cancer were reported between January 1992 and December 1994. Two sampling frames were used to select the control groups from each state. The first sampling frame comprised women aged from 50 to 64 years who were selected from a list of licensed drivers. The second sampling frame was selected from a list of Medicare beneficiaries and comprised women aged between 65 and 74 years. Interviews were conducted with the experimental groups (n=1949 cases) and control groups (n=2498) between June 1994 and July 1995. Telephone interviews were used to collect data on usage of electric blankets or mattress covers. The study provides evidence against a positive association between the occurrence of breast cancer and usage of electric blankets or mattress covers.[17]

A residential study[18] was conducted to investigate whether exposure to 60 Hz magnetic fields may increase the risk of breast cancer in Washington. Cases of breast cancer (n=813) diagnosed between November 1992 and March 1995 were included in the study. The control group (n=793) comprised subjects who were identified by means of random digit dialling. Magnetic field measurements were used to estimate the exposure in homes. The usage of electrical appliances as well as the wiring configuration in homes was used to estimate the exposure. According to the findings of the study, there was no relationship between the occurrence of breast cancer and the measured night-time bedroom magnetic field level in relation to the wiring configuration of homes or the usage of electric appliances. Therefore the results of the study do not support the hypothesis that exposure to residential magnetic fields increases the risk of breast cancer.[18]

During the years 1995-1998, a study[19] was conducted among African-American women aged between 20 and 64 years who were residing in one of the Tennessee counties. The experimental group comprised 304 patients diagnosed with breast cancer while the control group comprised 305 women without breast cancer. The information about cancer cases was obtained from the Tennessee Cancer Reporting System. Information on the usage of electric bedding devices was obtained by means of telephone interviews. The subjects reported the usage of electrical bedding devices to some extent. Seventy-three pre-menopausal women reported that they had used electrical bedding devices for the past ten years, while 16 reported that they had used them for more than ten years. The usage of electrical bedding devices among pre- and postmenopausal women was linked to the cases of breast cancer.[19]

The occurrence of breast cancer in males was reported in a follow-up study[20] in 1989 among employees in Sweden. The study population consisted of men aged between 25 and 59 years of age at the start of the follow-up, who were employed in 1970. Consistent excessive occurrence of breast cancer was observed among machinery repairers. Few cases of breast cancer were reported among other workers such as metal processing workers, non-specified clerical workers, bank employees, librarians/archivists/curators, policemen and custom surveillance officials. The association between exposure to electromagnetic fields and risk of breast cancer was observed among occupations with intermittent ELF EMFs exposure. Variation in exposure levels over the work day was associated with the risk of breast cancer.[20]

A cohort study[21] was conducted to investigate the incidence of cancer among employees in industries that use resistance welding in Sweden. The companies that use resistance welding were identified from 1985 to 1994 and employees working in these industries were identified through their tax returns. The job exposure matrix on ELF EMFs was linked to the occupation based on the census information of the years 1980, 1985 and 1990. The jobs were classified into four exposure groups based on the exposure levels of magnetic fields as follows: (1) “low” (< 0.164 μT), (2) “medium” (0.164-0.250 μT), (3) “high” (0.250-0.530 μT) and (4) “very high” (>0.530 μT). The exposure to ELF magnetic fields was estimated by using the job exposure matrix supplemented by additional information. About 75% of workers employed as resistance welders were classified in the “Very High” category. The National Cancer Registry and mortality data were used to obtain the incidence of cancer from 1985 to 1994. From the data obtained, the risk of breast cancer among women in the category of “very high” was relatively low (37 cases reported).[20] There was an association between cancer of the corpus uteri and multiple myeloma and magnetic field exposure in the very high exposure group. The study indicated an association between cancer incidence (brain tumours and leukaemia) among women employed as resistance welders.[21]

The study[22] was conducted as a follow-up to cancer cases among Norwegian female radio and telegraph operators. The study was based on the cohort reported in 1996 that consisted of 2619 women employed as radio and telegraph operators between 1960 and 1980. About 98% of the subjects worked on Norwegian merchant ships. Spot measurements for electromagnetic fields were conducted on two ships during the time when the transmitter was active, and then again when it was off. The measurements taken ranged from 0.02 to 6 µT depending on the position occupied by the radio operator. The incidences of breast cancer were identified through the national cancer registry. Ninety-nine cases of breast cancer were identified. Forty-four women with breast cancer who were younger than 50 years of age, and 55 who were over the age of fifty, were identified. The study indicated that the risk of breast cancer among Norwegian female radio and telegraph operators was related to the ELF magnetic fields exposure.

A case-control study[23] reported the occupational risks of breast cancer without focusing of the ELF magnetic field measurements. The risks were reported for occupations with presumed exposure to ELF magnetic fields. The cases were identified according to the British Columbia Cancer Register. Women aged below 75 years with breast cancer diagnosed between June 1998 and June 1989 were identified. The control group was selected from the electoral roll. Questionnaires were used to obtain information on job history and various potential confounders. The results of the study indicated a high risk of breast cancer among electronic data-processing equipment operators.[23]

A report from the Carolina Breast Cancer Study in the United States of America (USA) indicates the results of a case-control study on occupational exposure to magnetic fields.[24] Individuals aged between 20 and 74 years and diagnosed from May 1993 to September 1995, were identified from the North Carolina Cancer Register. The control group was sampled from a list of motor vehicle license holders aged up to 65 years, and health care finance workers aged above 65 years old. The time-weighted average in the six broad occupational groups and in the homemaker category was used to estimate the occupational exposure to magnetic fields. The personal average magnetic field exposure meter (AMEX 3-D) was used to take measurements for the participants. The longest and second longest held occupations were used to assign individual exposure. The number of years worked and hours worked per week were also used to determine the occupational exposure. The occupational exposure levels to magnetic fields for participants with cases of breast cancer ranged from 0.59 to 0.90 µT. The findings of the study indicated a weak association between electromagnetic field exposure and the risk of breast cancer.[24]

In Montreal, Canada, a case-control study[25] investigated the association between occupational exposure to electromagnetic fields and occurrence of female breast cancer. The records of subjects with breast cancer were obtained from the pathology departments and cancer registries from eighteen major hospitals in the greater Montreal area between 1996 and 1997.The control group was selected from the same hospitals over the same period and comprised of 667 subjects. Interviews were held to obtain the details of all occupations held over the working life-time. A four-category scale was used to assign the duration of exposure to ELF magnetic fields as follows: (1) “no exposure” (<0.2 µT); (2) “low exposure” (0.2 - <0.5 µT); (3) “medium exposure” (≥0.5 - <1.0 µT); and (4) “high exposure” (≥1.0 - 10 µT). There were 608 cases of subjects with breast cancer that were included in the study. A small increased incidence of breast cancer was observed among postmenopausal women who were exposed to ELF magnetic fields.[25]

The epidemiological and aetiological factors of male breast carcinoma were evaluated by a study[26] conducted in eastern Turkey. Breast carcinoma was evaluated in patients who were admitted to a regional hospital from 1990 to 2000. A total of 196 patients were admitted to the hospital and 5% (n=11) were males. Four of these patients worked for the Turkish Institution of Electricity. These cases were among the thirteen in the records of the Turkish Institution of Electricity. Right-sided breast cancer was observed among seven cases while left-sided breast carcinoma was observed in four cases. The incidence rate of breast cancer among these workers was estimated to be 0.3%. The study indicated a relationship between exposure to EMFs from light at night and the occurrence of male breast carcinoma. The duration of exposure to EMFs was also identified as a risk factor.[26]

The relationship between occupational history and the risk of breast cancer was examined in a case-control study[27] in Shanghai, China. Data from subjects with breast cancer (n=1458) was collected and compared with the control group (n=1556). A high incidence of breast cancer was observed among subjects employed as laboratory technicians, telephone and telegraph operators, leather and fur processors and glass manufacturing workers. Several occupations were associated with increased risk of breast cancer among women. The study did not focus on exposure levels to electromagnetic fields and therefore there were no significant excess risks reported among occupations thought to have a potential for exposure.[27]

A study[28] was conducted to investigate whether occupational magnetic field exposure is associated with breast cancer or not. About 20 400 cases of female breast cancer were identified from the cancer registry and 116 227 controls were randomly selected from the study base. Women who were employed between 1976 and 1999 in Stockholm or Gotland country in Sweden were included in the study. About 49 of the most common occupations for women in Stockholm Country were included. An Emdex Lite personal monitor was carried on the belts by the participants for 24 hours in order to measure the magnetic fields. The personal exposure levels to magnetic fields were measured on participants among all occupational groups. About 11369 cases of breast cancer were related to the magnetic field exposure levels of between 0.1 - 0.19 µT while 814 cases were related to exposure levels of about ≥ 3 µT. The link between the breast cancer incidence and the exposure measurement was relatively weak and did not yield positive results. Therefore according to the study, there was no positive association between occupational exposure to magnetic fields and the risk of breast cancer.[28]

2.9.2 Electromagnetic fields and leukaemia

Leukaemia refers to cancer of the blood and the bone marrow. It is classified according to the cell types of origin and the rate at which the disease progresses. It is commonly found in children and constitutes more than a third of all childhood cancers.[7] The incidence rate of leukaemia differs among various regional and ethnic groups. The highest rate in the United State of America (USA) is found among the Hispanics in Los Angeles and the Filipinos as well as the Chinese and Japanese in California and Hawaii. According to the International Association of Cancer Registries (IARC)[29] the global incidence of childhood leukaemia was estimated in 2000. The incidence rate of leukaemia among Caucasians was moderate to high, and low among African-Americans. The regional differences in the United States with regard to leukaemia rates range from 2.2 - 5.6 per 100 boys and 1.4 - 6.3 per 100 000 for girls.[30] A high incidence rate of leukaemia were reported in Costa Rica, and also among the non-Maori population in New Zealand.[30,31] There were some reports on the high incidence of leukaemia in Scandinavian countries, Australia, Hong Kong and the Philippines. The rates were similar to those of Hispanic males in Los Angeles and were ranged from 4.5 to 5.5 cases per 100 000 annually.[30,31] High incidence rates of leukaemia were reported in countries such as Germany, Great Britain, France and Hungary as well as in Japan and China.[30] High incidence rates were also reported among Jews in Israel.[31] The incidence rates observed in India, among Kuwaitis in Kuwait and black children in Africa were low.[32,33,34]

The sex ratio of incidence and the patterns of age-specific rates were similar among various countries. The early childhood peak in all incidences was absent among African children. The differences in the incidence rates may be due to genetic factors. Inherited genetic factors may predispose certain ethnic groups to childhood leukaemia. Other factors such as unidentified environmental factors or higher socioeconomic status may predispose children in more developed countries to an increased risk of leukaemia. Leukaemia develops from the chromosomal changes and mutations that disturb the differentiation of the lymphoid or myeloid progenitor cells. The trigger for this mutation may be inherited at conception, or may occur during foetal development or infancy.[32] The development of childhood leukaemia is a multi-step process that requires one prenatal event in combination with additional prenatal and postnatal events. A number of factors are involved in the etiology of childhood leukaemia. Ionizing radiation is one of the environmental factors that increases the risk of childhood leukaemia.[32]

Data from various cancer registers was used in a case-control study[35] conducted in England and Wales among 33 000 children aged from birth to 14 years. Subjects were identified who were residing within the distance of 1 km from the 275 kV or 400 kV and a few 132 kV power lines were identified. The shortest distance to any power line that had existed in the year of birth was used to determine the exposure. The excess risk of leukaemia was observed by comparing the distances to the transmission lines (between 500-599 m and greater than 600 m). An association between childhood leukaemia and proximity of home address at birth to high voltage lines was observed and reported in the study.[34] Children who were living within a distance of 200 m from the power lines had a high risk of leukaemia as compared to those who were residing where the distance from power lines was greater than 600 m. Feychting (1997)[36] reports that the risk of leukaemia is doubled among subjects who have resided for at least one year within a distance 300 meters from the power lines and were exposed to magnetic fields at or above 2 mG.

The research conducted in past years indicates an increased incidence of leukaemia among employees in the electrical industry. A study was conducted in Washington State during the years 1950 to 1982 to investigate the mortality rate among employees exposed to electromagnetic fields. There were about 486 000 deaths recorded in Washington State. Nine occupations which were considered to have a high exposure to electromagnetic fields were included in the study. These occupations were electrical and electronic technicians, radio and telegraph operators, radio and television repairmen, telephone and power linemen, power station operators, welders, aluminium reduction workers, motion projectionists and electricians. A total of 12 714 deaths were recorded in these occupations. An increase in the mortality rate due to leukaemia was observed in eight occupations. The findings of the study support the hypothesis that exposure to electromagnetic fields is carcinogenic and increases the risk for leukaemia.[37]

The relationship between exposure to extremely low frequencies and the mortality rate due to leukaemia was investigated in a cohort study[38] of Swiss railway workers between the years 1972 and 2002. The mortality rate of train drivers and that of station masters were compared. The average occupational exposure level to magnetic fields was 21 µT and 1 µT for train drivers and station masters respectively. The findings of the study indicated a high mortality rate due to myeloid leukaemia among train drivers as compared to station masters. The findings of the study provide evidence for association between heavy exposure to electromagnetic fields and increased mortality rate due to leukaemia.[39]

Exposure to magnetic fields poses a threat to the development of childhood leukaemia. The childhood leukaemia incidence rate increases with an increase in exposure to magnetic fields. One study[39] indicates that an increase in the incidence of childhood leukaemia at around the age of three years is linked to electrification and exposure thereto. The study was conducted among children aged 15 years or less and diagnosed between 1999 and 2002 in Japan. About 10.7 million children aged from 0-15 years from the total 20 million were included in the study. Three control groups were selected for each case and matched according to gender, age and residential area. The magnetic fields were measured for five minutes in a room where each child spent the longest time of the day. Measurements were taken for one week in the four corners of the house and at an entrance. The distance from each house to the closest overhead power transmission line was measured. The number of years that the subjects resided at the current house from the period of conception to the diagnosis was taken into consideration. The main exposure metric comprised a weekly arithmetic mean magnetic field in the child's bedroom. The results of the study indicate that an increase in the incidence rate of common acute lymphoblastic leukaemia was linked to electrification. An increase in the mortality rate due to leukaemia was observed among children aged between 2 and 4 years who were residing in houses supplied with electricity.[38] Previous studies[40-45] were conducted to investigate the risk of leukaemia and occupational exposure to electromagnetic fields in electrical occupations. One study[40] indicates an increased risk of leukaemia among men who were occupationally exposed to electromagnetic fields. The relative risk for all types of leukaemia was 1.28 (28% increase), while for acute leukaemia and acute myeloid leukaemia the risk was 1.72 (72% increase) and 2.07 (20.7% increase) respectively.[40]

The relationship between exposure to EMFs and the mortality rate among electrical workers was investigated in 1983. The null hypothesis of the study was that the incidence of leukaemia would be similar in all occupations. The findings of the study[41] show a 17% increase in the risk of leukaemia in electrical occupations. Another study investigated the risk of leukaemia among male coal miners who had prolonged EMFs exposure in 1985. Results of this study[42] indicate an increased risk for chronic leukaemia, myelogenous leukaemia and chronic lymphocytic leukaemia among the subjects. The study[43] reports an increase in the incidence of acute myeloid leukaemia among electrical workers was related to EMF exposure. Stern *et al*. (1986) investigated the incidence of leukaemia among electricians and welders who were occupationally exposed to EMFs.[44] The findings of the study did not indicate an increased risk of leukaemia among welders. Therefore the study does not support the hypothesis that increased risk of leukaemia among workers in electrical trades is due to their occupational exposure to EMFs.[44] Floderus (1994) reports an increase risk of chronic lymphocytic leukaemia among Swiss railway workers who were exposed to extremely low frequency EMFs ranging from 5.5 to 40.3 mG.[45] An increase risk of chronic lymphocytic leukaemia among subjects occupationally exposed to electromagnetic fields was also reported by Floderus (1993).[46]

2.10 Conclusion

There is compelling research to suggest that exposure to electromagnetic fields can have potential adverse health impacts despite differing perspectives on the part of researchers. The intensity of the impact of electromagnetic fields on human health remains a subject to be debated. Modern society is facing some challenges with regard to the matter of electromagnetic fields. These challenges are: (1) schools and residences continue to be built in close proximity to power lines; (2) mobile phone masts continue to be constructed in residential areas; (3) pregnant women are exposed to radiation in various occupations; and (4) employees in various industries such as welding and electrical industries are exposed to high electromagnetic field levels. This is due to a lack of knowledge about the health risks associated with exposure to electromagnetic fields. There is a need to inform the public and various industries about the potential adverse health effects associated with exposure to electromagnetic fields and precautions that should be taken to minimise the risks associated with exposure to electromagnetic fields.

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CHAPTER 3

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3 Assessment of occupational exposure to electromagnetic fields in the welding industry

3.1 Abstract

The assessment of occupational exposure to extremely low frequency (ELF) electromagnetic fields amongst 88 randomly selected welders and fitters in a South African welding industry was conducted. Measurements of ELF electromagnetic fields were taken at three workstations (workshop A, workshop B and 'offices') and time weighted average (TWA) exposure levels at a distance of 1, 2 and 3 m were determined. The exposure levels of magnetic fields were high in the welding workshops compared to the offices, with welders and fitters being exposed on average to magnetic fields of about 7.6 microtesla (μT) in the two welding workshops. Electric fields were relatively low at all three workstations, viz. -15.50 and -13.50 volts per meter (v/m) in workshops A and B, respectively (p=0.02), and 1.80 v/m in 'offices.'

Keywords: electric fields, electromagnetic fields, extremely low frequency, welders, fitters

3.2 Introduction

Electromagnetic fields (EMFs), which comprise both electric and magnetic fields, are invisible lines produced by power lines, electrical wiring, and equipment. Electric fields are produced by differences in the voltage whereas magnetic fields are produced whenever there is a flow of electric current. Electric fields exist even if there is no flow of current.[1] The usage of electricity generates extremely low frequency (ELF) EMFs with a frequency of 50 - 60 Hz.[2] According to the EMF spectrum, ELF EMFs have frequencies ranging from 3 to 3000 Hz. The wavelengths of ELF electromagnetic fields are very wide (approximately 6000 and 5000 km at 50 and 60 Hz, respectively) and therefore the electric and magnetic fields propagate effectively.[3] High frequency (HF) electromagnetic fields have a frequency that ranges from 3 to 30 Mega Hertz (MHz) with wavelengths of between 10 and 100 m. They are commonly found in the communication industry for transmission of information (e.g. television antennas and radio station or mobile phone base stations).[4] In developed countries, many people are exposed to devices that generate HF EMFs.

An increased risk of brain cancer has been associated with exposure to HF EMFs.[5] Cervallati *et al*. report that exposure to HF EMFs can modify connexin mRNA expression patterns and protein localisation in extravillous trophoblast cells.[6] Numerous *in vitro* and *in vivo* studies were performed to determine the effects of HF EMFs on the DNA molecule. Laboratory studies report that exposure to HF EMFs increases DNA damage and induces carcinogenesis.[7,8] Some studies, however, have shown no association between DNA damage and HF EMF exposure.[9,10]

In the welding industry, welding equipment produces ELF EMFs of around 50 to 60 Hz. Some studies suggest that exposure to EMFs has negative effects on humans and can lead to the development of leukaemia, neurodegenerative diseases, cardiovascular diseases, and brain, breast and other types of cancer.[11-17] Studies conducted in the electrical industry indicate an association between the risk of developing leukaemia and occupational exposure to ELF EMFs.[18,19] Studies on the incidence of breast cancer associated with occupational exposure to EMFs have produced conflicting results.[20-22]

Studies have reported that welding and working near high voltage power lines is associated with increased exposure to ELF EMFs.[23,13,17] Håkansson *et al*. show that welders were exposed to high levels of ELF EMFs and had an increased risk of developing tumours of the endocrine glands.[24] This has become a concern as welding is an occupation with the highest workday mean exposure to EMFs.[25]

Epidemiological studies[25-34] have investigated the association between exposure to ELF EMFs and the risk of developing chronic diseases. The relative risks for developing chronic diseases and other adverse health effects have been related to exposure level and job category. A study conducted to quantify magnetic field intensities in certain working environments with individual measurements[35] indicates high exposure to EMFs among employees in certain workplaces, such as at a transformer substation, and welding and railroad maintenance sites. It also indicates that welders were exposed to high levels of magnetic fields at about 600 µT for a short time, subjecting them to possible risk for the development of cancer.[35]

3.3 Problem statement

Given that exposure to ELF EMFs in the welding industry can pose a serious health risk among welders and fitters and that there has been little published research on this field in South Africa, there is a need to assess such exposure for different occupations in the industry and to improve health and safety conditions where necessary. This chapter describes a study which was conducted to measure the levels of ELF EMFs in a group of fitters and welders in South Africa, in order to comment on the possible risks associated with identified levels of exposure.

3.4 Methodology

3.4.1 Sampling

The workers that participated in the study were welders, fitters and office workers employed in a heavy engineering CO_2 (carbon dioxide) welding company in the Free State, South Africa. The exposed group comprised 37 welders and 21 fitters employed in workshops A and B with similar tasks; the control group comprised of 30 office workers (88 workers in total). Subjects were randomly selected and gave their consent to participate in the study by signing a consent form.

3.4.2 Measurement of ELF EMFs

Daily ELF electromagnetic exposure measurements were taken in three workstations, viz workshop A, workshop B and offices for a period of 14 days. Measurements were taken for the entire work shift for a period of 8 hours per day at different intervals. Different sampling techniques were used to measure the electric and magnetic fields in the three workstations. Measurements were taken in the workshops only when the subjects were welding and fitting. Time-weighted average (TWA) exposure levels were determined from the measurements. Measurements of magnetic fields were taken at different distances[35] (1 m, 2 m and 3 m) from the welding tips in the workshops and from computers, photocopy machines and electrical wires in the offices. In all workstations, a Trifield meter (model 100XE) with a frequency of 50 Hz was used to measure the magnetic fields, whilst a digital alternating current (AC) electric field meter with a frequency range of 40 Hz to 50 kHz was used to measure the electric fields. The Trifield and digital AC electric field meters were hand-held in a vertical direction with the sensor facing towards the source of the EMFs when the measurements were taken. The different distances were not used when measuring the electric fields. Measurements were taken for ELF electromagnetic fields at the frequency of 50 Hz. The measurements were recorded on a data collection sheet.

3.4.3 Data analysis

Data from the EMFs were captured electronically in Microsoft Excel 2007. Analysis was performed using SAS Version 9.2. Frequencies and percentages were calculated for categorical data; medians and percentiles were calculated for continuous data. The data were not normally distributed and therefore Kruskal-Wallis tests were used to compare median values obtained from the groups. The statistical significance level used was 95%.

3.4.4 Ethical clearance

Ethical clearance was obtained from the Ethics Committee of the University of the Free State (reference number 170/2011).

3.5 Results

The data were skewed and therefore the median, with the lower and upper quartile range, was used to report the results. Table 1 displays the general characteristics of the study groups. Thirty percent and 29% of welders and fitters were smokers respectively; 27% of office workers smoked. The median number of hours spent welding and fitting by the exposed group was eight. The median number of years worked was four for fitters and five each for the welders and office workers. The sample was a young group with median age in the thirties. The median ages of fitters and welders were 32 and 33 years, respectively, and 37 years for office workers.

Table 3.1: General characteristics of the study groups (N=88)

General characteristics		**Fitters (n=21)**	**Office workers (n=30)**	**Welders (n=37)**	**P value**
Age	Median Lower quartile Upper quartile	32.00 28.00 37.00	37.00 31.00 49.00	33.00 29.00 39.00	0.07*
Smoking status (%) • Smokers • Non-smokers		 29.00 71.00	 27.00 73.00	 30.00 70.00	0.96**
Working hours per week	Median Lower quartile Upper quartile	40 40 40	40 40 40	40 40 48	0.33*
Working experience (years)	Median Lower quartile Upper quartile	4.00 3.00 4.00	5.00 2.00 7.00	5.00 3.00 10.00	0.13*
Hours spent fitting/welding per day	Median Lower quartile Upper quartile	8.00 6.00 8.00	–	8.00 7.00 8.00	0.17*

*Kruskal-Wallis Test

3.5.1 Magnetic fields

Figure 1 and Table 2 compare the median magnetic field exposures between the three workstations at 1, 2 and 3 m. The median TWAs of magnetic fields at 1 m in workshops A and B were 7.44 µT and 7.56 µT, respectively; in the offices it was 0.15 µT. There was a statistically significant difference between the median TWAs of workshop A and offices, and workshop B and offices, but no statistically significant difference between workshop A and workshop B.

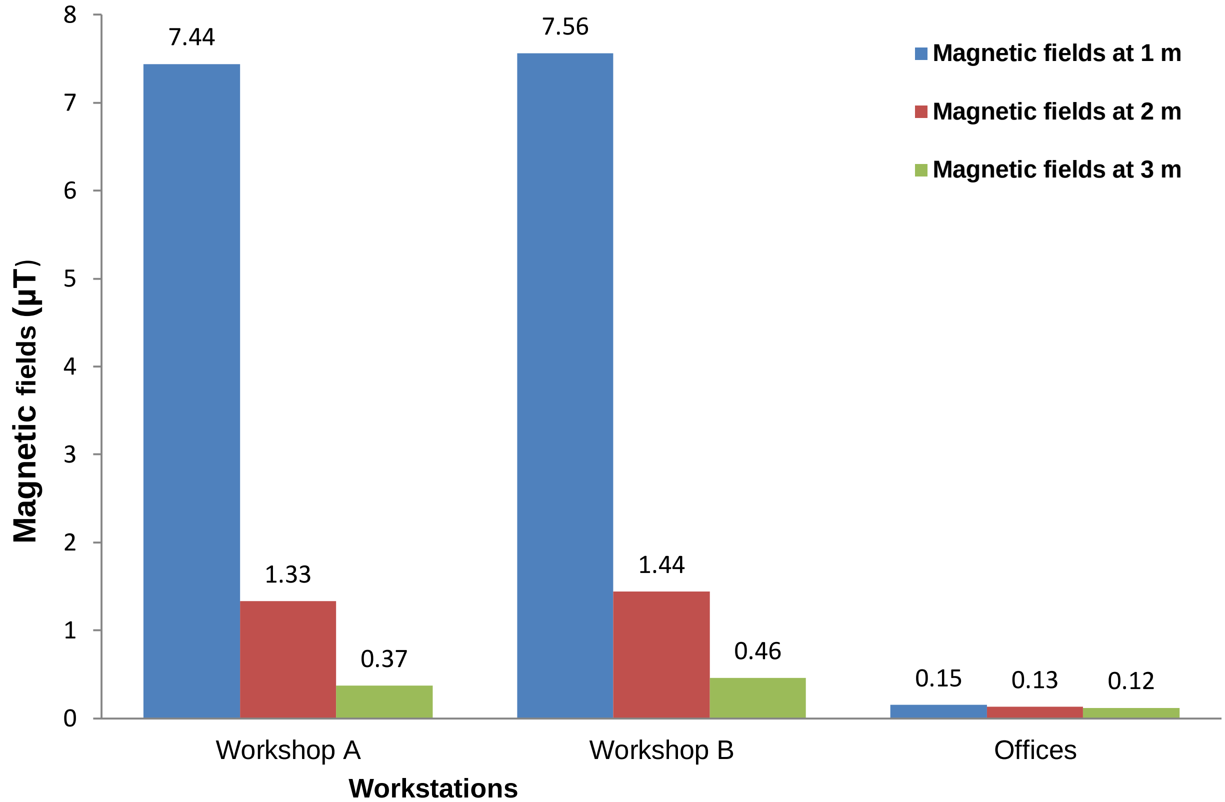

Figure 3.1. Comparison of TWA (medians) magnetic fields (µT) at 1, 2 and 3 meters

The median TWAs in workshops A and B at 2 m were 1.33 µT and 1.44 µT, respectively, and that in the offices was 0.13 µT. There was no statistically significant difference between the median values of workshops A and B. A statistically significant difference was observed between workshop A and the offices, and between workshop B and the offices. The median values TWAs at 3 m for workshops A and B were 0.37 µT and 0.46 µT respectively, and that in the offices was 0.12 µT. There was a statistically significant difference between the median values of workshops A and B, between workshop A and the offices and workshop B and the offices. The overall comparison of median values of magnetic fields between workstations at 1 m, 2 m and 3 m in Figure 1 shows the relationship between the magnetic field strength and the distance from the source of the fields.

Table 3.2: TWA magnetic field exposures measured at distances of 1, 2 and 3 meters

	One meter		Two meters		Three meters	
Workstation	**TWA (μT)**	**P value**	**TWA (μT)**	**P value**	**TWA (μT)**	**P value**
Workshop A						
Median	7.44	<0.0001* (A vs B vs Office)	1.33	<0.0001* (A vs B vs Office)	0.37	<0.0001* (A vs B vs Office)
Lower quartile	6.0		0.8		0.33	
Upper quartile	8.13		1.38		0.48	
Peak magnetic fields	9.40		2.40		0.73	
Workshop B						
Median	7.56	0.82 * (A vs B)	1.44	<0.27 * (A vs B)	0.46	<0.02* (A vs B)
Lower quartile	6.75		1.06		0.4	
Upper quartile	7.88		1.65		0.66	
Peak magnetic fields	9.38		2.19		0.80	
Office						
Median	0.15	<0.0001* (A vs Office)	0.13	<0.0001* (A vs Office)	0.12	<0.0001* (A vs Office)
Lower quartile	0.14	<0.0001* (B vs Office)	0.12	<0.0001* (B vs Office)	0.11	<0.0001* (B vs Office)
Upper quartile	0.17		0.13		0.12	
Peak magnetic fields	0.20		0.17		0.13	

*Kruskal-Wallis Test

The magnetic field strength decreased as the distance from the source of the fields increased. The values for the peak magnetic fields measured at a distance of 1 m in workshop A and workshop B, respectively, were 9.40 μT and 9.38 μT; and that in the office was 0.2 µT. The values for the peak magnetic fields at 2 m were 2.4 µT and 2.19 µT in workshop A and workshop B, respectively, and that in the office was 0.17 µT. The peak values for magnetic fields at a distance of 3 m were 0.73 µT and 0.8 µT, respectively, in workshop A and workshop B and that in the office was 0.13 µT. The peak values for magnetic fields were low as the distance from the sources of exposure was increased. The highest peak values were recorded at a distance of 1m.

3.5.2 Electric fields

Table 3 shows the median TWAs for the electric fields measured in the three workstations, viz -15.50 and -13.50 volts per meter (v/m) in workshops A and B, respectively.

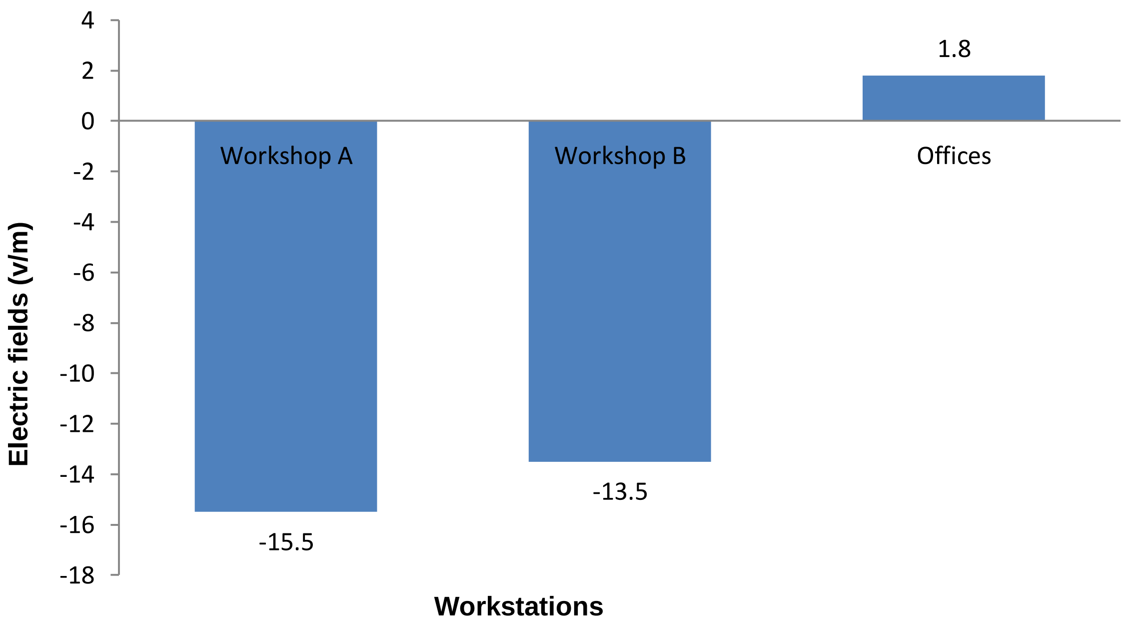

Figure 3.2. Comparison of TWA (medians) electric fields (v/m).

Welding is associated with low output voltage. It is assumed that the output voltage on the welding machines was lower than that on electrical machines and appliances in the offices, accounting for the negative electric fields recorded in the workshops and positive electric fields recorded in offices. The median TWA in the offices was 1.80 v/m. Figure 2 compares the median electric field exposures between the three workstations. There was a statistically significant difference between workshops A and B, between all three workstations, between workshop A and the offices and workshop B and the offices.

Table 3.3: TWA electric field exposures measured at three workstations

Workstation		TWA electric fields (v/m)	P value
Workshop A	Median Lower quartile Upper quartile	-15.50 -16.00 -15.50	<0.0001* (A vs B vs Office)
Workshop B	Median Lower quartile Upper quartile	-13.50 -15.00 -12.00	0.02* (A vs B)
Offices	Median Lower quartile Upper qurtile	1.80 1.50 2.00	<0.0001* (A vs Office)

*Kruskal-Wallis Test

3.6 Discussion

Industrialisation has introduced different kinds of electrical machines and appliances into the workplace, and the machines and appliances used in workshops and offices are examples of some that cause magnetic fields that may affect the users thereof. The exposure levels of magnetic fields were high in the welding workshops compared to the offices, with welders and fitters being exposed on average to magnetic fields of about 7.6 µT in the two welding workshops. Welding machines generate high magnetic field levels, accounting for the high magnetic field strengths observed. The high intensity of magnetic fields was also influenced by conditions such as distance from the generating source, frequency of usage of machines, and duration of work time.

Measurements may have been influenced by other generating sources such as electrical wires and electrical appliances, as well as by the layout of the welding workshops. The differences in magnetic field strength, particularly at a distance of 3 m, could be due to fields from surrounding sources, such as electrical main switch boxes. Welding requires a high current (over 80 amperes) which results in the generation of high levels of magnetic field.[1,4]

The magnetic fields were very low in the offices. Office workers use flat screen computers that generate low magnetic field levels. During the sampling period, the photocopy machines were not used and the magnetic fields measured in their vicinity were very low. Other sources generating low magnetic fields in offices were electric light bulbs, fax machines, printers, scanners and air conditioners. There were fewer electrical wires in the offices than in the welding workshops. On average, office workers were exposed to low levels of magnetic field, which are not considered to pose a serious health risk.[36,37]

Electric fields are created largely by differences in voltage. The low levels of electric field in offices and workshops seem to be due to low voltage. The higher the voltage, the stronger will be the electric fields.[1] During welding, a transformer converts the high voltage and low current from electricity into a high current and low voltage. It appears that the transformer reduces the voltage and this results in low electric fields in the workshops. The transformer used on the welding machines allows welders to select the output voltage. Electric fields from power lines outside the workshops and offices were shielded by walls and trees. Negative electric fields observed in the workshops were created by low output voltage on the welding machines, while positive electric fields observed in the offices were created by high output voltage on electrical appliances and machines. In the offices, the output voltage was not altered due to the fact that electrical appliances were not connected to a transformer and this may account for the positive electric fields observed. In the workshops, the welding machines were connected to transformers that alter the output voltage and this is assumed to contribute to negative electric fields recorded.

In South Africa, electricity is supplied to homes and business areas at a voltage of 220/230 volts at a frequency of 50 Hz. The statistically significant difference in electric fields observed in the workshops and offices may be due to the differences in the output voltage from the sources of exposure.

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) has recently revised its guidelines for exposure limits of EMFs. The occupational exposure limits for electric and magnetic fields at 50 Hz are 10 kV/m and 1000 µT or 1 mT, respectively.[38] In the current study, the median values for magnetic and electric fields were below the exposure limits. The values for the peak magnetic fields were also lower than the exposure limits at all distances. Exposure of cells to ELF magnetic fields below 50 mT has not been associated with the induction of genotoxicity.[39] Welding and fitting are known to be associated with exposure to high magnetic field levels which could result in adverse health effects. Epidemiological studies have indicated that daily exposure to ELF magnetic fields of above 0.3 - 0.4 µT increases the risk of childhood leukaemia.[40] TWA exposure levels of >0.2 µT for magnetic fields have been associated with a reduction in the natural killer cell activity among exposed workers.[41]

The exposure levels of welders observed in an Italian study[2] conducted in 2011 were also similar to those described in the present study at a distance of 1 m. The median value of the magnetic fields for the entire work shift was 7.2 µT. The occupational exposure levels to magnetic fields observed in a 2003 Japanese study[35] were higher than those of the present study. Welders were exposed to magnetic fields of about 600 µT. Qiu *et al.* report that exposure to ELF magnetic fields of about ≥0.2 µT was associated with the risk of development of Alzheimer's disease and dementia.[16] In a cohort study conducted among Swiss railway workers,[42] the average exposure levels to magnetic fields for train drivers was 21 µT. This exposure level was associated with a high incidence rate of myeloid leukaemia.

In the current study welders and fitters were exposed to high levels of magnetic field, and may therefore be at risk of developing chronic diseases such as leukaemia, brain cancer, breast cancer, and other types of diseases associated with excessive exposure to magnetic fields.[14, 17] On average, the subjects weld and fit for 8 hours per day. The longer the time they spent welding and fitting, the higher the exposure and risk of developing chronic diseases. It should be noted that smoking also increases the risk of developing certain cancers,[43] and about one third of the study population smoked. The potential risk of miscarriage is also assumed to be high among pregnant women exposed to magnetic fields of 1.6 µT or higher.[44]

3.7 Conclusion

Welders and fitters in this study were exposed to high magnetic field levels. The risk of developing adverse health effects may be high among welders and fitters and low among office workers. There is a need to improve working conditions and implement safety measures in order to minimise exposure to EMFs in the welding industry. In South Africa, data on occupational exposure to EMFs in the welding industry is currently lacking, and therefore this study provides valuable data essential for the improvement of occupational health and safety. This is important as occupational exposure to ELF EMFs may increase the risk of developing chronic diseases such as leukaemia, brain cancer and breast cancer among highly exposed employees such as welders and fitters.

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CHAPTER 4

This chapter has been partially published:

Raphela SF, Weyers C and Shale K. Symptoms of ill health associated with electromagnetic exposure in the welding industry. Occup Health Southern Africa. 2013, 19(4): 24-29.

4 Possible symptoms of ill health ascribed to electromagnetic field exposure in the welding industry – a questionnaire survey

4.1 Abstract

A questionnaire survey was conducted among employees in the welding industry. The employees were welders (n=37), fitters (n=21) and office workers (n=30), totalling eighty-eight (88) respondents from one company. The objective of the survey was to gain a better knowledge about the prevalence of possible health symptoms among employees exposed to extremely low-frequency electromagnetic fields. Participation in the study was voluntary. The exposed group comprised welders and fitters while the control group comprised office workers. Workers completed structured questionnaires and consent forms. On the questionnaires the workers indicated the type and prevalence of symptoms experienced in the three months prior to the survey. The values for the median age of welders and fitters were thirty-three and thirty-two respectively, and thirty-seven for office workers. Welders (70%), fitters (61%) and office workers (56%) experienced headaches most of the time during working hours and even after work. Welders also reported that they suffered from sleep disorders (32%), fatigue (37%) and distress (27%). Fitters had sleep disorders (23%), distress (28%) and fatigue (33%). Office workers also experienced sleep disorders (30%), distress (36%) and fatigue (26%) among other possible symptoms. There were statistically significant difference in the proportion of exposed and control group who reported ocular-visual symptoms and skin burning sensation.

Keywords: health symptoms, survey, distress, fatigue, electromagnetic fields

4.2 Introduction

Since the introduction of machines and pieces of electrical equipment in the workplace, electromagnetic fields (EMFs) have been present in buildings and in the natural environment. Due to an increase in exposure to EMFs over the past few years, many people have reported hypersensitivity to electromagnetic fields. The term electromagnetic hypersensitivity (EHS) refers to a clinical condition where people complain of health symptoms which are ascribed to exposure to electromagnetic fields.[1] In most instances people suffer from symptoms of ill health such as headaches, sleep disorders, skin rash, dizziness, fatigue, concentration difficulty and others related to EMF exposure.[2] Other symptoms related to hypersensitivity to electromagnetic fields include distress, neuroticism and psychiatric morbidity.[3] It is estimated that the prevalence of health symptoms among individuals differs according to the type and level of exposure to electromagnetic fields. Considerable psychological stress is caused in these individuals by health complaints related to exposure to EMFs.[4] Adequate medical treatment for these individual is difficult due to lack of knowledge of the pathophysiology of the symptoms. A population survey conducted in Stockholm indicated that about 1.5% of the population reported suffering from symptoms of ill health associated with exposure to electromagnetic fields.[5]

A survey conducted in California indicated that about 3.2% of the population reported a degree of hypersensitivity to EMFs.[6] Similar results were also reported in a study that used a more sophisticated procedure to determine hypersensitivity to electromagnetic fields,[7] in that the perception threshold and its standard deviation were used to investigate and characterise electromagnetic hypersensitivity.[7] The prevalence of EHS was first estimated at 1.5% and recently[8] at 2.6 to 3.2% in Sweden. Prevalence in Australia[9] was estimated to be less than 2% in 1994 but had increased to 3.5% in 2001, while about 5% of the population in Switzerland had been estimated to suffer from EHS.[5] Some controlled experimental studies indicated contradictory results although health symptoms were reported in other studies.[10,11] There is no specific symptom profile or validated diagnostic criteria to diagnose the degree of hypersensitivity to electromagnetic fields.[6]

4.3 Problem statement

Public discussions about hypersensitivity to electromagnetic fields have increased very rapidly since the early nineties, especially because of concerns that adverse health impacts and some symptoms of ill health are related to exposure to electromagnetic fields. There is a need to assess the prevalence of the symptoms of ill health among employees in the welding industry and to determine the degree of compliance to safety standards.

The objective of the study was:

- to describe and calculate the prevalence of health symptoms among the employees.

4.4 Methodology

4.4.1 Subjects and ethical clearance

The study population consisted of all full-time welders, fitters and office workers from one mega company in the heavy engineering CO_2 welding industry in the Mangaung Metropolitan Municipality. A total of 88 workers participated voluntarily in the study. The exposed group comprised 37 welders and 21 fitters, while the control group comprised 30 office workers. Ethical clearance was obtained from the Ethics Committee of the University of the Free State (reference number: 170/2011). The study population consisted of all full-time welders and fitters and office workers. Permanent welders, fitters and office workers were included in the study. Both male and female workers of different races from within the country (South Africa) and other foreign countries were included. At the time of the survey, in November 2011, there were 124 full-time employees working at the welding company.

4.4.2 Questionnaires and confidentiality

A self-administered questionnaire, consisting of open- and close-ended questions, and compiled in English, was used to collect data. The questionnaire was piloted among part-time employees (welders, fitters and office workers) in the company before commencement of the survey, and included demographic information such as age, gender, and smoking status, as well as work-related information, such as duration of service, hours of work per week, hours spent welding or fitting, and current position in the company. Questions were asked about health with regard to neurological, musculoskeletal, respiratory, dermatological and ocular-visual symptoms. Questions were also asked with regard to safety equipment and use, general work environment and general health information.

4.4.3 Evaluation of the data obtained from questionnaires

The information obtained from the subjects through completion of the questionnaires was used to evaluate the extent to which employees are exposed to EMFs. The information from the experimental and the control groups was compared against each other. The prevalence of symptoms associated with exposure to EMFs among employees was used to evaluate the exposure. The type of equipment used was taken into consideration when evaluating the exposure of employees.

4.4.4 Data analysis

Data from the questionnaires was captured electronically on Microsoft Excel 2007. Further analysis was done using SAS Version 9.2. Descriptive statistics, namely frequencies and percentages, were calculated for categorical data. Medians and percentiles were calculated for numerical data. The Chi squared statistics and Fisher's Exact tests were used to compare the percentages and the median obtained from the groups (i.e. welders, fitters and office workers).

4.4.5 Site inspection and safety standards

The health and safety standards in the workplaces were inspected, and general housekeeping and safety precautions in the workplace were examined. The protective clothing and equipment used by employees were examined to determine whether any risks were associated with them.

4.5 Results

4.5.1 Study subjects

The results in Table 4.1 indicate that the median ages for welders and fitters were 33 and 32 years respectively, with the median age for office workers being 37. The comparison for the median values of age among the subjects is shown in Figure 4.1. Figure 4.2 shows the comparison of gender distribution among the subjects: 11% of the welders were female, with 89% being male. Ten percent of the fitters were female and 90% were males. Thirty percent of office workers were females and 70% were males. Twenty nine and twenty seven percent of fitters and office workers respectively were smokers, as were 30% of the welders. The value for the median of working hours per week was 40 in all the groups. The median number for the duration of service of the was four years for fitters, and five years each for welders and office workers.

Table 4.1: General characteristics of the subjects

Variable	Fitters	Office workers	Welders	P value
Age in years (median)	32	37	33	0.07*
Female	10% (n=2)	30% (n=9)	11% (n=4)	0.06***
Male	90% (n=19)	70% (n=21)	89% (n=33)	
Smokers	29% (n=6)	27% (n=8)	30% (n=11)	0.96***
Non-smokers	71% (n=15)	73% (n=22)	70% (n=26)	
Hours of work per week (median)	40	40	40	0.17*
Duration of service in years (median)	4	5	5	0.13*
Hours spent welding/fitting per day (median)	8	8	8	0.17*

*Kruskal-Wallis test ***Chi square statistic

There was no statistically significant difference in terms of the general characteristics of the subjects among the three groups ($p>0.05$).

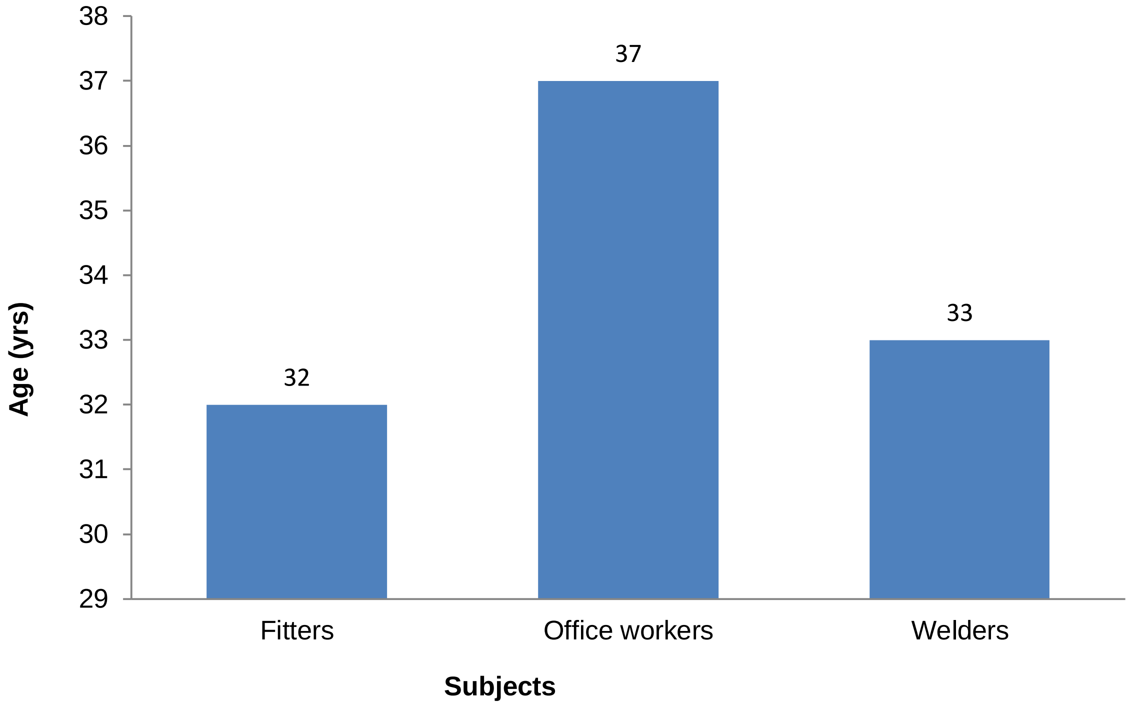

Figure 4.1. Comparison for age distribution (median)

4.5.2 Educational qualifications of the subjects

The qualifications and highest level of education for the subjects are shown in Table 4.2. Thirty six and nine percent of fitters and office workers respectively had N2-N6 level certificates while 45% of welders had the same qualifications. Office workers (13%) and welders (8%) had national diplomas as their highest qualifications. Fifteen and 17 percent of fitters and welders respectively had grades 8-11 as the highest level of education. The majority of fitters (47%) and office workers (76%) had a Grade 12 certificate as their highest qualification.

Table 4.2: Qualifications of subjects

Qualification	Fitters	Office workers	Welders	P value
N2 –N6	36.8% (n=7)	9.9% (N=3)	45.7% (n=16)	0.0012**
Diploma	0	13.3% (N=4)	8.6% (n=3)	
Grade 8 -11	15.8% (n=3)	0	17.2% (n=6)	
Grade 12	47.4% (n=9)	76.7% (N=23)	28.6% (n=10)	

**Fisher's Exact test

4.5.3 Utilisation of protective clothing and equipment by welders and fitters during welding and fitting

The results in Table 4.3 summarise the degree of utilisation of protective clothing and equipment by the subjects. Welders (81%) and fitters (81%) wore face masks. All welders and 95% of fitters were wearing hard hats.

Table 4.3: The degree of utilisation of protective clothing and equipment

Equipment	Fitters	Welders	P value
Face mask	81% (n=17)	81.1% (n=30)	0.49**
Hard hats	95% (n=20)	100% (n=37)	0.75**
Safety glasses	95% (n=20)	81.1% (n=30)	0.46**
Ear plugs	100% (n=21)	100% (n=37)	0.52**
Overall/ apron	95% (n=20)	100% (n=37)	0.75**
Leather jacket	76.2% (n=16)	91.9% (n=34)	0.13**
Gloves	95% (n=20)	100% (n=37)	0.27**
Safety boots	100% (n=21)	100% (n=37)	1.0**

**Fisher's Exact test

The results also indicate that 95 and 81% of fitters and welders respectively were wearing safety glasses. Welders (100%) and fitters (100%) were always wearing ear plugs. Welders (100%) and fitters (95%) were also using aprons more frequently. Leather jackets were worn by 76 and 91% of fitters and welders respectively. Safety boots were worn by all subjects (100%) while welders (100%) and fitters (95%) were using gloves. There was no statistical significant difference between welders and fitters in terms of the utilisation of protective clothing and equipment ($p>0.05$). The results indicate that the majority of welders and fitters are complying with regard to the utilisation of protective clothing and equipment.

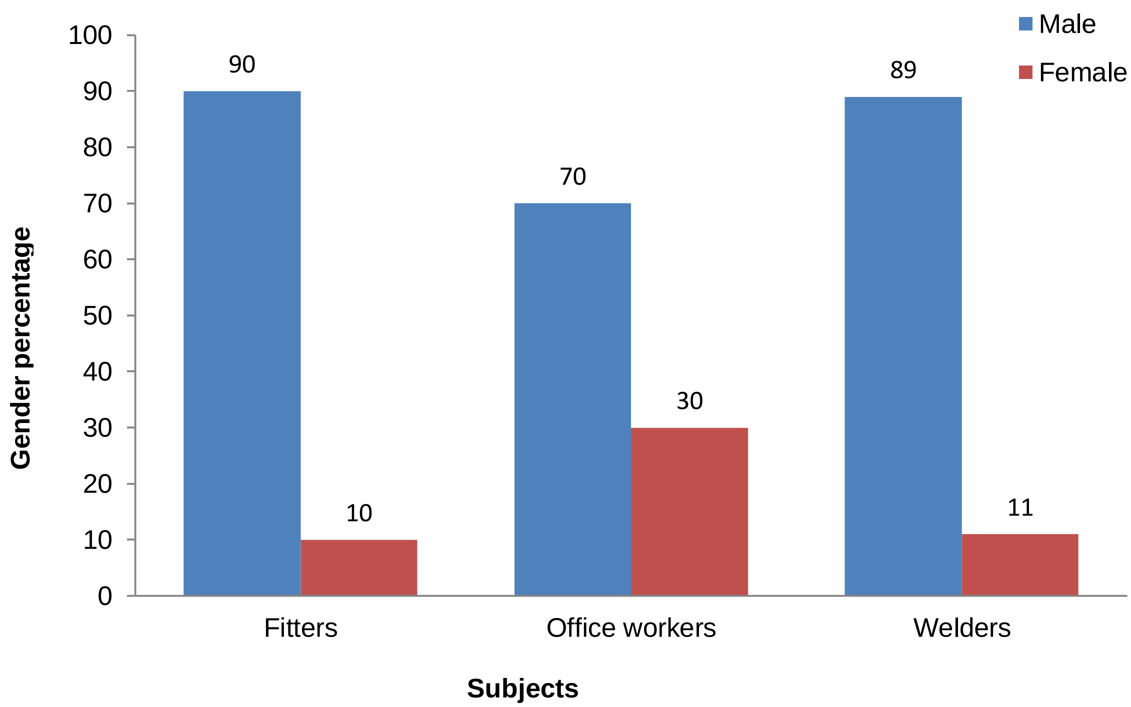

Figure 4.2. Comparison for gender distribution

4.5.4 Prevalence of electric shock

The prevalence of electric shock is indicated in Table 4.4. None of the fitters indicated having experienced severe electric shock. Thirteen percent of the office workers had experienced static electric shock while ten had experienced severe electric shock. Eleven percent of the welders had experienced static electric shock while 3% had experienced severe electric shock. There was no statistically significant difference among the three groups in terms of the prevalence of electric shock at work ($p > 0.05$).

Table 4.4: Prevalence of electric shock among the subjects

Variable	Fitters	Office workers	Welders	P value
Static electric shock	0	13% (n=4)	11% (n=4)	0.28**
Severe electric shock	0	10% (n=3)	3% (n=1)	1.0**

**Fisher's Exact test

4.5.5 Neurological symptoms

The results in Table 4.5 show the prevalence of neurological symptoms among the subjects. Figure 4.3 shows the comparison between the three groups in terms of the prevalence of symptoms. Headaches were more prevalent among the subjects (61% for fitters, 56% for office workers and 70% for welders). Twenty three and 30% of fitters and office workers respectively were suffering from sleep disorders while the percentage for the welders was 32. Fitters (28%), office workers (36%) and welders (27%) were experiencing distress to a certain extent. Thirty three and 26% of fitters and office workers respectively were suffering from fatigue while the percentage for welders was 37.

Table 4.5: Prevalence of neurological symptoms

Symptom	Fitters	Office workers	Welders	P value (Fisher's Exact test)
Headaches	61.9% (n=13)	56.7% (N=17)	70.3% (n=26)	0.75**
Sleep disorders	23.8% (n=5)	30% (N=9)	32.4% (n=8)	0.51**
Distress	28.6% (n=6)	36.7% (N=11)	27.1% (n=10)	0.82**
Fatigue	33.4% (n=7)	26.7% (N=8)	37.8% (n=14)	0.64**
Concentration difficulty	28.6% (n=6)	16.7% (N=5)	16.2% (n=6)	0.06**
Hearing impairment	14.3% (n=3)	3.3% (N=1)	10.8% (n=4)	0.64**
Dizziness	23.8% (n=5)	16.7% (N=5)	27% (n=10)	0.93**
Memory difficulty	14.3% (n=3)	13.3% (N=4)	5.4% (n=2)	0.17**

**Fisher's Exact test

Fitters (28%) and office workers (16%) as well as welders (16%) were experiencing concentration difficulty. Fitters (23%), office workers (16%) and welders (27%) were suffering from dizziness. Fourteen and 10% of fitters and welders respectively, were suffering from hearing impairment. A small proportion of office workers (3%) suffered from hearing impairment. Fitters (14%), office workers (13%) and welders (5%) were suffering from memory difficulty. There was no significant difference between the three groups in terms of the prevalence of neurological symptoms (p>0.05).

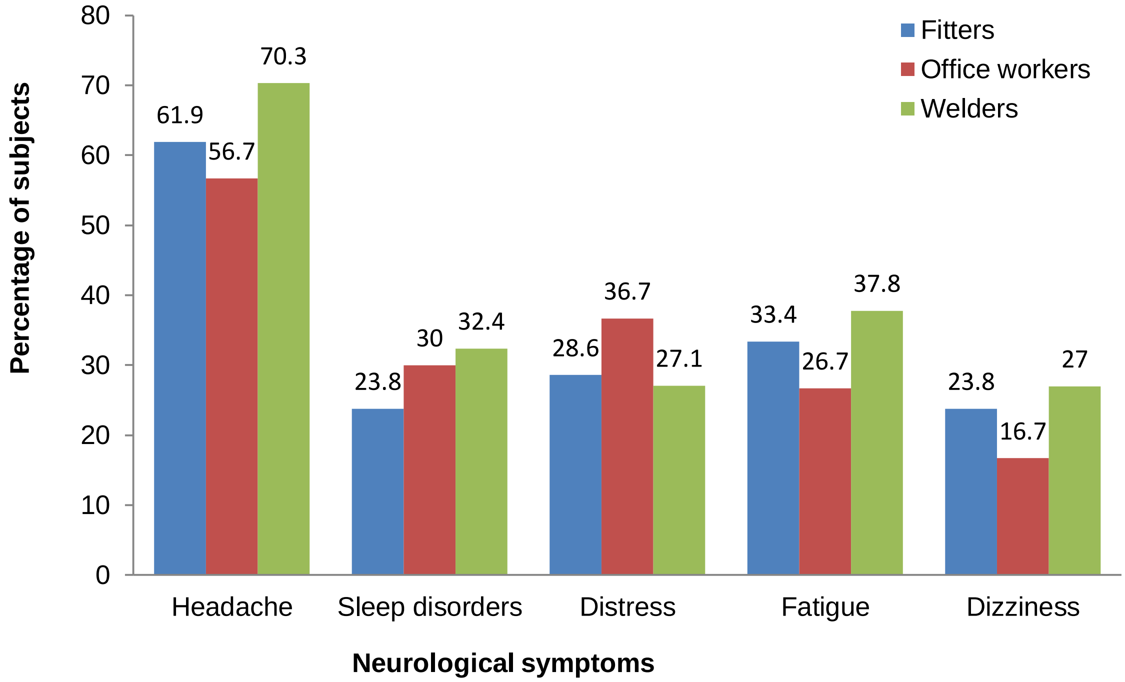

Figure 4.3. Comparison for the prevalence of neurological symptoms

4.5.6 Musculoskeletal symptoms

Table 4.6 indicates the results in regard to the prevalence of neuromuscular symptoms among the three groups. Sixty six and 43% of fitters and office workers respectively were suffering from back pain, along with 70% of welders. Forty two and 16% of fitters and office workers respectively were suffering from pain in their hands. Figure 4.4 shows the comparison for the prevalence of musculoskeletal disorders among the subjects.

Table 4.6: Prevalence of musculoskeletal symptoms

Symptom	Fitters	Office workers	Welders	P value
Back pain	66.7% (n=14)	43.3% (n=13)	70.3% (n=26)	0.11**
Pain in hands	42.9% (n=9)	16.7% (n=5)	37.8% (n=14)	0.39**
Pain in the neck	33.4% (n=7)	43.3% (n=13)	51.3% (n=19)	0.59**
Pain in arms	33.3% (n=7)	16.7% (n=5)	40.8% (n=15)	0.15**
Muscular weakness	23.9% (n=5)	13.3% (n=4)	32.4% (n=12)	0.27**

**Fisher's Exact test

Thirty seven percent of welders were also suffering from pain in their hands. Fitters (33%), office workers (43%) and welders (51%) were suffering from pain in their necks. Thirty three and 16% of fitters and office workers respectively were suffering from pain in the arms, while 40% of welders suffered with the same symptom. Subjects also reported muscular weakness to a certain extent. Welders (32%), fitters (23%) and office workers (13%) had muscular weakness. There was no statistically significant difference between the three groups in terms of the prevalence of the neuromuscular symptoms ($p>0.5$).

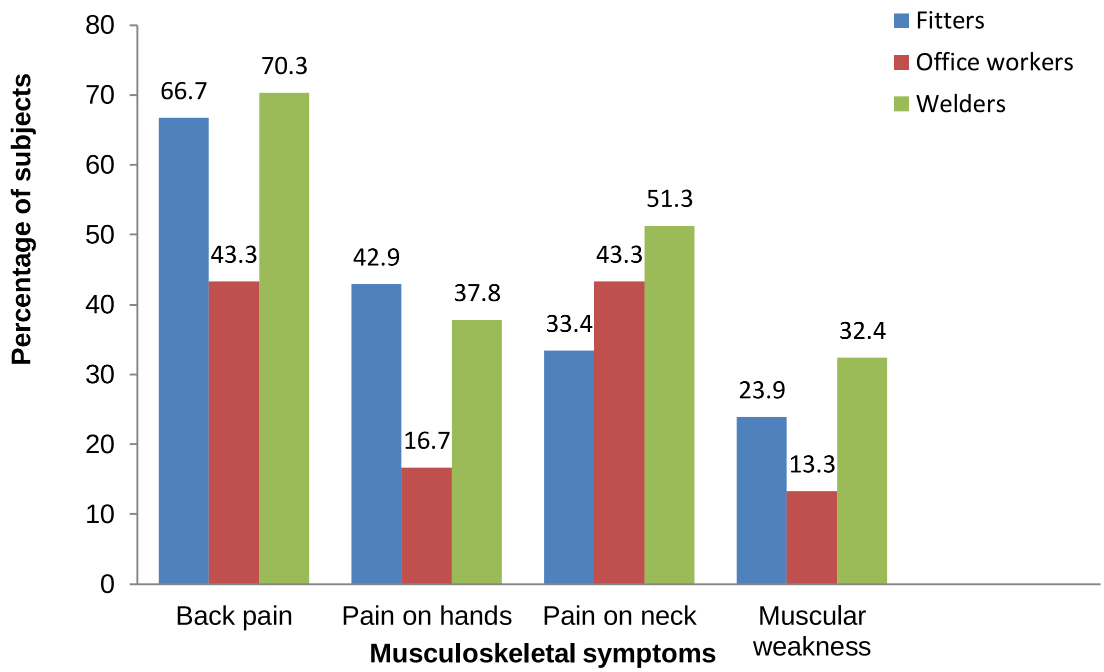

Figure 4.4. Comparison for the prevalence of musculoskeletal disorders

4.5.7 Respiratory symptoms

The results in Table 4.7 show the prevalence of respiratory symptoms among the subjects. Twenty eight and 13% of fitters and office workers respectively were suffering from chest pain. Welders (35%) were also suffering from chest pains. Fitters (14%), office workers (10%) and welders (16%) were experiencing chest tightness/dyspnoea. Subjects also reported a cough symptom to a certain extent. Welders (62%), fitters (28%) and office workers (30%) were coughing most of the time. Nineteen percent of fitters had wheezing sounds in the chest, while 3% and 18% of the office workers and welders respectively also reported this symptom. Irritation of the respiratory tract was also reported by the subjects. Twenty eight percent and 13% of fitters and office workers respectively were suffering from irritation to the respiratory tract, as were 16% of the welders.

Table 4.7: Respiratory symptoms

Symptom	Fitters	Office workers	Welders	P value
Chest pain	28.6% (n=6)	13.3% (n=4)	35.1% (n=13)	0.38**
Chest tightness/dyspnoea	14.3% (n=3)	10% (n=3)	16.2% (n=6)	0.95**
Coughing	28.6% (n=6)	30% (n=9)	62.2% (n=23)	0.051**
Wheezing sounds	19.1% (n=4)	3.3% (n=1)	18.9% (n=7)	0.28**
Irritation of respiratory tract	28.6% (n=6)	13.3% (n=4)	16.2% (n=6)	0.26**

**Fisher's Exact test

4.5.8 Dermatological symptoms

Dermatological symptoms were also reported by the subjects. The results in Table 4.8 indicate that fitters had skin numbness (14%), skin redness (28%), and burning sensation on the skin (38%), skin rash (19%) and skin swelling (19%).

Table 4.8: Prevalence of dermatological symptoms

Symptom	Fitters	Office workers	Welders	P value
Skin numbness	14.3% (n=3)	6.7% (n=2)	10.8% (n=4)	0.68**
Skin redness	28.6% (n=6)	9.9% (n=3)	27% (n=10)	0.56**
Burning sensation on skin	38% (n=8)	3.3% (n=1)	40.5% (n=15)	0.0009**
Skin rash	19.1% (n=4)	10% (n=3)	18.9% (n=7)	0.76**
Skin swelling	19.1% (n=4)	6.7% (n=2)	18.9% (n=7)	0.15**

**Fisher's Exact test

Office workers were also suffering from skin numbness (6%), skin redness (9%), burning sensation on the skin (3%), skin rash (10%) and skin swelling (6%). Welders also had skin numbness (10%), skin redness (27%), burning sensation on the skin (40%), skin rash (7%) and skin swelling (7%). Figure 4.5 shows the comparison for the prevalence of dermatological symptoms among the subjects. There was no statistically significant difference among the subjects in terms of the prevalence of dermatological symptoms (p>0.05) except for a burning sensation on the skin (p=0.0009).

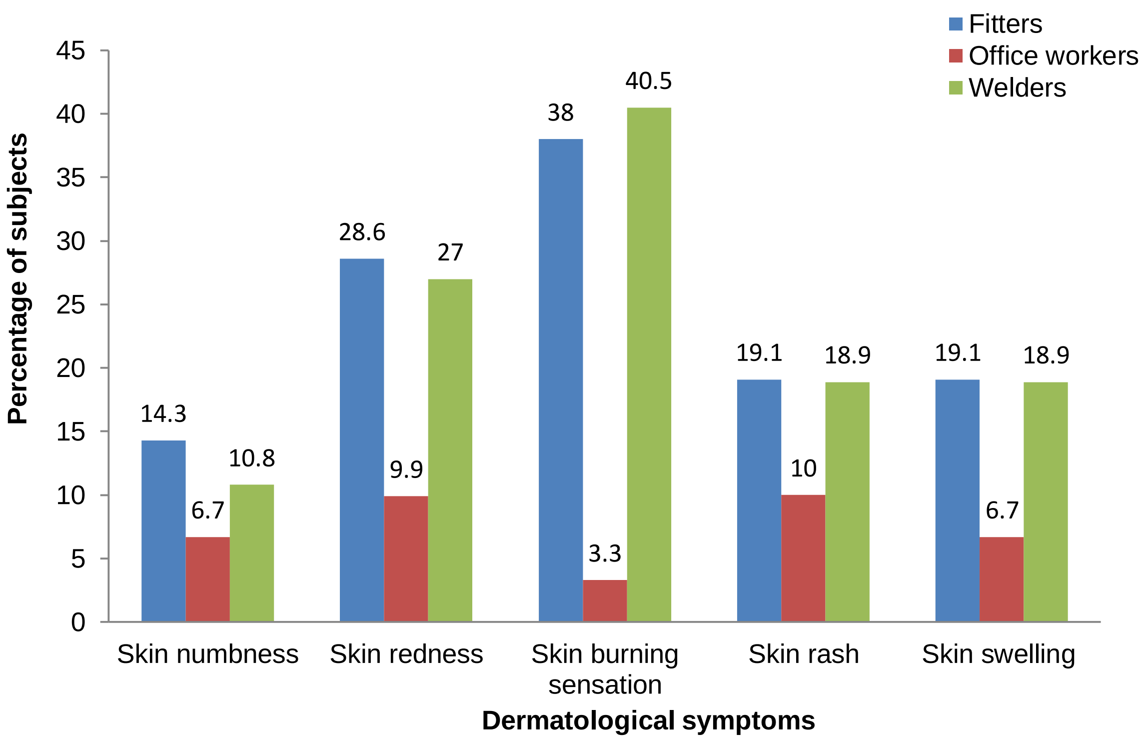

Figure 4.5. Comparison for the prevalence of dermatological symptoms

4.5.9 Ocular-visual symptoms

The prevalence of ocular-visual symptoms among the subjects is indicated in Table 4.9. Fitters had blurry vision (28%), irritation of the eyes (47%) and dryness of the eyes (42%). Thirteen percent and 37% of office workers and welders respectively reported blurry vision. Office workers (30%) and welders (64%) were suffering from irritation of the eyes. Dryness of the eyes was also reported by office workers (23%) and welders (54%). There was a statistically significant difference among the subjects in terms of the prevalence of ocular-visual symptoms (p<0.05).

Table 4.9: Prevalence of ocular-visual symptoms

Symptom	Fitters	Office workers	Welders	P value
Blurry vision	28.6% (n=6)	13.4% (n=4)	37.8% (n=14)	0.02**
Irritation of eyes	47.6% (n=10)	30% (n=9)	64.9% (n=24)	0.005**
Dryness of eyes	42.9% (n=9)	23.3% (n=7)	54.1% (n=20)	0.02**

**Fisher's Exact test

4.5.10 General symptoms

Few subjects reported general symptoms as indicated in Table 4.10. The symptom of vomiting was reported by fitters (4%), office workers (6%) and welders (2%). Fitters (9%), office workers (13%) and welders (10.8%) were suffering from nausea. Nine percent and 6% of fitters and office workers respectively were suffering from heart palpitations while 5% of welders had the same symptom.

Table 4.10: Prevalence of general symptoms among the subjects

Symptom	Fitters	Office workers	Welders	P value
Vomiting	4.7% (n=1)	6.7% (n=2)	2.7% (n=1)	0.82**
Nausea	9.5% (n=2)	13.3% (n=4)	10.8% (n=4)	1.0**
Heart palpitation	9.4% (n=2)	6.6% (n=2)	5.4% (n=2)	0.69**

**Fisher's Exact test

4.5.11 Prevalence of chronic diseases among subjects

Fitters (33%), office workers (16%) and welders (13%) were suffering from different chronic diseases. Seventeen subjects in total reported different types of chronic diseases as indicated in Table 4.11. There was no statistically significant difference among the subjects in terms of the prevalence of chronic diseases among the subjects. Only one welder (25%) out of five with chronic disease was suffering from arthritis.

One welder (25%) was suffering from asthma and another one (25%) was suffering from diabetes. One fitter (14%) was suffering from both hypertension and diabetes. Four fitters (57%), three office workers (60%) and one welder had hypertension. Only one fitter (14) reported nose bleeding. One office worker (20%) had sinusitis while one fitter (14%) had skin cancer.

Table 4.11: Types of chronic diseases among the subjects

Chronic disease	Fitters	Office workers	Welders	P value
Arthritis	0	0	25% (n=1)	0.61**
Asthma	0	20% (n=1)	25% (n=1)	
Diabetes and hypertension	14.3% (n=1)	0	0	
Diabetes	0	0	25% (n=1)	
Hypertension	57% (n=4)	60% (n=3)	25% (n=1)	
Nose bleeding	14.3% (n=1)	0	0	
Sinusitis	0	20% (n=1)	0	
Skin cancer	14.3% (n=1)	0	0	

******Fisher's Exact test

Fitters (18%), office workers (50%) and welders (40%) were aware of the health risks associated with exposure to electromagnetic fields. There was no statistically significant difference among the subjects in terms of the prevalence (p=0.17) and types (p=0.61) of chronic diseases. There was also no statistically significant difference among subjects in terms of their awareness about health risks associated with exposure to electromagnetic fields (p=0.12).

4.6 Discussion

Most workers who participated in this study reported some neurological, respiratory, musculoskeletal, dermatological and/or ocular-visual symptoms. Welders and fitters were exposed to EMFs from welding, while office workers were exposed to EMFs from office equipment such as computers. Both groups reported similar health symptoms. Symptoms of EHS, including headaches, concentration difficulty, sleep disorder, and distress were described in persons working on visual display units (VDUs) in the 1980s.[12] In a study by Röösli *et al*. in 2004, subjects exposed to EMFs also reported sleep disorders (58%), headaches (41%), distress (18%) and concentration difficulty (16%) as the most common health symptoms.[13]

Although all symptoms were reported in the exposed and control groups, there is no link between the exposure levels measured in Chapter 3 and the reported symptoms. The symptoms in this study are non-specific. Information from the environment is monitored and integrated by the nervous system.[14] The nervous system is highly sensitive to EMFs.[14] There is evidence that exposure to high levels of EMFs can lead to neurodegenerative diseases, such as Alzheimer disease.[15] The reported symptoms may have been due to other causes. Factors such as medical and psychological conditions, and exposure to occupational or environmental hazards, may also contribute to the development of these symptoms. For example, Poole *et al.* reported a high incidence rate of depression among subjects whose houses were located closer to power lines.[16]

There is a possibility that some participants were suffering from chronic diseases which could manifest some of these symptoms. For example, a headache is a common symptom of hypertension as well as a number of other illnesses. It has been reported that there is a connection between EHS and other idiopathic environmental illnesses.[17] Ergonomic factors in the workplace could also play a role in the development of some symptoms. Welders and fitters spend much time lifting objects, standing, and bending their bodies. This may cause them to experience muscular symptoms such as back pain, and pain in their arms, hands and necks. Office workers spend many hours sitting in front of computers in static position and this could also account for musculoskeletal symptoms.

Skin burning sensation was observed more commonly among the exposed than the control group. The human skin is a highly sensitive organ with receptors that detect various stimuli. Many workers also reported other dermatological symptoms, such as skin redness, numbness, swelling and rash. These symptoms may occur due to viral infections, allergies, insect bites, chronic skin conditions (such as acne), and extremely hot and cold temperatures. Welders and fitters were also exposed to ultraviolet radiation from welding which may contribute to the development of skin and visual-ocular symptoms. Welding produces a full spectrum of ultraviolet wavelengths and welders are therefore at a high risk of developing dermatological symptoms.[18] Ultraviolet radiation causes damage to all skin types, but the effects are more severe in lightly pigmented skin. Dermatological symptoms have been shown to not be associated with cellular phone use and VDU exposure in some studies. For example, skin problems were not observed among subjects who were using GSM mobile phones at a distance of 4 cm from the ear for 60 minutes.[19] Reduction of electric fields from VDU by electric-conducting screen filters did not reduce the prevalence of skin symptoms among study subjects in Norway.[20]

A review of 46 studies by Rubin *et al.* in 2010, and a study conducted in 2008 by Röösli *et. al*., did not support the hypothesis that exposure to EMFs causes EHS.[21,22] A systematic review of 31 experimental studies testing whether EHS can be caused by exposure to EMFs also found no correlation.[23] Respiratory symptoms such as coughing, chest pain, wheezing, irritation of the respiratory tract and chest tightness/dyspnea were very common among fitters and welders. Exposure to ultraviolet radiation and EHS may trigger these symptoms. The symptoms could also be triggered by other hazards such as fumes and gases produced during welding and fitting,[24] as well as smoking. However, respiratory symptoms among welders have been reported in previous studies conducted in the welding industry.[25,26,27]

4.7 Conclusion

The overall prevalence of health symptoms was high among the study participants, with exposed group experiencing a higher prevalence of some symptoms than control group. However, there is no clear relationship between EMF exposure and the development of the reported symptoms. It is, nevertheless, necessary to implement safety measures in the workplace and to provide medical treatment to alleviate the symptoms that workers are experiencing.

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CHAPTER 5

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5 A safety model for reducing occupational exposure to electromagnetic fields in the welding industry

5.1 Abstract

Employees in the welding industry are exposed to high electromagnetic field levels (EMFs) which may increase the risk for development of adverse health effects. The literature indicates a high incidence rate of cancers among employees who are over-exposed to electromagnetic fields. The Occupational Health and Safety Act of South Africa aims to maintain a safe and healthy working environment for all workers. Compliance with the act is however a major challenge in many workplaces, and many workers are over-exposed to occupational hazards such as electromagnetic fields, thus facing a high risk of acquiring occupational diseases. A safety model was developed for the industry using data from literature and the results of the study shown in Chapter 3. This safety model highlights the importance of implementing safety control measures in an attempt to reduce the occupational exposure levels. The recommended control measures are presented in this chapter and include engineering and administrative controls as well as the use of personal protective equipment.

Keywords: occupational hazards, occupational diseases, compliance, safety model, personal protective equipment

5.2 Introduction

Although there is still controversy regarding the health effects of electromagnetic fields (EMFs) to human beings, it is however essential to implement safety measures to reduce exposure to EMFs.[1] The International Commission of Non-ionizing Radiation (ICNIRP) has developed exposure limits.[2] Research shows that excessive heating of the human body can be caused by over-exposure to radiofrequency fields.[1] Exposure to high levels of extremely low frequency electromagnetic fields may increase electric currents in the human body and ultimately lead to nerve excitation.[1] Occupational exposure limits were established to prevent nerve excitation and physiological effects such as vertigo and nausea, as well as adverse influence on blood flow that can be caused by exposure to static magnetic fields.[2, 3] According to the study by Reilly, myelinated nerve fibres have been estimated to have a minimum threshold value of around 6 V_{peak} m^{-1} when a theoretical calculation of a nerve model is used.[4] The study[5] estimated that the minimum threshold for peripheral nerve stimulation applied on the skin or subcutaneous fat is between 4 and 6 V/m. High exposure levels that exceed the international safety guidelines are found in various industries where employees use devices that generate high level of EMFs.[6,7] The usage of magnetic resonance devices such as magnetic resonance imaging (MRI) is associated with increased occupational exposure to static magnetic fields.[8] Long term daily exposure to ELF magnetic fields above 0.4 µT have been linked with an increased risk for the development of childhood leukaemia.[9] In Germany, the recommended exposure limits for electric and magnetic fields at 50/60 Hz are 5 v/m and 1 µT, respectively for the general population. The exposure limits, recommended by the ICNIRP in 1998 for workers and their working environments, are 100 v/m for electric fields and 10 µT for magnetic fields.[10] According to these guidelines,[10] the exposure levels of workers to electric fields for a maximum duration of 2 hours should not exceed 25 V m^{-1}. Furthermore it was recommended that the daily exposure levels to magnetic fields for few hours should not exceed 5 000 µT.

Extremely low frequency electromagnetic fields are generated by welding machines, industrial arc ovens, induction heating furnaces and devices. High intermediate magnetic field levels are produced by MRI scanners while high voltage power lines produce high levels of extremely low frequency electric fields.[1] Welders, electricians, power line operators, railway engine drivers, radio and television tower operators as well as radar operators are exposed to high electromagnetic field levels.[1] The World Health Organisation (WHO) encourages the establishment of exposure limits and safety measures for health protection of all the people against exposure to electromagnetic fields. WHO also recommends the development of safety standards to limit the exposure of people to EMFs as well as EMF emissions from electrical devices. Exposure standards that limit human exposure to EMFs are derived from studies in various disciplines that address possible adverse effects on health and provide information about the safety measures.[11]

5.3 Problem statement

Electromagnetic fields exist in the work environment as a result of the usage of electrical devices. Common sources of exposure to electromagnetic fields are the industrial devices used for induction heating mostly found in the welding environment. Strong magnetic fields exist in close proximity to induction heaters and welding machines supplied by a strong electrical current. The objective in this Chapter was to develop a safety model with guidelines aimed at reducing the exposure of employees to electromagnetic fields in the welding industry.

5.4 Developing a safety model with guidelines to reduce EMF exposure in the welding industry

The aim of developing the safety model illustrated in Figure 5.1 was to guide the industry on how to reduce the exposure levels to electromagnetic fields and thus preventing the occurrence of possible occupational diseases. This model focuses on recognition, evaluation and controlling exposure to electromagnetic fields. The model was developed based on the results obtained from the measured exposure levels to EMFs in Chapter 3 as well as the data from questionnaires about the prevalence of health symptoms among employees. The first step is recognition of EMFs as a hazard, after which a risk assessment should be done by investigating the exposure levels and the prevalence of health symptoms among employees. Control measures should be implemented when the health risk is high in terms of exposure levels and health symptoms. Engineering control measures should be implemented first, followed by administrative controls. The use of personal protective equipment is a last resort. The development of the safety model was achieved by applying a multi-step approach related to the management of health risks in the working environment.[12] EMFs exist everywhere, total elimination of EMF exposure is a major challenge and hence this model differs from models used to manage other hazards in the industry. Figure 5.1 illustrate the different steps of the safety model to be followed during implementation.

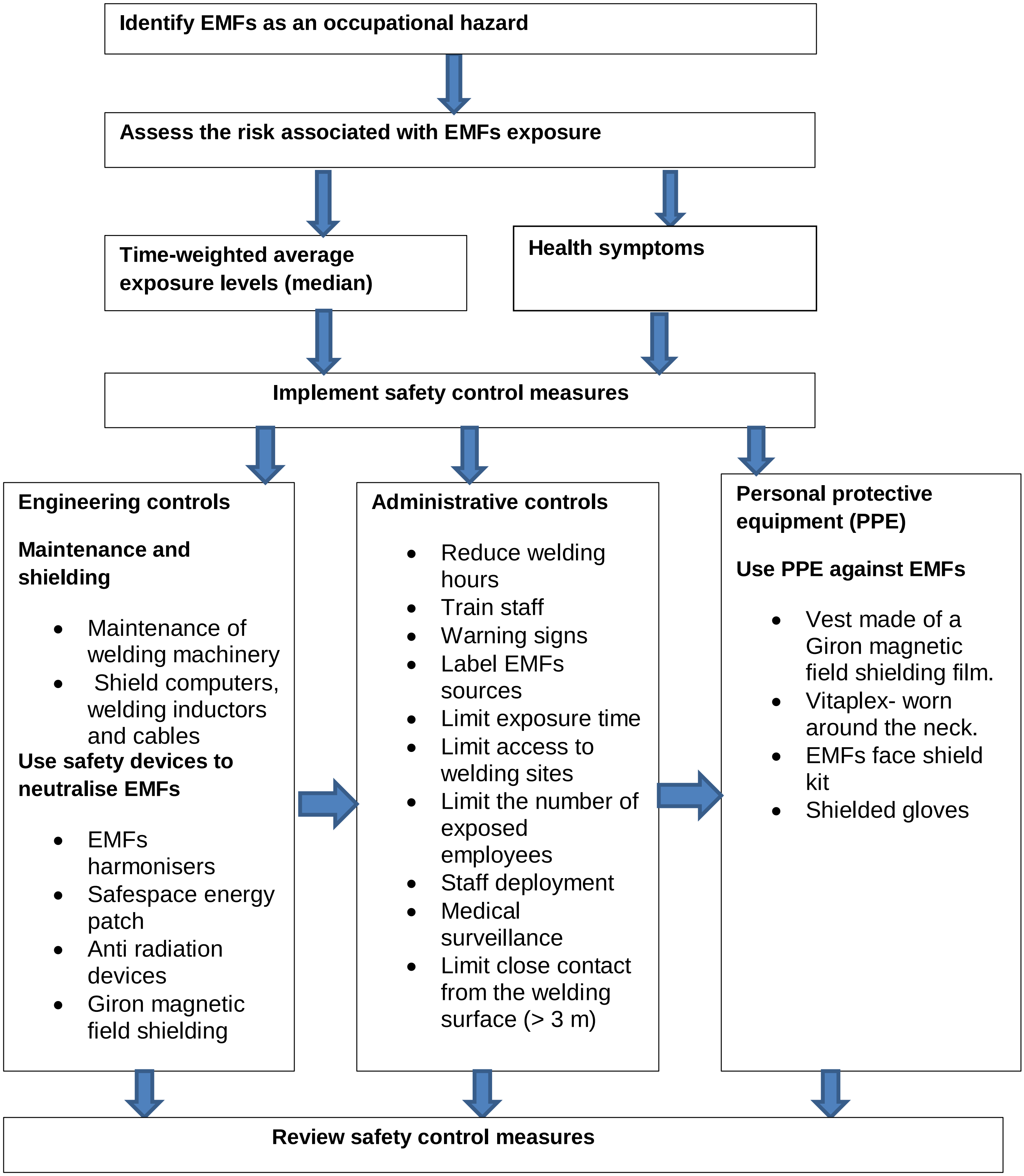

Figure 5.1 Safety model for reducing occupational exposure to EMFs

5.4.1 Identifying the hazard

The first step is to identify EMFs as an occupational hazard in the welding environment. Strong electromagnetic fields that act as a potential carcinogen are emitted by welding machinery and equipment. These fields interact with the human body and may induce damage to the deoxyribonucleic acid (DNA) molecule.[13] Changes in cellular functions and cell death may result from DNA damage. Damage to the DNA molecule is a precursor in the development of the majority of cancers. Welding requires a high current and as a result strong electromagnetic fields are generated. A walkthrough survey should be conducted by an occupational hygienist in consultation with the workers or their representatives in order to obtain information on health and safety problems encountered in the workplace.[12] During the walkthrough survey, the work environment, machinery and equipment should be inspected and hazardous conditions that can affect the health of the employees should be checked.[14] Although, in the welding industry, an occupational hygienist is responsible for conducting such a survey, it can also be conducted by an approved inspection authority in the industry if there is no occupational hygienist available. The exposure levels of electromagnetic fields should be measured once a month by one of these persons using the relevant instruments to determine whether there are any health risks associated with the exposure levels.[12] Training should be provided regarding the use of the instruments.

5.4.2 Assess the risk of exposure to EMFs

The second step is to assess the risk associated with exposure to EMFs.[12] Risk assessment is necessary and should be used:

- to implement a system that will follow up on new employees' exposure levels from where they worked before (in case of previous work in similar environment);
- to identify employees who are at high risk according to the exposure levels;
- to identify potential sources of EMFs in the workplace;
- to identify suitable control measures for implementation; and
- to check the effectiveness of existing control measures.[12]

According to the Occupational Health and Safety Act, Act 85 of 1993, the employer is required to identify the hazards in the workplace and assess the risks of exposure.[15]

5.4.2.1 Setting exposure limits according to recommended safety standards

The threshold level is defined as the lowest exposure level, below which no adverse health effects have been observed.[11] Different approaches are used to determine the threshold levels. A health risk assessment from scientific data provides valuable information from which the threshold level can be derived.[11] Furthermore a biological approach could also be used to determine the exposure limit from the scientific database. The exposure limit should be determined at a level below which no biological effects have been observed.[10] Information from extensive research studies that have indicated the possibility of the manifestations of the diseases at a particular exposure level should be used as a guide to set the exposure limits. According to the new guidelines released by the International Commission of Non-Ionizing Radiation Protection (ICNIRP) in 2010, the occupational exposure limits for electric and magnetic fields are set at 10 kV/m and 10 000 mG respectively, at a frequency of 50 Hz for the whole working day.[10] According to these guidelines, the short term exposure limit for two hours is 50 000 mG for magnetic fields and 30 kV/m for electric fields.

The literature indicates that exposure to magnetic fields at about 0.4 µT may increase the risk for development of childhood leukaemia.[9] Some epidemiological research suggests that there may be an association between an increase in cancer incidence and exposure to electromagnetic fields at lower exposure levels.[18] The literature recommends that the 10 mG and 100 V/m levels for magnetic and electric fields respectively should not be exceeded during prolonged exposure for the whole working day over an 8-hour shift.[14] The employer should take action to limit the exposure of employees to electromagnetic fields more especially in occupations with the highest mean exposure level per working day. According to the Occupational Health and Safety Act, Act 85 of 1993, “every employer is required to maintain and provide a working environment that is safe and does not pose a threat to the health and safety of the employees”. The employer is also required to take action to mitigate any hazard to the safety and health of the employees”.[15]

5.4.3 Implementing control measures

Control measures should be implemented when it is not reasonably practicable to eliminate the hazard and associated risks.[12] Electromagnetic fields are found everywhere in the workplace due to the usage of electricity, and therefore total elimination is a major challenge. Three control measures namely engineering control, administrative control and the usage of personal protective equipment should be used in an effort to reduce the exposure of employees to electromagnetic fields.[12]

5.4.3.1 Engineering controls

- **Maintenance of machinery and equipment**

Maintenance of machinery is an important engineering control measure that should be used to reduce the emission of electromagnetic fields. Maintenance of machinery involves repairing, servicing, inspecting and testing machines.[12] Machines that are properly maintained on a regular basis operate efficiently and are safe to use. High electromagnetic field levels are more likely to be generated by machines that are not regularly maintained. The employer should make provision for maintenance of the welding machinery and equipment.

- **Shield welding cables**

Magnetic shielding foil is a thick material made of nickel and offers shielding against electrical devices that generate extremely low frequency magnetic fields such as those commonly found in the welding industry.[16] It is recommended that magnetic shielding foil be used to make magnetic barriers on electrical devices and welding cables.[16] The foil can be used in multiple layers on welding cables to provide greater reduction in the generation of electromagnetic fields. The metglas magnetic shielding film is a cobalt-based material that also shields against the electromagnetic fields. It can be wrapped along welding pipes, cables and electrical devices to minimise the strength of magnetic fields.[16]

- **Use safety devices to neutralise EMFs**

The EMFs harmoniser (Figure 5.2) is a free-standing device designed to counteract the electromagnetic fields emitted by electrical appliances.[17] This device can be placed on electrical appliances to reduce the harmful effects of electromagnetic fields on the human body. It does not change the nature of the fields but has the ability to counteract them and enhances the natural defence mechanism of the human body. It reduces the damaging effects of the EMFs on the human body and protects the immune system. [17]

Figure 5.2 EMFs harmoniser

Safe Space Energy Patch is another safety device that helps to neutralise the strength of the EMFs.[18] It can be placed on electrical appliances and next to the power inputs of the appliances to neutralise the fields. Safe Space Energy patch (Figure 5.3) acts by altering the energetic properties of EMFs and changing their harmful nature to render them harmless.[18]

Figure 5.3 Safe space energy patch

A Clearfield plate resonator (Figure 5.4) is an EMF protective device which was designed in the year 2000. It is most effective in clearing harmful effects of electromagnetic fields from power lines, power substations and cell phone towers.[19] It is the only EMF protection device known around the world to clear all geopathic EMFs in an entire building by changing their harmful nature to become harmless.[19]

Figure 5.4 Clearfield plate resonator

The usage of the above-mentioned EMF protection devices is highly recommended for the welding industry. The employer should make provision for the availability of these protection devices to workers who are exposed to electromagnetic fields.

5.4.3.2 Administrative controls

The implementation of administrative control measures involves introducing precautionary measures aimed at lowering human exposure to EMFs.[12] The employer must introduce work methods or procedures that are designed to minimise exposure to electromagnetic fields.[12] These work procedures include reducing welding hours, limiting access to welding sites, limiting exposure time in the welding areas, limiting the number of staff entering the welding sites, limiting close contact with the welding surface, using warning signs, and implementing staff deployment and training as well as a medical surveillance programme.

- **Reducing welding hours**

Normal working hours for the majority of employees in South Africa is approximately eight hours a day. This is according to the labour laws in South Africa. Employees such as welders, fitters and electricians are highly exposed to electromagnetic fields and should not work at their respective work stations for longer hours. The risk of developing adverse health effects increases with the increase in the duration of exposure. The study has shown that welders were exposed to a magnetic field strength of about 600 µT for a short time.[20] Reduction of welding hours can be achieved by rotating employees and assigning welding tasks to them for a limited number of hours per day.[11] It is highly recommended that highly exposed employees should not work in the same environment with high exposure levels on a daily basis. Supervisors should ensure that employees in highly exposed occupations are rotated accordingly.[11] Based on the findings of this study it is recommended that the exposure time at the welding sites should not exceed four hours per employee over an 8-hour working shift.

- **Training staff and enhancing awareness about EMFs**

Employees should be trained about the working procedures to enable them to perform their duties safely.[12] The key element of training is to educate and inform employees about the health risks associated with exposure to electromagnetic fields and to equip them with the necessary knowledge required to apply safety measures in an attempt to reduce the health risks.[12] Employees who are aware of the health risks associated with their occupations are more likely to take action to protect themselves. The employees should also be trained on the proper use, wearing, storage and maintenance of protective equipment.[12] The occupational health specialist should consider the educational level of employees when developing the training programme. Training should be conducted in the form of workshop sessions in languages that can be understood by the employees.[12]

The training programme should make provision for promoting and developing the literacy level of illiterate employees to enable them to read and write. During the training, employees should be informed about major sources of EMFs exposure in the workplace such as welding cables and surface. Employees should also be informed on how to avoid prolonged exposure to such sources, and on how to take precautionary measures to protect themselves. Awareness about occupational exposure to electromagnetic fields should be enhanced in the work place. Awareness can be conveyed by means of posters, awareness campaigns, intranet, information booklets and regular meetings. The employer must ensure that workers have access to these resources. The training programme should be centred around the three key elements, namely induction, job training and refresher training.[21]

- **Induction**

Induction should be done for new employees to enable them to familiarise themselves with working procedures, emergency situations and reporting incidences.

- **Job training**

Job training involves informing workers about recognition of hazards and procedures that must be taken to reduce the risks.

- **Refresher training**

Refresher training should be given to employees when any new technology is introduced in the workplace.[21]

- **Using warning signs**

Warning signs[22] (Figure 5.5) should be placed at the entrance of all working areas where electromagnetic fields are very high. The purpose of placing the warning signs is to warn persons entering such areas about the high electromagnetic field levels. In addition to the usage of warning signs, it is also essential to label all EMFs sources where there is potential exposure. Employees should be well informed about possible EMF sources.[1]

Figure 5.5. Warning sign for electromagnetic fields

- **Limiting access to welding sites**

The number of employees entering the welding sites per working shift should be restricted in an effort to limit the number of people exposed to electromagnetic fields. This can be achieved by rotating employees during the working day. Employees who are highly exposed should avoid standing in close proximity to the sources of EMFs such as welding surfaces and cables as well as electrical wiring. Evidence exists that the fields are stronger closer to the sources and weaker away from the sources.[20] To avoid over-exposure, welders and fitters should also avoid draping the welding cable around their own bodies. The cable carries a high electromagnetic field level.[21] The welding machine and cable are illustrated in Figure 5.6.

Figure 5.6 Welding machine and cable

- **Staff deployment**

Staff deployment should be used as a strategy to avoid long term exposure to electromagnetic fields among certain employees. Pregnant women who are employed in jobs with high exposure levels such as welding, should be redeployed to other jobs with less exposure to electromagnetic fields in an attempt to avoid the development of adverse health effects on the foetus. Pregnant women who are occupationally exposed to high levels of electromagnetic fields are more likely to have miscarriages.[23] Pregnant women should inform their supervisors as soon as they become aware of their pregnancy status. Employees who are declared medically unfit to work in workstations with high exposure levels should also be redeployed to other jobs with lower exposure levels. Employees of advanced age should also be deployed to work at stations with lower exposure levels. A high incidence rate of cancer among elderly people is assumed to be due to a decrease in the immune response.[24] The progression and development of certain cancers increases with aging, when the immune system becomes compromised.

- **Develop a medical surveillance programme**

A medical surveillance programme should be developed in an effort to provide screening and management of diseases. The other purposes of developing a medical surveillance programme are to reduce the occurrence of occupational diseases and prevent death resulting from occupational diseases. The programme should make provision for health examinations of all employees, and it should be in line with the South African health laws and regulations.[15, 25] The Occupational Health and Safety Act, Act 85 of 1993, makes provision for the implementation of a planned medical surveillance programme and health examination of employees by an occupational health practitioner. An initial medical examination should be conducted on employees hired to work in highly exposed jobs such as welding.[1] The pre-employment history should also be taken into account for such employees. The pre-employment history and initial medical examination should be used to determine previous exposures and the level of fitness before commencement of employment. According to the Occupational Health and Safety Act, medical records should be kept for a period of 20 years.[15] It is recommended that the welding industry keep the medical records of employees for the term of employment and for 20 years after termination of employment.

5.4.3.3 Personal protective equipment

- **Use personal protective equipment (PPE) against EMFs**

Employees who are highly exposed to electromagnetic fields should use personal protective equipment designed to protect them from EMFs. A giron magnetic field shielding film can be used to design a vest that can be worn by such employees to protect their upper torsos.[16] A personal EMF harmoniser is device that can be worn or carried by employees. This device offers protection from damaging electromagnetic fields found in workplaces and homes.[17] Vitaplex life force pendant (Figure 5.7) is a device that has been scientifically proven to offer protection against EMFs. It is worn around the neck and interacts with the energy fields of the human body in order to maintain balance.[18]

Figure 5.7 Vitaplex life force pendant

- **Shielded gloves**

Figure 5.8 illustrates the shielded gloves which are recommended for highly exposed workers to protect exposure to their hands. The shielded gloves offer protection against electromagnetic fields.

Figure 5.8. Shielded gloves

5.4.4 Reviewing control measures

Control measures that are put in place to minimise exposure to electromagnetic fields should be reviewed regularly to determine whether they are effective.[14] The common review methods should include workplace inspection, consultation with workers and their representatives, testing equipment and analysing records. The reviewing process should be viewed as an essential process in monitoring and evaluating the safety control measures. The objectives of reviewing the implementation of the control measures are:

- to determine whether the control measures are effective in reducing the occupational exposure levels to EMFs and associated health risks;
- to identify problem areas encountered during the implementation; and
- to improve the efficiency of control measures.[14]

Risk control measures must be reviewed in order to meet the health and safety requirements. This is required when:

- the health risk is not controlled by the designed control measures
- changes take place at the workplace and potential health risks are more likely to be encountered
- requested by a health and safety representative
- new hazard is identified in the workplace
- required by the law[12]

Table 5.1 illustrates the objectives for implementing control measures as well as the target groups. The control measures should be selected and implemented according to the exposure level to electromagnetic fields in the workstations.

Table 5.1 Choosing the relevant control measures

Control measure	Action	Target group	Objective
Engineering	Maintain machinery	All employees	To keep machinery safe and in good operating condition
	Shield EMFs sources	All employees	To minimise the emission of EMFs
	Use environmental EMFs harmonisers	All highly exposed employees	Neutralisation of EMFs
Administrative	Conduct walkthrough survey	All workstations	Assessment of health risks associated with exposure levels
	Set exposure limits	All employees	To identify workers who are highly exposed and are at high risk
	Limit welding hours	All highly exposed employees	Reduce the exposure level
	Train staff	All employees	To educate employees about EMFs
	Promote awareness about EMFs	All employees	To raise the level of awareness about EMFs
	Limit access to welding sites	All employees	Reduction of occupational exposure levels
	Rotate staff	All highly exposed employees	To reduce the exposure levels
	Deploy staff	Pregnant women, highly exposed employees of advanced age	To reduce the risk for the developing adverse health effects
	Limit close contact with EMF sources	Highly exposed employees	Reduction of exposure levels
	Conduct medical surveillance	All employees	To prevent the occurrence of occupational diseases and provide health care
Personal protection	Use PPE against EMFs	All highly exposed employees	To neutralise EMFs

5.5 Discussion

Measures to reduce exposure to electromagnetic fields are essential to protect workers from developing adverse health effects. It has been shown that heart variability in adults was affected by exposure to electromagnetic fields of above 2 µT.[26] Changes in alpha activity measured on the occipital and parietal lobes of the brain were due to acute exposure of volunteers to magnetic fields of about 200 µT.[27] Exposure to 60 Hz magnetic field at 200 µT for 4 hours was not associated with DNA damage in peripheral blood leucocytes. [28] It has been shown that repeated, acute exposure to extremely low frequency magnetic fields at 3 or 4 µT does not cause significant effects on the content of calcium, magnesium and fluoride ions in saliva.[29]

The effects of ELF electromagnetic fields were observed in a study using human breast cancer cells. The growth of breast cancer cell line MCF-7 was inhibited by melatonin at relevant physiological concentration (10^{-9} mol/l). This inhibitory effect of melatonin was attenuated when the cells were simultaneously exposed to electromagnetic fields at 1.2 µT.[30] It was also found that the inhibitory effect of tamoxifen on cancer cell growth was reduced, suggesting a possible relationship between exposure to electromagnetic fields and carcinogenesis.[31] The results presented in Chapter 3 indicate that exposure levels to magnetic fields in the workshops were higher than in the office. Therefore it can be assumed that the inhibitory effects of melatonin and tamoxifen may be suppressed among welders and fitters exposed to these levels, increasing their vulnerability to cancer development.

An increase in cell proliferation, changes in cell cycles and increased DNA damage were reported in a study of HL-60 leukemia cells and two fibroblast cell lines exposed to 50 Hz magnetic fields at 0.5 -1 mT up to 72 hours.[32] The study[32] suggests that exposure to ELF EMFs influences DNA damage in both normal and cancerous cells. Previous studies have shown that there were no DNA damage in the blood cells of healthy donors exposed to 50 Hz magnetic fields at 1 mT for 2 hours and 48 hours.[33,34]

The study[35] indicated that exposure to electromagnetic fields at 400 mT up to 6 hours stimulate cell signalling and enhance the expression of neuron-derived orphan receptor 1 (NOR-1) gene. It was shown that the NOR-1 gene respond to electromagnetic fields at above 5 mT, indicating an induction of gene expression at that level.[35] Exposure to high levels of electromagnetic fields at about 400 mT had been linked with mutation on cultured cells, suggesting a possibility of cancer development.[36] It has been reported in a study[37] that exposure to ELF EMFs at 5 mT for 1 hour inhibits the secretion of insulin from the islets-deriver insulinoma cell line by influencing the inflow of calcium through the calcium channels. This effect suggests that exposure to ELF EMFs at 5 mT may impairs the normal functioning of the pancreas.

Previous studies[38-40] reported that occupational exposure to magnetic fields increases the risk for developing cardiovascular diseases. It has been shown that exposure to magnetic fields decreases the heart rate variability, an indicator of altered autonomic nervous system control of the heart. The reduction can lead to diseases such as acute myocardial infarction and arrhythmia.[38] This suggest that exposure to magnetic fields may interact with the control of the autonomic nervous system on the heart, leading to decreased heart variability.[41] It has been shown that reduction in heart rate variability is a risk factor for acute cardiac morbidity and mortality.[42] The study[43] showed that there were no effects on the electrocardiogram among 100 persons who were exposed to magnetic fields of about 100 mT. There were no significant effects on the heart rate among persons exposed to electric fields at 20 kV/m and magnetic fields at 0.3 mT.[44] It has been shown that the heart rate in persons exposed to magnetic fields up to 2.2 µT did not change significantly.[45] Statistical significant alterations in the heart rate variability were reported among 77 healthy men exposed to magnetic fields of 14.1 µT or 28.3 µT.[46] It has been shown that exposure to 60 Hz magnetic fields at 20 µT reduces the normal heart rate variability.[46] Literature suggest that reduction in heart rate variability increases mortality rate among survivors of myocardial infarction[47] and increases the risks for developing heart diseases[48] and sudden cardiovascular death.[49]

The literature indicates controversy about the health effects of EMFs. There is no clear link between EMF exposure and the development of both acute and chronic adverse health effects. Although the exposure levels recorded in the present study were high in the workshops and low in the offices, there is no clear link between the reported health symptoms and the recorded exposure levels. However, it is vital to mitigate exposure to electromagnetic fields in the welding industry and other workplaces with high exposure levels.

5.6 Conclusion

Occupational exposure to electromagnetic fields depends on three factors, namely: the strength of the fields, the distance from the source of exposure and the time spent near those sources. Since electromagnetic fields exist everywhere, complete avoidance is a major challenge. Lowering exposure levels to electromagnetic fields that can be achieved by introducing the relevant control measures is essential to reduce associated health risks. Compliance with the legislation and safe working procedures by all parties is also essential to ensure the effectiveness of the control measures. Currently, South African literature lacks a safety model on limiting long term exposure to electromagnetic fields in the welding industry. In this study, the proposed safety model contributes positively towards sustainable development in the South African welding industry by providing new technological information essential to solve major challenges faced by the industry with regard to electromagnetic field exposure. The wellbeing of employees is essential in any industry to ensure sustainable growth and development. In this study, the safety model focuses on the promotion of employee wellbeing which is essential for sustainable development. Therefore this study highlights the importance of preventing occupational diseases related to EMF exposure to ensure sustainable growth and development in the welding industry.

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CHAPTER 6

6 Recommendations

6.1 Introduction

The development of new technology in recent years has increased the possibility of human exposure to electromagnetic fields (EMFs). Humans are increasingly exposed to electromagnetic fields due to the growth of electric power generation and transmission, development of new telecommunication systems and advances in medical and industrial applications. Exposure limits has been issued in several countries, governments or other relevant authorities with the intention to minimise human exposure to electromagnetic fields. The World Health Organisation encourages the development of exposure limits and other control measures that are necessary to protect of all people against EMF exposure.[1] The recommendations presented in this Chapter are based on the findings presented in Chapters 3 and 4. The recommendations presented in this Chapter highlight the most important control measures and actions that should be taken to reduce human exposure to EMFs.

6.2 General discussion

In this study an overview was presented in Chapter 1. The study design, population, methodology, hypothesis and ethical matters were outlined. The aim and objectives were also described in Chapter 1 as well as the brief review of literature with specific reference to the welding industry. In Chapter 2, a broad review of studies about the possible health effects associated with EMFs was presented. There is controversy with regard to the health effects of EMFs on humans according to several studies. Some research studies have shown a relationship between EMF exposure and development of adverse health effects while others did not show any relationship. In Chapter 3, the results with regard to the occupational exposure levels to electric and magnetic fields were presented. The exposure levels to magnetic fields were significantly higher in the workshops than the offices. Although the results in Chapter 4 showed that workers experienced health symptoms, most of these symptoms did not differ significantly between the exposed and control groups. The symptoms in this study are non-specific and may have been influenced by the fact that many people with symptoms participated in the study than those without the symptoms. However, there is no clear relationship between EMF exposure and the development of the reported symptoms. It is, nevertheless, necessary to implement safety control measures in order to reduce exposure to electromagnetic fields. The control measures were outlined in the safety model presented in chapter 5. The implementation of the model will help the welding industry to maintain reduce exposure to EMFs.

6.3 Recommendations

Recommendations are based on the main findings of the study and are as follows:

1. The welding industry should develop a policy on avoidance of long term exposure to electromagnetic fields. Targets and objectives about limiting the exposure to electromagnetic fields should be set and executed. The policy needs to be approved and reviewed by top management, and should be documented, accessible and communicated to all employees.
2. A Health and Safety surveys on exposure to electromagnetic fields should be conducted regularly to monitor the effectiveness of the policy.
3. Areas in the welding workshops that have magnetic fields above 2 µT should be identified and access to such areas should be restricted. Evidence exists that exposure to magnetic fields of above 0.3 - 0.4 µT is associated with the risk of developing leukaemia. According to the results of the current study, welders and fitters were exposed to magnetic fields of about 7.6 µT at 1 meter from the welding point. Therefore it is recommended that access to such areas be restricted.
4. Warning signs should be posted in areas where the magnetic field strength is above 2 µT. Any employee or person entering an area where the magnetic fields are above 2 µT should wear appropriate protective clothing and equipment.
5. If an area is identified with levels of magnetic fields of above 2 µT, action must be taken to mitigate the exposure. These actions should include:
    i. the shielding of electrical cables;
    ii. relocation of electrical cables;
    iii. relocation of staff away from the area;
    iv. reducing the time spent welding and fitting in such area;

v. reducing the number of employees entering such area per working shift;
vi. using personal protective equipment against EMFs;
vii. reducing the number of hours spent welding and fitting per day; and
viii. maintaining the welding machines and equipment regularly to minimise the generation of high levels of magnetic fields.

6. Employees who smoke should be encouraged to quit smoking. The risk of developing chronic diseases associated with exposure to electromagnetic fields is high among welders and fitters who smoke.
7. Employees should be informed and educated about the health risks associated with electromagnetic fields.
8. Welders and fitters exposed to magnetic fields above 2 µT should undergo medical examinations at least twice a year and be screened for chronic diseases such leukaemia, neurodegenerative diseases, cardiovascular diseases, brain cancer, breast cancer and other types of diseases associated with exposure to electromagnetic fields.
9. Pregnant women employed as welders and fitters should be redeployed to other jobs with less exposure to magnetic fields to minimise the adverse effects of magnetic fields on the foetus. The literature suggests that the risk of miscarriage is high among pregnant women exposed to magnetic fields of 1.6 µT or higher.[2]
10. It is recommended that subjects who are experiencing symptoms of ill health due to exposure to electromagnetic hypersensitivity should seek medical help. This should be done in consultation with the medical personnel and occupational hygienist to address the symptoms, identify other contributing factors and implement control measures.
11. The treatment of an individual with reported symptoms should focus on the health symptoms and a clinical picture and not just on the person‘s perception on reducing or eliminating electromagnetic fields at the workplace.
12. A thorough medical evaluation of the subjects should be conducted to identify and treat any condition that may be responsible for the symptoms.

13. A psychological assessment should be done to determine if there are any other psychiatric or psychological conditions that may cause the symptoms.
14. Subjects who experience these symptoms should try to reduce their exposure to electromagnetic field sources. Complete avoidance is however a major challenge in modern society. Methods that can be used are (1) avoiding close contact with sources of exposure, (2) disconnecting electrical devices when not used, and (3) using screens or shields against electromagnetic fields.
15. An assessment of the workplace for other contributing factors to the development of the symptoms should be conducted by the occupational hygienist.
16. It is also recommended that the subjects adhere to the prescribed medication from the medical personnel to alleviate the symptoms of ill health.
17. Treatment should focus on establishing a good physician-patient relationship, helping individuals to cope with the situation and encouraging them to live a normal life.
18. The employees should be informed and educated about the potential health hazards of electromagnetic fields. Currently there is no scientific basis for connection between electromagnetic field hypersensitivity and exposure to electromagnetic fields.
19. Management in the welding industry should budget for the implementation of recommendations to minimise exposure to electromagnetic fields.

6.4 Future research

This study has opened the following research possibilities:

- The study can be extended by assessing the exposure levels to high frequency electromagnetic fields in the South African welding industry
- A larger study should be conducted to determine if the EMF exposure levels are related to the development of adverse health effects, taking potential confounders into account.

6.5 Conclusion

Exposure to electromagnetic fields is a major challenge in the modern society and has received little attention in many industries more especially in developing countries. It has been scientifically proven in developed countries such as United State of America (USA) that shielding devices offer protection against the harmful effects of EMFs. Given that exposure to ELF EMFs can pose a serious health risk to welders and fitters, there is a need to implement safety measures to mitigate exposure. Currently there is no legislation in South Africa that regulates exposure to ELF EMFs. This study suggests a need for establishment and implementation of such legislation.

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APPENDIX 1: QUESTIONNAIRE

QUESTIONNAIRE:

OCCUPATIONAL EXPOSURE TO ELECTROMAGNETIC FIELDS IN THE HEAVY ENGINEERING CO_2 WELDING INDUSTRY IN THE MANGAUNG METROPOLITAN MUNICIPALITY.

This is an independent research project of the Central University of Technology, Free State. The purpose of this project is to identify problems associated with exposure to electromagnetic fields in your company and to make recommendations to improve the current situation. The information provided on the questionnaire will be kept confidential. Your name and company will remain anonymous throughout the entire of the project and after the project.

INSTRUCTIONS:

Please complete the form by putting "X" next to the relevant answer where applicable and by writing the anwers in the lines provided.

For office use only

Number ☐☐☐ 1-3

SECTION A: Biographical information

1. What is your age?________________ years ☐☐ 4-5

2. What is your highest level of education?_____________________________ ☐☐ 6-7

3. What is your gender? ☐ 8
   - ☐ Male
   - ☐ Female

4. Do you smoke? ☐ 9
   - ☐ Yes
   - ☐ No

5. Marital status ☐ 10
   - ☐ Single
   - ☐ Married
   - ☐ Divorced
   - ☐ Living together
   - ☐ Other

5.1 If OTHER, please specify:____________________________ ☐☐ 11-12

SECTION B: Employment information

6. What is your current employment? ☐ 13
   - ☐ Full time
   - ☐ Part time

7. How many hours do you work per week?____________________ ☐☐ 14-15

8. What is your job title? ☐ 16
   - ☐ Welder
   - ☐ Fitter
   - ☐ Office worker

9. How long have you been in this position?_____________________ ☐☐ 17-18

NB:

If you indicated WELDER or FITTER in (8.) continue with <u>SECTION C</u> on the next page.
If you indicated OFFICE WORKER in (8.) continue with <u>SECTION D</u> on the next page.

SECTION C: Safety Equipement and Use

(Only complete section C if you are a WELDER or FITTER.)

10. How many hours do you spent welding/fitting per DAY?____________________hours 19-20

11. Do you wear protective clothing when welding/fitting? ☐ Yes ☐ No 21

11.1 If **YES**, name ALL the protective clothing you wear (e.g. apron, leather jacket, etc.):

____ 22-23

____ 24-25

12. Are there sufficient protective equipment in your workplace? ☐ Yes ☐ No 26

12.1 If YES, name the protective equipment that is available (e.g. eye googles, ear plugs, etc.):

____ 27-28

____ 29-30

13. How frequently are protective equipment serviced? 31
- ☐ Once a month
- ☐ Twice a month
- ☐ Once a year
- ☐ Not serviced

14. How often do you use the following safety devices when welding/fitting?

		Never	Monthly	Weekly	Daily	
14.1	Face masks					32
14.2	Helmets					33
14.3	Eye googles					34
14.4	Ear plugs/mufs					35
14.5	Overall/apron					36
14.6	Leather Jacket					37
14.7	Hand gloves					38
14.8	Safety boots					39

SECTION D: General Work Environment

15. Have you ever experienced a static electric shock at work? ☐ Yes ☐ No 40

15.1 If **YES**, how many times? 41
- ☐ Once a day
- ☐ Once a week
- ☐ Once a month
- ☐ Once a year
- ☐ Other (specify): _________________________ 42-43

16. Have you ever experienced a severe electric shock at work? ☐ Yes ☐ No 44

16.1 If **YES**, how many times? 45
- ☐ Once a day
- ☐ Once a week
- ☐ Once a month
- ☐ Once a year
- ☐ Other (specify): _________________________ 46-47

17. How often do you undergo medical examination at your company? [ ] 48

- [ ] Once a year
- [ ] Twice a year
- [ ] Three times a year
- [ ] Not done
- [ ] Other (specify): ______________________ [ ][ ] 49-50

18. Have you ever been trained in protection against electromagnetic fields? [ ] Yes [ ] No [ ] 51

19. How often is a survey on exposure to electromagnetic fields done in your workplace? [ ] 52

- [ ] Once in three months
- [ ] Twice in three months
- [ ] Once a year
- [ ] Not done
- [ ] Don't know
- [ ] Other (specify): ________________________ [ ][ ] 53-54

20. Have you ever been injured at work? [ ] Yes [ ] No [ ] 55

20.1 If **<u>YES</u>**, state the <u>nature</u> of the latest injury: ____________________________________ [ ][ ] 56-57

20.2 If **<u>YES</u>**, state the <u>date</u> of the latest injury: ____________________________________ [ ][ ] 58-59

21. Have you ever sustained the following injuries at work?

		Yes	No		
21.1	Cuts on hands and fingers				60
21.2	Burns				61
21.3	Foreign objects in the eye				62
21.4	Bone fractures				63
21.5	Other				64

21.6 If other, please specify:______________________ [ ][ ] 65-66

SECTION E: Health Symptoms

22. How often do you suffer from the following symptoms?

		Never	Monthly	Weekly	Daily		
22.1	Blurry vision						67
22.2	Headaches						68
22.3	Sleep disorders						69
22.4	Distress						70
22.5	Fatigue						71
22.6	Concentration difficulty						72
22.7	Skin redness						73
22.8	Skin burning sensation						74
22.9	Pain on the arm						75
22.10	Heart palpitation						76
22.11	Hearing impairement						77
22.12	Back pain						78
22.13	Pain on the hand						79

22. How often do you suffer from the following symptoms?

		Never	Monthly	Weekly	Daily		
22.14	Dizziness						1
22.15	Pain on the neck						2
22.16	Skin swelling						3
22.17	Skin rash						4
22.18	Memory difficulty						5
22.19	Skin numbness						6

23. How often do you suffer from the following symptoms?

		Never	Monthly	Weekly	Daily		
23.1	Chest pain						7
23.2	Chest tightness/ dyspnea						8
23.3	Coughing						9
23.4	Wheezing sounds						10
23.5	Vomiting						11
23.6	Nausea						12
23.7	Irritation of the eyes						13
23.8	Irritation of respiratory tract						14
23.9	Dryness of the eyes						15
23.10	Muscular weakness						16

SECTION F: General Health Information

24. Do you suffer from chronic illness such as asthma, pneumonia, cancer, etc.? ☐ 17

☐ Yes
☐ No

24.1 If **YES**, name the illness ____ ☐☐ 18-19 ☐☐ 20-21

25. Would you describe yourself as a healthy person? ☐ 22

☐ Strongly agree
☐ Agree
☐ Not sure
☐ Disagree
☐ Strongly disagree

26. Are you aware of the health risks associated with exposure to electromagnetic fields? ☐ 23

☐ Yes
☐ No

Thank you for your participation!

APPENDIX 2: CONSENT FORM

CONSENT FORM

CONSENT TO PARTICIPATE IN RESEARCH

PROJECT TITLE: Occupational exposure to electromagnetic fields in the heavy engineering CO_2 welding industry in the Mangaung Metropolitan municipality.

You have been asked to participate in a research study.

You have been informed about the study by Mr. J. Maritz

You may contact **Mr.S.F. Raphela** at **051 507 3436** any time if you have questions about the research or if you are injured as a result of the research.

You may contact the Secretariat of the Ethics Committee of the Faculty of Health Sciences, UFS at telephone number (051) 4052812 if you have questions about your rights as a research subject.

Your participation in this research is voluntary, and you will not be penalised or lose benefits if you refuse to participate or decide to terminate participation.

If you agree to participate, you will be given a signed copy of this document as well as the participant information sheet, which is a written summary of the research.

The research study, including the above information has been verbally described to me. I understand what my involvement in the study means and I voluntarily agree to participate.

______________________ Signature of Participant	__________________ Date
______________________ Signature of Witness *(Where applicable)*	__________________ Date
______________________ Signature of Translator *(Where applicable)*	__________________ Date

INFORMATION DOCUMENT

Study title: Occupational exposure to electromagnetic fields in the heavy engineering CO_2 welding industry in the Mangaung Metropolitan Municipality.

Dear Participant

I **S.F. Raphela, from the Central University of Technology, Free State** am doing research on occupational exposure to electromagnetic fields in the heavy engineering CO_2 welding industry in the Mangaung Metropolitan Municipality. Research is just the process to learn the answer to a question. In this study we want to investigate the health effects of occupational exposure to electromagnetic fields in the welding industry. A safety model will be developed to guide welding industry about the protection against electromagnetic fields.

We are asking you to participate in a research study

The study will be based on obtaining exposure measurements to electromagnetic fields. A sample of 58 exposed group and 30 control group will participate in the study. A total number of subjects will be 88. The exposed group consist of welders (n=37) and fitters (n=21) while the control group (n=30) consist of employees who work in offices and are not exposed to electromagnetic fields from welding. All selected subjects (South African and non-South African) are requested to complete the questionnaires. The measurements will be taken in welding workshops while the subjects weld and in offices near the computers, photocopy machines, electrical wires and other electrical equipment.

The subject will be given pertinent information on the study while involved in the project and after the results are available.

Participation is voluntary, and refusal to participate will involve no penalty or loss of benefits to which the subject is otherwise entitled; the subject may discontinue participation at any time without penalty or loss of benefits to which the subject is otherwise entitled.

Confidentiality: Efforts will be made to keep personal information confidential. Absolute confidentiality cannot be guaranteed. Personal information may be disclosed if required by law. Organisations that may inspect and copy your research records for quality assurance and data analysis include groups such as the Ethics Committee for Medical Research. If the results are published, this may lead to cohort identification.

Contact details of researcher(s) – for further information/reporting of study-related adverse events.

Mr. S.F. Raphela
Department of Clinical Sciences
Central University of Technology, Free State
Telephone: 051 507 3436

APPENDIX 3: DATA COLLECTION SHEET

Data collection sheet

Workshop/ Office No _______________________________

Magnetic/ electric fields_______________________________

	INTERVALS											
DAY	**Distance (m)**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**TWA**
1	1											
	2											
	3											
2	1											
	2											
	3											
3	1											
	2											
	3											
4	1											
	2											
	3											
5	1											
	2											
	3											
6	1											
	2											
	3											

7	1											
	2											
	3											
8	1											
	2											
	3											
9	1											
	2											
	3											
10	1											
	2											
	3											
11	1											
	2											
	3											
12	1											
	2											
	3											
13	1											
	2											
	3											
14	1											
	2											
	3											

TWA- Time weighted average

APPENDIX 4: ETHICAL CLEARANCE

UNIVERSITEIT VAN DIE VRYSTAAT
UNIVERSITY OF THE FREE STATE
YUNIVESITHI YA FREISTATA

Direkteur: Fakulteitsadministrasie / Director: Faculty Administration
Fakulteit Gesondheidswetenskappe / Faculty of Health Sciences
Research Division
Internal Post Box G40
☎(051) 4052812
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E-mail address: StraussHS@ufs.ac.za

Ms H Strauss

2011-11-11

REC Reference nr 230408-011
IRB nr 00006240

MR SF RAPHELA
PO BOX 666
LESHWANE
0724

Dear Mr Raphela

ECUFS NR 170/2011
PROJECT TITLE: OCCUPATIONAL EXPOSURE TO ELECTROMAGNETIC FIELDS IN THE HEAVY ENGINEERING CO_2 WELDING INDUSTRY IN THE MANGAUNG METROPOLITAN MUNICIPALITY.

- You are hereby kindly informed that the Ethics Committee approved the above project at the meeting held on 08 November 2011.
- Committee guidance documents: Declaration of Helsinki, ICH, GCP and MRC Guidelines on Bio Medical Research. Clinical Trial Guidelines 2000 Department of Health RSA; Ethics in Health Research: Principles Structure and Processes Department of Health RSA 2004; Guidelines for Good Practice in the Conduct of Clinical Trials with Human Participants in South Africa, Second Edition (2006); the Constitution of the Ethics Committee of the Faculty of Health Sciences and the Guidelines of the SA Medicines Control Council as well as Laws and Regulations with regard to the Control of Medicines.
- Any amendment, extension or other modifications to the protocol must be submitted to the Ethics Committee for approval.
- The Committee must be informed of any serious adverse event and/or termination of the study.
- A progress report should be submitted within one year of approval of long term studies and a final report at completion of both short term and long term studies.
- Kindly refer to the ECUFS reference number in correspondence to the Ethics Committee secretariat.

Yours faithfully

....
CHAIR: ETHICS COMMITTEE

Cc Dr C Weyers

339, Bloemfontein 9300,RSA ☎ (051) 405 2812 StraussHS@ufs.ac.za
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