Strål säkerhets myndigheten

Swedish Radiation Safety Authority

Author: SSM's Scientific Council on Electromagnetic Fields

Research

2019:08

Recent Research on EMF and Health Risk -

Thirteenth report from SSM's Scientific Council on Electromagnetic Fields, 2018

SSM perspective

Background
The Swedish Radiation Safety Authority's (SSM) Scientific Council on Electromagnetic Fields monitors current research on potential health risks with a correlation to exposure to electromagnetic fields and provides the Authority with advice on assessing possible health risks.
The Council gives guidance when the Authority must give an opinion on policy matters when scientific testing is necessary. The Council is required to submit a written report each year on the current research and knowledge situation.

This is a consensus report. This means that all members of the Scientific Council agree with the complete report. This increases the strength of the given conclusions.

Objective
The report has the objective of covering the previous year's research in the area of electromagnetic fields (EMF) and health. The report gives the Swedish Radiation Safety Authority an overview and provides an important basis for risk assessment.

Results
The present report is number thirteen in a series and covers studies published from April 2017 up to and including March 2018. The report covers different areas of EMF (static, low frequency, intermediate, and radio frequency fields) and different types of studies such as biological, human and epidemiological studies.

No new causal relationship between EMF exposure and health risks have been established.

Overall, the age standardised incidence of brain tumours is within the annual variations which can be statistically expected and do not give support to any causal relationship with radio wave exposure from mobile phone use.

The majority of the animal studies carried out on oxidative stress have indicated a possible relationship with radio wave exposure, some even below reference levels. The results are however not an established effect and further studies are needed to confirm the association in animals and to establish whether, and to what extent, it may occur in humans. Oxidative stress is a natural biological process that can sometimes be involved in pathogenesis, but under what circumstances needs to be investigated.

Two large animal studies (the US National Toxicology Program (NTP) study and the Italian Falcioni et al. study) have been published during the period. Both studies observed a relationship between radio wave exposure and Schwannoma in the heart for male rats. There is some inconsistency in the results between the two studies which weakens the significance of the results. Even if radio wave exposure could induce

Schwannoma in the heart in humans, it is a very rare tumour in humans and therefore, the relevance for public health is most likely low.

MRI workers are exposed to strong static magnetic fields. New epidemiological studies on MRI-exposed workers suggest increased risks of menometrorrhagia (excessive uterine bleeding, both at the usual time of menstrual periods and at other irregular intervals) in women using intrauterine devices, accidents during commuting and high blood pressure. Underlying mechanisms are unclear. Future studies should explore if these associations are true or if alternative explanations such as residual confounding, i.e. other factors related to MRI work and the outcomes under investigations, underlie the observed associations.

The annual report also has a section covering other relevant scientific reports published recently.

Many studies have been excluded due to poor quality. From a scientific perspective, studies of poor quality are irrelevant. They are also a waste of money, human resources and, in many cases, experimental animals

Relevance
The results of the research review give no reason to change any reference levels or recommendations in the field.

The hands-free recommendation for mobile phone calls remains even though trends of glioma incidences do not provide support for an increasing risk caused by mobile phone exposure. However, uncertainties regarding possible long-term effects justifies caution.

The authorities' recommendation to limit the exposure for low frequency magnetic fields still remains, due to the conceivable correlation between this kind of fields and childhood leukemia.

Need for further research
Despite the fact that no health risks with weak electromagnetic fields have been established today, the Authority considers that further research is important especially regarding long-term effects especially as the entire population is exposed. One key issue here is to further investigate the possible relationship between radio wave exposure and oxidative stress. Another vital issue is to clarify the association between weak low frequency magnetic fields and childhood leukemia as observed in epidemiological studies.

New technology for inductive wireless energy transfer based on intermediate frequency magnetic fields will probably be implemented for many different applications in the near future. In contrast to wireless information transfer technology, wireless energy transmission in principle always requires relatively strong local fields. This makes it very important to obtain a robust basis for risk assessment of such fields. Today there is a lack of studies in this frequency domain, therefore there is a special need for research here.

Wireless information technology is constantly taking new steps and new frequency ranges will be used. The 5th generation mobile telephony system (5G) will be installed all over the world within the next few years. Despite the lack of established mechanism for affecting health with weak radio wave exposure there is however need for more research covering the novel frequency domains, used for 5G. We also encourage researchers to start forward-looking epidemiological studies, i.e. cohort studies, in this area.

It is also desirable to investigate different health effects based on combinations between electromagnetic fields and other factors, physical factors as well as chemical factors.

There is also a need to better clarify the origin for the different problems MRI-exposed workers have experienced.

Project information
Contact person at SSM: Torsten Augustsson
Reference no: SSM2019-2006

2019:08

Recent Research on EMF
and Health Risk –
Thirteenth report from SSM's Scientific
Council on Electromagnetic Fields, 2018

Recent Research on EMF and Health Risk

Thirteenth report from SSM's Scientific Council on Electromagnetic Fields, 2018

Content

Preface

In 2002, the Swedish Radiation Protection Authority (SSI) established an international scientific council for electromagnetic fields (EMF) and health with the main task to follow and evaluate the scientific development and to give advice to the authority. The SSI was the responsible authority until July 2008. That year, the Swedish government reorganized the radiation protection work and the task of the scientific council is since then handled by the Swedish Radiation Safety Authority (SSM).

In a series of annual scientific reviews, the Council consecutively discusses and assesses relevant new data and put these in the context of available information. The result will be a gradually developing health risk assessment of exposure to EMF. The Council presented its first report in December 2003. The present report is number thirteen in the series and covers studies published from April 2017 up to and including March 2018.

The composition of the Council that prepared this report has been:

Prof Heidi Danker-Hopfe, Charité – University Medicine, Berlin, Germany
Prof Clemens Dasenbrock, Fraunhofer Institute for Toxicology and Experimental Medicine, Hannover, Germany
Dr Anke Huss, University of Utrecht, the Netherlands
Dr Leif Moberg, Sweden (chair)
Dr Aslak Harbo Poulsen, Danish Cancer Society, Copenhagen, Denmark
Dr Eric van Rongen, Health Council of the Netherlands, The Hague, The Netherlands
Prof Martin Röösli, Swiss Tropical and Public Health Institute, Basel, Switzerland
Dr Maria Rosaria Scarfi, National Research Council, Naples, Italy
Mr Lars Mjönes, B.Sc., Sweden (scientific secretary)

Declarations of conflicts of interest are available at SSM.

Stockholm in December 2018

Leif Moberg
Chair

Executive Summary

This report reviews studies on electromagnetic fields (EMF) and health risks, published from April 2017 up to and including March 2018. The report is the thirteenth in a series of annual scientific reviews which consecutively discusses and assesses relevant new studies and put these in the context of available information. The result will be a gradually developing health risk assessment of exposure to EMF.

Static fields

Exposure to static (0 Hz) magnetic fields much greater than the natural geomagnetic field can occur close to industrial and medical/scientific equipment that uses direct current such as some welding equipment and various particle accelerators. The main sources of exposure to strong static magnetic fields (> 1 T)[1] are magnetic resonance imaging (MRI) devices for medical diagnostic purposes. Volunteer studies have demonstrated that movement in such strong static fields can induce electrical fields in the body and sensations such as vertigo and nausea. The thresholds for these sensations seem to vary considerably within the population. Workers exposed to fields from MRI scanners are also affected by these transient symptoms.

Epidemiology
New studies on MRI-exposed workers suggest increased risks of menometrorrhagia (Excessive uterine bleeding, both at the usual time of menstrual periods and at other irregular intervals) in women using intrauterine devices, accidents during commuting and high blood pressure. Underlying mechanisms are unclear. Future studies should explore if these associations are true or if alternative explanations such as residual confounding, i.e. other factors related to MRI work and the outcomes under investigations, underlie the observed associations.

Human studies
There is no new information concerning effects of static field exposure from human experimental studies.

Animal studies
Only two studies were identified. These did not show adverse biological effects on spermatogenesis or diabetes. By contrast, the rat study on diabetically induced osteoporosis exemplarily demonstrated that 4 mT static magnetic field exposure may biophysically antagonize osteopenia/osteoporosis.

Cell studies
As stated in previous reports, a large number of studies have been published on the effect of exposure to static magnetic fields on cell cultures but in most of these no sham-controls have been assessed. Therefore, such papers have not been included in the analysis. The studies considered confirm that static magnetic fields are able to modify, by increasing or decreasing, the effect induced by chemical agents.

Extremely low frequency (ELF) fields

The exposure of the general public to extremely low frequency (ELF) fields (>0 Hz-300 Hz) is primarily from 50 and 60 Hz electric power lines and from electric devices and wiring in buildings. Regarding the exposure to ELF magnetic fields and the development of childhood leukaemia, the latest studies did not consistently observe an association. However, these studies did not use new approaches and the same limitations as in previous research apply. Thus, the conclusion from previous

---

[1] These magnetic fields (>1 T) are about a thousand times stronger than magnetic fields used in animal and cell studies which are most often in the mT-range. The geomagnetic field at the Earth´s surface ranges from 25 to 65 microtesla (µT).

Council reports still holds: epidemiologically, associations have been observed, but a causal relationship has not been established.

Epidemiology
Three new studies on ALS suggest an association with occupational ELF magnetic field exposure. One of the studies also evaluated occupational risk of electric shocks but did not observe associations with ALS risk. Overall, whether electric shocks are underlying observed increased risks in workers or whether associations are due to ELF magnetic field exposure (or possibly other factors) still remains unclear. A meta-analysis on this topic indicates that the chance to observe an association with ELF magnetic field exposure depends on the quality of the exposure assessment, with higher quality exposure assessment studies more likely to observe increased risks, which speaks for a possible association. Another meta-analysis on Alzheimer's disease found an overall increased risk but with substantial heterogeneity between studies, which could not be explained by study characteristics. One study did not identify increased risks of ALS with respect to residential exposure, but the study included only very few exposed cases. Two other original studies addressed adult cancer risk in relation to occupational ELF magnetic field exposure. Overall the results of occupational studies on adult cancer are inconsistent and no firm conclusions can be made on this subject. A large French study did not find a link between maternal ELF magnetic field exposure during pregnancy and various pregnancy outcomes, not supporting the hypothesis that ELF magnetic field exposure during pregnancy is a health risk for the foetus. One study evaluating residential ELF magnetic field exposure and leukaemia risk of children observed slightly elevated risks, in line with previous reports. An analysis stratified over the two decades of observation period did not indicate strongly differing risks by time period, thus not confirming two earlier reports that had observed strongly decreasing risks over time.

Human studies
Since human experimental studies are very scarce, the only conclusion that can be drawn is that there is no substantial new information on effects of exposure to extremely low frequency (ELF) magnetic fields in humans.

Animal studies
For this reporting period fewer animal studies were identified. Similar to previous Council reports, most studies looked at one exposure level only, typically in the 1 mT range at 50 or 60 Hz, which is five times higher than the ICNIRP reference value. These studies cannot evaluate exposure-response relationships relevant for public exposure. Four brain and behavioural studies did not provide insight on potential ELF magnetic field mechanism(s). The same holds for single studies addressing oxidative stress, (immune) physiology and fertility.

In addition to the two large Italian co-carcinogenicity studies reported in the previous, twelfth, Council report, the same research group reported now the corresponding cancer study after ELF magnetic field mono-exposures. However, again only on single tumour types, including hemolymphoreticular neoplasia. Various magnetic field strengths did not result in significant differences of specific (adenocarcinomas of the mammary gland, malignant Schwannomas of the heart, thyroid C-cell carcinomas, hemolymphoreticular neoplasias) and total malignant tumour incidences. Including this cancer study, none of the animal studies directly addressed childhood leukaemia which is still of relevance in view of the results of epidemiological studies.

Cell studies
The ELF *in vitro* studies evaluated several biological endpoints, including proliferation, viability, senescence, antioxidant defences and DNA damage. As for the previous report, the results are not univocal, with increase, decrease or no difference compared to sham controls. Moreover, also in this case, several studies lack sham-controls and have been excluded.

Intermediate frequency (IF) fields

The intermediate frequency (IF) region of the electromagnetic spectrum (300 Hz-10 MHz) is defined as being between the low frequency and the radiofrequency ranges. Despite increasing use of IF magnetic field-emitting sources such as induction hobs and anti-theft devices, scientific evaluation of potential health risks is scarce. For some of these sources, exposure assessment, especially of induced internal electric fields, remains challenging. Very few experimental studies are available on (health) effects of IF electromagnetic fields and no conclusions can be drawn at present. Additional studies would be important because human exposure to such fields is increasing, for example from different kinds of electronic article surveillance systems. Studies on possible effects associated with chronic exposure at low levels are particularly relevant for confirming adequacy of international exposure limits.

Epidemiological studies
Only one study dealt with potential risks from intermediate field exposure on miscarriage or other birth outcomes. The study was small and had large uncertainty regarding exposure levels. It is therefore limited in its ability to determine presence or absence of increased risks.

Human studies
There is no new information concerning effects of intermediate field exposure from human experimental studies.

Animal studies
In the 7.5 kHz range three mouse studies did not result in adverse effects on fertility, reproduction, learning and behaviour. In this context it should be noted that the upper magnetic field strength (120 µT) is about twice of nowadays cashiers' work place-exposures.

Cell studies
There is no new information concerning effects of intermediate field exposure from cell studies.

Radiofrequency (RF) fields

The general public is exposed to radiofrequency fields (10 MHz-300 GHz) from different sources, such as radio and TV transmitters, Wi-Fi, cordless and mobile phones and their supporting base stations and wireless local area networks. Among parts of the public there is concern about possible health effects associated with exposure to radiofrequency fields. Particularly, in some countries, concern about the use of Wi-Fi in schools has grown in recent years. Measurements and exposure calculations have shown that radiofrequency field exposure is dominated by personal mobile phone use. Environmental sources such as mobile phone base stations play a minor role.

Epidemiology
Several new meta-analyses on brain tumour risk in relation to mobile phone use have been published. However, these papers do not contribute to a better understanding as essentially the identical underlying study base was re-analysed several times. Moreover, the selection of studies in these meta-analyses was not done in a systematic manner. Overall, time trends of brain tumour incidence stay rather constant over time. Increases have been reported for specific subtypes of tumours and decreases in some others. Most likely, changes in coding praxis are responsible for shifting number of cases between different diagnoses. Thus, future incidence studies should carefully report results for all diagnoses and locations within a disease entity to allow better interpretation of the data.

Two studies on mobile phone use during pregnancy found positive and negative effects suggesting other factors than radiofrequency EMF exposure may be at play. In terms of symptoms, several studies reported associations with self-reported mobile phone use but not exposure from transmitters. These

studies may indicate that other aspects related to frequent mobile phone use (e.g. distraction or stress) than radiofrequency EMF emissions may have an impact on health-related quality of life.

Human studies
Three studies on effects of radiofrequency EMF exposure address endpoints other than the studies covered in the last reporting period. One human experimental study on EMF concludes that there is no effect on visually evoked potentials, a second study underlines that a 40 Hz modulation of the radiofrequency signal affects EEG power. The conclusion of a third study, that radiofrequency exposure does not affect the autonomous nervous system in subjects who declared themselves to be electrohypersensitive is certainly limited by the small sample size and the related small power.

Animal studies
Two animal studies (the US National Toxicology Program (NTP) study and the Italian Falcioni et al. study) both have a number of positive aspects, including their sample size and the duration of the exposure and the attempts to provide a comprehensive analysis of the pathology. For most of the endpoints studied in mice and rats in the US NTP study, no significant association with radiofrequency EMF exposure was observed. An exception was schwannoma of the heart in male rats. However, the results are inconsistent between the US and the Italian studies in terms of the exposure levels where increased tumour incidences are observed, and the main endpoint, schwannoma of the heart, is a very rare tumour in humans and therefore, likely, the public health relevance is not very high. Moreover, it is a tumour that has never appeared in any experimental radiofrequency carcinogenesis study. It is peculiar that it now appears in two studies published at the same time, and that the tumour shows up only in male rats and not in mice. Strikingly, male rats showed a higher increase in core temperature than female rats and mice but a discussion on the effects of heating at the high exposure level in male rats is missing. Altogether, these studies cannot be considered as clear indications for carcinogenicity of exposure to radiofrequency fields in humans.

Eleven studies of sufficient quality were identified that investigated behavioural and cognitive effects and effects on neurotransmitters of exposure to radiofrequency EMF. In most studies some effect was observed, but it is difficult to find a clear overall picture. It is remarkable that both in studies with relatively low (whole-body average SAR 14-179 mW/kg) and high (brain SAR 7 W/kg) exposure levels effects on memory were observed, while in studies employing whole-body average SARs of 0.2-3.3 W/kg no effect was found. Anxiety was found to be increased in two out of three studies. Several studies found effects on neurotransmitter/signalling pathways in cortex or hippocampus, but this was also not clearly related to exposure levels. In one study using transgenic mice for human Alzheimer-related genes, the effects on behaviour of the genetic alterations was cancelled out by radiofrequency EMF exposure.

In eight of the nine studies on apoptosis or oxidative stress, an effect indicative of increased oxidative stress was observed. The one study on blood-brain barrier found leakage only with the very high local brain exposure of 13 W/kg, which might have resulted in heating. Finally, a whole-body average SAR of 0.01 W/kg was shown to result in changes in Purkinje cells in the cerebellum. In contrast to earlier studies, newer studies indicate possible effects of relatively low-level radiofrequency EMF exposures on oxidative stress. The results are however not conclusive and further studies are needed to confirm if the association occurs in animals and to establish whether and to what extent it may occur in humans.

Cell studies
Also in this evaluation period a large number of studies have been published on the effect of radiofrequency EMF exposure on cell cultures, given alone or in combination with other chemical or physical agents, but about 50% of them have not been included in the analysis due to scanty quality of the research. Most of the studies considered do not indicate effects of radiofrequency exposure. In addition, they confirm that radiofrequency EMF exposure is able to modify (by increasing or decreasing) the effect induced by chemical or physical agents.

Sammanfattning

I rapporten granskas studier av elektromagnetiska fält och hälsorisker, publicerade från april 2017 till och med mars 2018. Det är den trettonde i en serie årliga vetenskapliga granskningar som fortlöpande diskuterar och utvärderar relevanta nya data och värderar dessa i förhållande till redan tillgänglig information. Resultatet blir en kontinuerligt utvecklad uppskattning av hälsorisker från exponering för elektromagnetiska fält.

Statiska fält

Exponering för statiska (0 Hz) magnetfält som är mycket starkare än det naturligt förekommande geomagnetiska fältet kan förekomma i närheten av industriell och medicinsk/vetenskaplig utrustning som använder likström, som t.ex. elsvetsutrustningar och olika typer av partikelacceleratorer. Den viktigaste källan till exponering för starka statiska magnetfält (> 1 T)[2] är användningen av magnetkamera för medicinsk diagnostik. Studier på frivilliga försökspersoner har visat att rörelser i starka statiska fält kan inducera elektriska fält i kroppen och orsaka yrsel och illamående. Tröskelvärdena för dessa effekter tycks dock variera avsevärt mellan olika individer. Personal som arbetar med magnetkameror kan påverkas av dessa fenomen.

Epidemiologi
Nya studier på personal som arbetar med magnetkamera antyder ökade risker för olyckor i samband med färd från och till arbetet, förhöjt blodtryck samt för kvinnor en ökad risk för blödningar från livmodern både under menstruation och mellan menstruationerna (menometrorragi). De underliggande mekanismerna är oklara. Framtida studier bör undersöka om dessa samband är verkliga eller om alternativa förklaringar skulle kunna orsaka de observerade sambanden: t.ex. kvarliggande förväxlingsfaktorer, dvs. andra faktorer som kan ha samband med arbete med magnetkamera och de observerade riskerna.

Ingen ny information har tillkommit rörande påverkan från exponering för statiska magnetfält från experimentella humanstudier

Djurstudier
Endast två studier har identifierats. De visar inte på några skadliga biologiska effekter på spermieproduktion eller diabetes. Däremot demonstrerade en studie på råttor med diabetiskt inducerad benskörhet att exponering för 4 mT statiskt magnetfält skulle kunna, på biofysisk väg, motverka benskörhet och försämrad mineraltäthet i ben.

Cellstudier
Som konstaterats i föregående rapporter har ett stort antal studier publicerats rörande effekter från exponering för statiska magnetfält på cellkulturer, men i de flesta fall saknas utvärdering av oexponerade kontroller. Studier där oexponerade kontroller saknas beaktas inte i rapporten. De studier som analyserats bekräftar att statiska magnetfält kan modifiera, antingen förstärka eller försvaga, effekter som inducerats av kemiskt verksamma faktorer.

Lågfrekventa fält

Allmänheten exponeras för lågfrekventa fält ($>$0-300 Hz) i första hand från kraftledningar med frekvenserna 50 och 60 Hz och från elektriska installationer och apparater i byggnader. När det gäller sambandet mellan exponering för lågfrekventa magnetfält och utvecklingen av barnleukemi visar de

---

[2] De statiska magnetfälten i en magnetkamera är större än 1 T vilket är omkring tusen gånger starkare än de magnetfält som normalt används i djurstudier och cellstudier som oftast är i milliteslaområdet. Det geomagnetiska fältet vid jordytan varierar mellan 25 och 65 mikrotesla.

senaste studierna inte samstämmigt på samband. Inga nya undersökningsmetoder har emellertid använts i dessa nya studier och de har därför samma begränsningar som tidigare forskning. Därför gäller fortfarande slutsatsen från Rådets tidigare rapporter: I epidemiologiska studier har samband observerats men orsaken till detta har inte kunnat fastställas.

Epidemiologi

Tre nya studier rörande ALS (amyotrofisk lateralskleros) antyder ett samband med yrkesexponering för lågfrekventa magnetfält. En av studierna utvärderade också yrkesrisken från elstötar men fann inget samband med risk för ALS. Sammantaget är det fortfarande oklart om elstötar ligger bakom observerade förhöjda risker för ALS i yrkeslivet eller om sambanden orsakas av exponering för lågfrekventa magnetfält, eller om sambanden orsakas av andra faktorer. En metaanalys i ämnet antyder att möjligheten att hitta ett samband med exponering för lågfrekventa magnetfält är beroende av kvaliteten på exponeringsuppskattningen. Högre kvalitet på exponeringsuppskattningen ökar möjligheterna att observera förhöjda risker och därmed möjligheten att hitta möjliga samband. En annan metaanalys, på studier av Alzheimers sjukdom, fann sammantaget en förhöjd risk men med påtagliga skillnader mellan de olika studierna som inte kunde förklaras av studiernas utformning. En studie fann ingen ökad risk för ALS från yrkesexponering, men den studien omfattade bara mycket få exponerade fall. Två andra originalstudier undersökte cancer i förhållande till yrkesexponering för lågfrekventa magnetfält.

Sammantaget är resultaten från studier av cancer hos vuxna och yrkesexponering för lågfrekventa magnetfält motsägelsefulla och inga säkra slutsatser kan dras. En stor fransk studie fann inget samband mellan moderns exponering för lågfrekventa magnetfält under graviditeten och olika graviditetsutfall. Studien ger inte stöd för hypotesen att exponering för lågfrekventa magnetfält under graviditeten skulle kunna utgöra en risk för fostret. En studie som utvärderade samband mellan exponering för lågfrekventa magnetfält i hemmet och risk för barnleukemi fann något förhöjda risker i likhet med tidigare rapporter. En analys som omfattade en observationsperiod av 20 år fann inga stora skillnader i risk över tid, och kunde sålunda inte bekräfta resultaten från två tidigare studier som rapporterat en starkt avtagande risk över tid.

Studier på människa

Eftersom mycket få experimentella humanstudier har identifierats, så är slutsatsen att det inte finns någon ny information om påverkan på människor från exponering för lågfrekventa magnetfält.

Djurstudier

Under den här rapporteringsperioden har färre djurstudier än tidigare identifierats. Liksom tidigare så har de flesta studierna undersökt endast en exponeringsnivå, oftast i 1 mT-området vid 50 eller 60 Hz, vilket är fem gånger högre än ICNIRP:s referensvärde för allmänheten. Dessa studier kan därför inte utvärdera exponering-responssamband som är relevanta för exponering av allmänheten. Fyra studier som undersökte hjärna och beteende gav ingen kunskap om möjliga mekanismer för påverkan av exponering för lågfrekventa magnetfält. Detsamma gäller för enstaka studier som undersökte oxidativ stress, (immun)fysiologi och fertilitet.

Utöver de två stora italienska cancerstudierna, där exponering för lågfrekventa magnetfält kombinerats med samtidig exponering för gammastrålning respektive intag av formaldehyd, som diskuterades i föregående rapport från Rådet har samma forskargrupp nu rapporterat motsvarande cancerstudie efter exponering för en enda typ av exponering för lågfrekventa magnetfält. Dock omfattar studien bara enstaka tumörtyper, däribland maligna lymfoida tumörer (lymfom, lymfatisk leukemi m.fl.). Exponering för magnetfält av olika styrka resulterade inte i signifikant olika incidenser av specifika tumörer (adenokarcinom i bröstkörteln, schwannom i hjärtmuskeln, tyroid c-cellscancer, lymfoida tumörer) eller totala antalet tumörer. Ingen av de identifierade studierna behandlade mekanismer som skulle kunna ha betydelse för utveckling av barnleukemi, något som fortfarande är relevant med tanke på resultaten från epidemiologiska studier.

Cellstudier

In vitro-studierna för exponering för lågfrekventa magnetfält undersökte flera olika biologiska utfall, inklusive celltillväxt, cellöverlevnad, cellåldrande, antioxidantförsvar och DNA-skador. Liksom i föregående rapport från Rådet är resultaten från studierna inte entydiga utan kan innebära både ökning, minskning och ingen skillnad jämfört med oexponerade kontroller. Många studier saknar oexponerade kontroller och har därför inte granskats.

Intermediära fält

Det intermediära frekvensområdet (300 Hz-10 MHz) av det elektromagnetiska spektret ligger definitionsmässigt mellan det lågfrekventa och det radiofrekventa områdena. Trots en ökande användning av apparater som medför exponering för intermediära fält, som t.ex. larmbågar i butiker och induktionsspisar, så har möjliga hälsorisker utvärderats endast i mycket liten utsträckning. Exponeringsuppskattningen, särskilt för inducerade interna elektriska fält, är fortfarande en utmaning för den här typen av exponeringskällor. Mycket få experimentella studier rörande hälsoeffekter från exponering för intermediära fält finns tillgängliga, och inga slutsatser kan dras för närvarande. Fler studier skulle vara värdefulla eftersom människor exponeras för dessa fält i ökande grad. Studier av möjliga effekter av långvarig exponering för låga nivåer är särskilt betydelsefulla för att bekräfta tillförlitligheten i gällande rikt- och gränsvärden.

Epidemiologi

Den enda studie som identifierats undersökte möjliga risker från exponering för intermediära fält för missfall eller andra graviditetsutfall. Studien var liten och hade stora osäkerheter vad gäller exponeringsnivåer. Möjligheten att utifrån denna studie bedöma risker är därför begränsad.

Studier på människa

Inga nya humanstudier har identifierats.

Djurstudier

I tre studier på möss som exponerats i frekvensområdet 7,5 kHz framkom inte några negativa effekter på fertilitet, fortplantning eller beteende. Den maximala styrkan på magnetfälten i undersökningarna, 120 µT, är ungefär dubbelt så hög som arbetsplatsexponeringen för dagens kassapersonal.

Cellstudier

Inga nya cellstudier har identifierats

Radiofrekventa fält

Allmänheten exponeras för radiofrekventa fält (10 MHz-300 GHz) från en mängd olika källor som radio- och TV-sändare, trådlösa telefoner och mobiltelefoner och deras respektive basstationer samt från trådlösa datornätverk. Delar av allmänheten känner oro för möjliga hälsoeffekter som skulle kunna orsakas av exponering för radiofrekventa fält. Framför allt har oron för användningen av trådlösa datornätverk i skolor ökat under senare år i en del länder. Mätningar och beräkningar har visat att de högsta exponeringsnivåerna orsakas av användning av egen mobiltelefon. Omgivningskällor som basstationer för mobiltelefoni spelar endast en mindre roll.

Epidemiologi

Flera nya metaanalyser av risk för hjärntumör relaterat till användning av mobiltelefon har publicerats. Dessa studier bidrar emellertid inte till ökad kunskap eftersom det i huvudsak är samma underliggande studiebas som analyserats upprepade gånger. Dessutom har urvalet av studier i dessa metaanalyser inte gjorts på något systematiskt sätt. Variationen över tid av nya fall av hjärntumörer är relativt konstant.

Ökning har rapporterats för vissa typer av tumörer och minskningar för andra. Det troliga är att variationen i antal fall för olika diagnoser orsakas av ändringar i kodningspraxis. Framtida studier av nya fall av hjärntumörer bör därför noggrant rapportera resultat för alla diagnoser för en viss typ av sjukdom för att möjliggöra en bättre bedömning av data.

Två studier av mobiltelefonanvändning under graviditet fann positiva och negativa effekter som antyder att andra faktorer än exponering för radiofrekventa fält kan vara orsaken. När det gäller symtom så rapporterar flera studier samband med egenrapporterad mobiltelefonanvändning men inte med exponering från olika typer av radiosändare. Dessa studier kan tyda på att andra faktorer (t.ex. distraktion eller stress) än exponeringen för radiofrekventa fält vid frekvent mobiltelefonanvändning kan ha betydelse för hälsorelaterad livskvalitet.

Studier på människa
Tre studier rörande effekter av exponering för radiofrekventa fält undersöker andra utfall än de studier som analyserats i föregående rapport. En experimentell humanstudie visar att en metod för att undersöka synnervens funktion inte påverkas av exponering för radiofrekventa fält. En annan studie understryker att 40 Hz modulation av den radiofrekventa signalen påverkar EEG. Slutsatsen från en tredje studie, att exponering för radiofrekventa fält inte påverkar det autonoma nervsystemet hos personer som anser sig vara elöverkänsliga är av begränsat värde eftersom urvalet var litet och den statistiska styrkan därför liten.

Djurstudier
Två djurstudier, NTP-studien (National Toxicology Program) från USA och den italienska studien av Falcioni och medarbetare har båda ett antal positiva aspekter, bl.a. storleken, exponeringstiden och ambitionen att göra en noggrann analys av patologin. För de flesta resultatmått som studerades för möss och råttor i den amerikanska NTP-studien sågs inte några signifikanta samband med exponering för radiofrekventa fält. Ett undantag var schwannom i hjärtat hos hanråttor. Detta observerades också i den italienska studien, som enbart studerade råttor. Resultaten överensstämmer emellertid inte mellan de två studierna när det gäller vid vilka exponeringsnivåer ökad tumörförekomst har observerats. Det viktigaste undersökningsresultatet, schwannom i hjärtat, är en mycket ovanlig tumör hos människor och därför är betydelsen ur folkhälsosynpunkt tveksam. Dessutom är det en tumör som aldrig tidigare har förekommit i någon experimentell cancerstudie med radiofrekventa fält. Det är anmärkningsvärt att den nu dyker upp i två studier som publicerats samtidigt och att tumören hittas bara hos hanråttor och inte hos möss. Det är slående att hanråttor uppvisade en större ökning av kroppstemperaturen än honråttor och möss och att en diskussion om uppvärmningseffekter från den höga exponeringsnivån för hanråttor saknas. Sammantaget kan dessa studier inte anses ge några klara indikationer på att radiofrekventa fält skulle vara cancerframkallande hos människor.

Elva studier av godtagbar kvalitet har identifierats som har undersökt beteendemässiga och kognitiva effekter respektive effekter på ämnen (neurotransmittorer) som förmedlar nervsignaler på kemisk väg från en nervcell till en annan vid exponering för radiofrekventa fält. I de flesta studierna observerades någon typ av effekt, men det är svårt att urskilja någon klar och sammanhängande bild. Det är anmärkningsvärt att effekter på minnesfunktioner observerades både i studier med relativt låga exponeringsnivåer (genomsnittlig helkropps-SAR på 14-179 mW/kg) och höga nivåer (hjärn-SAR 7 W/kg) medan några effekter inte observerades i studier med helkropps-SAR på 0,2-3,3 W/kg. Oro/ångest ökade i två av tre studier. Flera studier fann effekter på neurotransmittorer/signalvägar i cortex eller hippocampus, men det fanns ingen tydlig koppling till exponeringsnivå. I en studie som använde transgena möss i en djurmodell anpassad för Alzheimer hos människa försvann de beteendemässiga effekterna vid exponering för radiofrekventa fält.

I åtta av de nio granskade studierna av apoptos och oxidativ stress observerades en effekt som indikerar ökad oxidativ stress. Den enda studien på blod hjärn-barriären fann läckage endast vid den mycket höga lokala exponeringsnivån 13 W/kg, vilket kan ha varit en effekt av uppvärmning. Slutligen observerades förändringar i Purkinje-cellerna (en speciell typ av nervceller) i lillhjärnan vid en nivå av helkropps-SAR på 0,01 W/kg. I motsats till tidigare studier så tyder nyare studier på möjliga effekter på oxidativ stress vid relativt låga exponeringsnivåer. Resultaten är emellertid inte

säkerställda och ytterligare studier är nödvändiga för att bekräfta sambandet hos försöksdjur och för att fastställa om, och i så fall i vilken utsträckning, detta även gäller för människor.

Cellstudier

Även under denna rapporteringsperiod har ett stort antal studier publicerats rörande påverkan på cellkulturer från exponering för radiofrekventa fält, antingen som enda exponering eller i kombination med kemiskt eller fysikaliskt verksamma faktorer. Ungefär 50 procent av studierna har dock inte beaktats i rapporten beroende på dålig kvalitet på forskningen. De flesta studier som inkluderats tyder inte på några effekter från exponering för radiofrekventa fält. Däremot bekräftar de att exponering för radiofrekventa fält kan modifiera, antingen förstärka eller försvaga, en effekt som inducerats av kemiskt eller fysikaliskt verksamma faktorer.

Preamble

In this preamble we explain the principles and methods that the Council uses to achieve its goals. Relevant research for electromagnetic fields (EMF) health risk assessment can be divided into broad sectors such as epidemiologic studies, experimental studies in humans and in animals, and *in vitro* studies. Studies on biophysical mechanisms, dosimetry, and exposure assessment are also considered as integrated parts in these broad sectors. A health risk assessment evaluates the evidence within each of these sectors and then weighs together the evidence across the sectors to provide a combined assessment. This combined assessment should address the question of whether or not a hazard exists, i.e. if a causal relation exists between exposure and some adverse health effect. The answer to this question is not necessarily a definitive yes or no, but may express the likelihood for the existence of a hazard. If such a hazard is judged to be present, the risk assessment should also address the magnitude of the effect and the shape of the exposure response function, i.e. the magnitude of the risk for various exposure levels and exposure patterns.

As a general rule, only articles that are published in English language peer-reviewed scientific journals[3] since the previous report are considered by the Council. A main task is to evaluate and assess these articles and the scientific weight that is to be given to each of them. However, some of the studies are not included in the Council report either because the scope is not relevant, or because their scientific quality is insufficient. For example, poorly described exposures and missing unexposed (sham) controls are reasons for exclusion. Such studies are normally not commented upon in the annual Council reports (and not included in the reference list of the report)[4]. Systematic reviews and meta-analyses are mentioned and evaluated, whereas narrative and opinion reviews are generally not considered.

The Council considers it to be of importance to evaluate both positive and negative studies, i.e. studies indicating that exposure to electromagnetic fields has an effect and studies indicating a lack of an effect. In the case of positive studies the evaluation focuses on alternative factors that may explain the positive result. For instance, in epidemiological studies it is assessed with what degree of certainty it can be ruled out that an observed positive result is the result of bias, e.g. confounding or selection bias, or chance. In the case of negative studies it is assessed whether the lack of an observed effect might be the result of (masking) bias, e.g. because of too small exposure contrasts or too crude exposure measurements. It also has to be evaluated whether the lack of an observed effect is the result of chance, a possibility that is a particular problem in small studies with low statistical power. Obviously, the presence or absence of statistical significance is only one of many factors in this evaluation. Indeed, the evaluation considers a number of characteristics of the study. Some of these characteristics are rather general, such as study size, assessment of participation rate, level of exposure, and quality of exposure assessment. Particularly important aspects are the observed strength of the association and the internal consistency of the results including aspects such as exposure-response relation. Other characteristics are specific to the study in question and may involve aspects such as dosimetry, method for assessment of biological or health endpoint and the relevance of any experimental biological model used.[5]

It should be noted that the result of this process is not an assessment that a specific study is unequivocally negative or positive or whether it is accepted or rejected. Rather, the assessment will result in a weight that is given to the findings of a study. The evaluation of the individual studies within a sector of research is followed by the assessment of the overall strength of evidence from that sector with respect to a given outcome. This implies integrating the results from all relevant individual studies into a total assessment taking into account the observed magnitude of the effect and the quality of the studies.

---

[3] Articles are primarily identified through searches in relevant scientific literature data bases; however, the searches will never give a complete list of published articles. Neither will the list of articles that do not fulfil quality criteria be complete.
[4] Articles not taken into account due to insufficient scientific quality are listed in an appendix and reasons for not being taken into account are indicated.
[5] For a further discussion of aspects of study quality, see for example the Preamble of the IARC (International Agency for Research on Cancer) Monograph Series (IARC, 2002).

In the final overall evaluation phase, the available evidence is integrated over the various sectors of research. This involves combining the existing relevant evidence on a particular endpoint from studies in humans, from animal models, from in *vitro studies*, and from other relevant areas. In this final integrative stage of evaluation the plausibility of the observed or hypothetical mechanism(s) of action and the evidence for that mechanism(s) have to be considered. The overall result of the integrative phase of evaluation, combining the degree of evidence from across epidemiology, human and animal experimental studies, *in vitro* and other data depends on how much weight is given on each line of evidence from different categories. Human epidemiology is, by definition, an essential and primordial source of evidence since it deals with real-life exposures under realistic conditions in the species of interest. The epidemiological data are, therefore, given the greatest weight in the overall evaluation stage. However, epidemiological data has to be supported by experimental studies to establish a causal link between exposure and health.

An example demonstrating some of the difficulties in making an overall assessment is the evaluation of ELF magnetic fields and their possible causal association with childhood leukaemia. It is widely agreed that epidemiology consistently demonstrates an association between ELF magnetic fields and an increased occurrence of childhood leukaemia. However, there is lack of support for a causal relation from observations in experimental models and a plausible biophysical mechanism of action is missing. This had led IARC to the overall evaluation of ELF magnetic fields as "possibly carcinogenic to humans" (Group 2B).

1. Static fields

1.1. Epidemiological studies

Previous SSM reports concluded that epidemiological studies confirmed associations between magnetic resonance imaging (MRI) work and experiencing acute symptoms, but little could be concluded in terms of potential long-term health effects. Traffic accidents while commuting had been suggested to be the consequences of workers' long term MRI exposure. No indication was observed for an increased risk of stillbirth for mothers with an MRI scan during pregnancy.

Petri et al. (2017) systematically reviewed studies evaluating effects of static electric fields on human (and vertebrates') health. One observational study (and several experimental studies, summarised under "Human Studies") published in 1984 was found. The study reported no adverse health effects in high voltage line workers.

In a Dutch survey among 381 female radiographers registered with their national association it was evaluated whether MRI work with intrauterine devices (IUDs) is related to abnormal uterine bleeding (menometrorrhagia) (Huss et al. (2018b)). A total of 68 women reported using IUDs. They were more likely to experience menometrorrhagia (OR=2.1 (95% confidence interval: 0.9–4.9) compared to unexposed women not using IUDs by considering age, self-reported physical, emotional, and general work stress in the analysis. Associations were stronger for women reporting being present during image acquisition (OR: 3.4, 95% CI 1.3–9.3).
This study indicates that stray fields from MRI scanners may cause abnormal uterine bleeding in radiographers using IUDs as suggested by previous case reports. Limitations of the study include the relatively small sample size and the modest participation rate (ca. 30%), which may have produced selection bias if affected and exposed persons were more likely to respond to the survey. The fact that both work practices and outcome are self-reported might also have introduced some bias.

In the same survey, Huss et al. (2017) investigated a potential association between occupational exposure to MRI and an increased risk of accidents in 490 male and female radiographers. After adjusting for a range of potential confounders (sex, age, work-related stress, work-related physical and emotional strain, sleeping problems, night shifts, caffeine and alcohol consumption) MRI workers had an increased risk for an accident or a "near-accident" event while commuting (OR 2.13, 95% CI 1.23−3.69). Risks were higher in persons who worked with MRI more often (OR 2.32, 95% CI 1.25−4.31) compared to persons who worked sometimes with MRI (OR 1.91, 95% CI 0.98−3.72), and higher in those who had likely experienced higher peak exposures to static and time-varying magnetic fields (OR 2.18, 95% CI 1.06–4.48). The effect was seen for commutes both to and from work and elsewhere.
This study broadly confirms the result of a previous Dutch study discussed in the SSM report 2017 (Bongers et al. (2016)). The mechanism how occupational MRI exposure may increase accident risk is not yet understood but might be the delayed consequences of established acute effects from MRI work such as dizziness, vertigo, effects on balance and disturbed visual perception and hand-eye coordination. The main limitation of the study is the low participation rate (29%) and cross sectional design with self-reported exposure and outcome. In particular, definition of near-accident events is not sharp and involves subjective judgment, which may be differential according to work type.

The association between hypertension and long-term exposure to static magnetic fields was investigated in an occupational cohort of 538 male workers from an MRI-manufacturing facility in the Netherlands (Bongers et al. (2018)). Exposure was assessed by linking individual job histories from the facility's personnel records with a facility-specific historical job exposure matrix. Hypertension was defined as systolic pressure of above 140 mm Hg and/or a diastolic blood pressure above 90 mm Hg in the last available blood pressure measurements from the facility's medical surveillance scheme. High cumulative exposure to SMF (≥7.4 kilotesla minutes) was positively associated with

development of hypertension (OR=2.32, 95% CI: 1.27 – 4.25) adjusted for age, body mass index and blood pressure at time of first blood pressure measurement. No indication for confounding from alcohol use and smoking was found in an analysis within a subsample with the corresponding information.

This is one of the first studies that suggest long term risks for MRI workers. The longitudinal design is an asset of this study. Systematic exposure and outcome assessment is expected to minimize bias in this study. However, residual confounding cannot be excluded. For instance, no data on occupational noise exposure of these workers was available, which might be a relevant confounder for this analysis.

A small pilot study on 12 MRI-exposed, and 12 MRI-unexposed hospital employees from the National Cancer Institute in Naples, Italy, was published by Sannino et al. (2017a). Static magnetic field exposure was measured over 2 weeks, and time-varying electric fields were simulated for exposed employees. The hospital used a 1.5 T whole-body scanner; the observed day-to-day exposure variability was reported to be high. Blood samples were taken to assess spontaneous and mitomycin C-induced chromosomal fragility in human peripheral blood lymphocytes, using a cytokinesis-block micronucleus assay. Only small and statistically non-significant differences were observed.

It is somewhat unclear why not commercially available measurement devices were used to measure static fields and dB/dT, and why time-varying fields had to be simulated. It is also unclear when blood samples were taken in respect to the exposure. All in all, this study is too small to draw clear conclusions as to exposure levels depending on work practices, or regarding any health effects from the exposure.

1.1.1. Conclusions on static field epidemiological studies

New studies on MRI-exposed workers suggest increased risks of menometrorrhagia in women using intrauterine devices, accidents during commuting and high blood pressure. Underlying mechanisms are unclear. Future studies should explore if these associations are true or if alternative explanations such as residual confounding, i.e. other factors related to MRI work and the outcomes under investigations, underlie the observed associations.

1.2. Human studies

Like last year, there is no new experimental human study in the current reporting period to be discussed here. One experimental study, which investigated effects on the electrocardiogram prior to and following an MRI assessment (Derkacz et al. (2018) did not meet the quality criteria (see Appendix).

Petri et al. (2017) performed a systematic literature review on biological effects of exposure to static electric fields. Eight human studies were identified, half of them investigated field perception and the other 50% investigated health/biological effects (three experimental studies and one epidemiological study). Field perception among others varies individually, with posture (higher sensitivity while sitting as compared to standing), co-exposure to air ions (increase of sensitivity with high concentrations of air ions) and co-exposure with AC fields (lower perception thresholds in the combined exposure). Thresholds to detect static electromagnetic fields are lower for whole-body exposure as compared to limb exposure only. Since this effect was confirmed by independent investigators, it can be considered as replicated. Results observed in three experimental studies on physiological/health effects are heterogeneous with regard to endpoints and effects. For skin symptoms (in combination with high dust concentration), effects were observed in one study and no effects in another. Furthermore, no effects on psychomotor and physiological functions were observed in a group of pilots. None of the results has yet been replicated.

1.2.1. Conclusions on static field human studies

Overall, there is no new information concerning effects of static field exposure from human experimental studies.

1.3. Animal studies

In contrast to the previous report, only a few studies on static field effects were found. One study addressed effects on spermatogenesis, another addressed the effect of 4 mT static magnetic fields (SMF) on diabetically induced osteoporosis. Two systematic review papers were identified.

1.3.1. Development and reproduction

Wu et al. (2017) exposed 10 male 4-week old ICR mice to a static EF of 56 kV/m for 49 days. 10 further males were sham-exposed. Spermatogenesis and parameters of testicular function were addressed. After 49 days there were no obvious differences between static EF- and sham-exposed mice for the endpoints relative organ weights of testes and epididymis, serum testosterone, sperm motility, sperm morphology, and testicular histology. However, transmission electron microscopy demonstrated some losses of mitochondria cristae in spermatogenic cells which did not affect sperm motility. Exposure to static EF of 56 kV/m thus has very limited effects, if any, on the reproductive system in male mice.

1.3.2. Physiology and pathophysiology

Zhang et al. (2018) tested bone growth and regeneration capacity in diabetic and non-diabetic male Sprague-Dawley rats following whole-body exposure to 4 mT SMF 2h/d for 16 consecutive days. Three groups with n=8 males each were used: 1) control, 2) diabetic (D), and 3) D+SMF. Controls and diabetic rats were sham-exposed. Prior to exposure of groups 2 and 3, type 1 diabetes (T1D) was induced in these rats by a single dose 50 mg/kg streptozocin (STZ). It resulted in blood glucose level ≥16.7 mmol/L and served as an inclusion criterion for these groups. After 16 weeks of exposure, blood samples and bilateral femoral bone samples were taken. Serum biochemical, bone histomorphometric, and skeletal gene expression data (via RT-PCR) were obtained. Body weight in rats of the D group (2) was significantly lower than in control and D+SMF. As shown by µCT analysis of the right femur, 4 mT SMF inhibited the architectural deterioration of bone. Accordingly demonstrated by biomechanical 3-point bending findings, mechanical strength reduction was inhibited by SMF; values were similar between control and D+SMF group. In diabetic rats SMF exposure led to higher serum osteocalcin, increased mineral apposition rate and osteoblast number of trabecular bone, higher skeletal osteocalcin, and higher gene expression of BMP2 (bone morphogenetic protein 2) and RUNX2 (runt related transcription factor 2). However, SMF did not significantly alter serum CTX (serum type I collagen), skeletal osteoclast number, or osteoclastogenesis-related RANKL-RANK (receptor activator of NF-κB (ligand)) signaling gene expression in diabetic rats (D+SMF). "Moderate SMF" (4 mT) thus inhibited the reduction of bone formation in diabetic rats. Therefore, SMF may biophysically antagonize T1D-related osteopenia/osteoporosis.

1.3.3. Systematic reviews

Petri et al. (2017) performed a systematic review entitled "Biological effects of exposure to static electric fields in humans and vertebrates: a systematic review". 48 articles fulfilled their eligibility criteria and showed "good evidence that humans and animals are able to perceive the presence of static EF at sufficiently high levels. […] A large number of studies reported responses of animals (e.g. altered metabolic, immunologic or developmental parameters) to a broad range of static EF strengths as well, but these responses are likely secondary physiological responses to sensory stimulation. Furthermore, the quality of many of the studies reporting physiological responses is poor, which raises

concerns about confounding." Overall, "the studies did not indicate that static EF have adverse biological effects in humans or animals. […] Physical considerations also preclude any direct effect of static EF on internal physiology, and reports that some physiological processes are affected in minor ways may be explained by other factors."

In a second paper the same group published a "systematic review of biological effects of exposure to static electric fields. Part II: Invertebrates and plants" (Schmiedchen et al. (2018)). Based on 33 studies (14 invertebrate and 19 plant studies) the authors concluded that field levels < 35 kV/m "provide reliable evidence that static EF can trigger behavioural responses in invertebrates" but do not result in adverse effects of other biological functions. "At far higher field levels (>35 kV/m), adverse effects on physiology and morphology, presumably caused by corona-action, appear to be more likely."

1.3.4. Summary and conclusions on static magnetic field animal studies

The two studies mentioned above did not show adverse biological effects on spermatogenesis or diabetes. The rat study on diabetically induced osteoporosis exemplarily demonstrated that 4 mT SMF may biophysically antagonize osteopenia/osteoporosis.

Table 1.3.1. Animal studies on exposure to static magnetic fields

Endpoint in rodents	Reference	Exposure SEF, SMF	Duration	Effect
Development & Reproduction	Wu et al. (2017)	56.3 ± 1.4 kV/m	49d (all day?)	Some losses of mito-chondria cristae in spermatogenic cells
Physiology & Pathophysiology	Zhang et al. (2018)	4mT	2h/d, 16d	Stimulation of bone growth & regeneration in diabetic rats

1.4. Cell studies

Four papers are described in this section, dealing with the effect of static magnetic field (SMF) exposure, given alone or in combination with chemical agents. Eleven more studies have been recognized but are not presented since five of them lack sham-exposed controls and six of them deal with biomedical applications of SMF.

Verdom and co-workers (2018) exposed a human breast adenocarcinoma cell line (MCF-7) and human foreskin fibroblast cells (HFF) to a SMF in the range 0.5 – 90 mT for 24 and 48 hours in presence and in absence of several concentrations of Doxorubicin (DOXO), a well-known chemotherapeutic drug. Several parameters were evaluated, such as: cell proliferation, viability, intracellular reactive oxygen species (ROS), intracellular iron and glutathione. Cell viability was tested following 24 and 48 hours exposure to 5, 10, 15 and 20 mT field intensity and was significantly reduced in both cell lines compared to sham exposed cultures, for all the conditions tested (p<0.001; three independent experiments), although the effect was stronger on MCF-7 cancer cells. Proliferation rate was also affected in both cell lines for all the field intensities and DOXO concentrations tested. Also in this case cancer cells resulted more susceptible than fibroblasts.
Mammalian cells need iron as an essential factor for crucial metabolic functions. In addition, iron increases ROS generation. Therefore, iron is potentially cytotoxic and can induce oxidative stress and DNA damage. In MCF-7 cells, iron concentration decreased after 24 and 48 hours magnetic field exposure or DOXO treatment; such a decrease was potentiated by combined treatments (p<0.001). The same results were achieved in the case of HFF cells, except for a transient higher iron content in DOXO-treated cultures at 24 hours (p<0.01). The authors also measured intracellular ROS formation and glutathione content in exposed and co-exposed cells. An increased ROS formation was found following either single treatments (SMF or DOXO) or combined at both 24 and 48 hours. Again, the effect was more pronounced in cancer cells.

Human leukaemia U937 cells were employed by Wojcik-Piotrowicz et al. (2017) to investigate cell viability, expression of Calmodulin (CaM), the most important protein binding calcium, and heat shock protein 70 (Hsp-70) following exposure to homogenous 6 mT static magnetic field (DCMF) combined with perpendicularly oriented sinusoidal component ACMF (35 Hz, 6.5 rms mT) or to (45 ± 5) mT, 50 Hz pulsed electromagnetic field (PEMF), with or without puromycin (PMC), an apoptotic inducer. No alteration in cell viability was detected after exposure to the different types of magnetic fields with respect to sham-exposed cultures, while PMC reduced the number of viable cells, as expected. When combined treatments were considered, cell viability was decreased in type of MF-dependent manner. AC-DCMF enhanced PMC-induced cytotoxicity, while PEMF exerted a protective role against PMC- induced cell death (p<0.05). CaM expression was not altered by MF exposure alone, but in cultures co-exposed it was increased or decreased in dependence on the type of applied MF compared to treatments with PMC alone. Hsp-70 expression was not affected by MF exposures alone, but treatments potentiated the effect of PMC (p<0.05).

Zhang and co-workers (Zhang et al., 2017e) exposed human nasopharyngeal carcinoma CNE-2Z cells and retinal pigment epithelium RPE-1 cells to a 27 T ultra-high static magnetic field to evaluate the effect on cytotoxicity, microtubules and chromosomes and on mitotic spindle orientation. To this purpose, a customized cell incubation system was realized using two sample holders that could fit inside a 32 mm bore ultra-high field magnets. The comparison between exposed and sham-exposed cultures indicated that cytotoxicity, evaluated as cell number, cell cycle progression and apoptosis, was not affected after 4 h exposure in CNE-2Z cells, although cell number decreased after 3 days post-exposure (three independent experiments). Mitotic spindle orientation, usually parallel to the tissue culture plate (lateral) was changed by the exposure: in four experiments it was reduced in exposed vs. sham-exposed cells with an increase in favour of non-lateral position (p<0.01). Such an effect was not detected after 4 hours exposure at 1 and 9 T and three days post-exposure at 0.05 or 1 T SMF. At variance, a slight but statistically significant decrease in lateral spindle orientation was detected three days post-exposure at 9 T (p<0.05). The authors also evaluated the role of chromosomes and microtubules in the spindle sensitivity to 27 T SMF on CNE-2Z and RPE-1 cells. They found a different orientation of the spindle in prometaphases cells with respect to metaphases cells (two different stages of chromatin condensation), indicating that the phenomenon is due to chromosomes more than microtubules and is not cell type-specific.

In a study carried out by Mao and co-workers, rat insulinoma INS-1 cells were exposed to a 400 mT SMF up to 72 hours to measure cell viability, proliferation and insulin secretion. In three independent experiments, the authors found no effects on cell viability and proliferation, but a MF-induced promotion of insulin secretion following 12 and 24 h exposure (p<0.05 and p<0.01, respectively). No effects were detected for shorter (6 hours) or longer (up to 72 hours) exposure duration. Such a promotion was induced by activating the transcription of the insulin gene and up-regulating the expression of vesicle-secreted proteins (Mao et al., 2017).

1.4.1. Summary and conclusions for cell studies

As stated in the previous reports, a large number of papers have been published on the effect of SMF on cell cultures but in most of them no sham-controls have been assessed. Therefore, such papers have not been included in the analysis. The studies considered confirm that static magnetic fields are able to modify (by increasing or decreasing) the effect induced by chemical agents.

Table 1.4.1. *In vitro* studies on exposure to static magnetic fields

Cell type	Endpoint	Exposure conditions	Effect	References
human breast adenocarcinoma cells (MCF-7) human foreskin fibroblasts (HFF)	Proliferation, viability, oxidative stress	0.5 - 90 mT 24 and 48 h Co-exposure with DOXO	Decreased cell viability and proliferation; Increased ROS formation; reduced iron content following SMF exposure alone and co-exposure. SMF enhances DOXO-induced cytotoxicity. Effects more pronounced in MCF-7 cells.	Verdom et al. (2018)
Human leukemia cells (U937)	Viability; expression of CaM and Hsp-70	DCMF 6 mT; DCMF+ACMF (35 Hz, 6.5 mT rms); 50 Hz PEMF, 45 ± 5 mT Co-exposure with PMC	No effects in cell viability, CaM and Hsp-70 expression following MF alone. PMC-induced cytotoxicity and CaM expression enhanced by DCMF+ACMF and reduced by PEMF. PMC-induced Hsp-70 expression increase resulted enhanced by co-exposures	Wojcik-Piotrowicz et al (2017)
Rat insulinoma INS-1 cells	Viability, proliferation, insulin secretion	400 mT Up to 72 h	No effect on cell proliferation and viability. Increased insulin secretion and activation of insulin gene transcription after 12 and 24 h exposure.	Mao et al (2017)
Human nasopharyngeal carcinoma cells CNE-2Z Human retinal pigment epithelium cells (RPE-1)	Cytotoxicity, mitotic spindle orientation	0.05 – 27 T 4 h	Cell number, cell cycle progression and apoptosis not affected after 4 h exposure to 27 T in CNE-2Z cells; decrease in cell number three days post-exposure. Alteration in mitotic spindle orientation only at 27 T in CNE-2Z cells. Slight effect on orientation three days post-exposure. In both cell lines the effect on orientation was due to chromosomes more than microtubules.	Zhang et al. (2017)

Abbreviations: ACMF: perpendicularly oriented sinusoidal component; CaM: calmodulin; DCMF: homogeneous static magnetic field; DOXO: doxorubicin; GSH: glutathione; PEMF: pulsed electromagnetic field; PMC: puromycin; ROS: Reactive oxygen species;

2. Extremely low frequency (ELF) fields

2.1. Epidemiological studies

In the previous Council reports it was concluded that little progress had been made to resolve whether the consistently observed association between ELF magnetic field (ELF-MF) exposure and childhood leukaemia in epidemiology is causal or not. In the previous SSM report (2017) there were also two studies reporting a trend of decreasing risks in more recent data, although the reason for this decrease is not known.

Another open question is related to occupational ELF-MF exposure and/or electric shocks as a risk factor for amyotrophic lateral sclerosis (ALS). Although associations are often reported, there is no consistent pattern that suggests either ELF-MF or electric shock as the cause. Studies evaluating occupational ELF-MF exposure and risk of Alzheimer disease (AD) have reported heterogeneous results.

2.1.1. Childhood cancer

Kheifets et al. (2017) performed a case-control study including all childhood leukaemia cases of children aged younger than 16 years and living in California at the time point of their diagnosis. Cases diagnosed between 1988 and 2008 were included. Cases were linked to the birth registry and matched based on age (±6 months) and sex. 87 % of cases could be matched to a birth certificate, and addresses of 89 % of all subsequently included cases and controls could be geocoded (assigned a coordinate). Exposure was modelled for all power lines above 100 kV (60 kV for two electricity providers) for the address at birth. Conditional and unconditional logistic regression was used for the analysis, adjusting for age, sex and several potential confounders such as maternal education, socio-economic position or race.
5 788 cases and a similar number of controls were included in the final analysis. 17 cases and 11 controls were exposed to levels above 0.4 microtesla, which translated to an OR of 1.5 (95%CI 0.7-3.3), compared to children exposed to levels below 0.1 microtesla. Several sensitivity analyses provided very similar results, although slightly higher OR were found among children who had had a site visit (OR 2.0, 95%CI 0.9-4.8).

In an additional analysis on the same data set, Amoon et al. (2018) evaluated the effect of changing place of residence on risk estimates. Addresses were available for birth and diagnosis address for cases only. Sensitivity analyses were performed using different stratifications depending on whether cases had moved in between birth and diagnosis. Overall, this was the case for 61 % of cases. Given the low exposure prevalence (0.3 % of cases exposed to levels >0.4 microtesla), this caused only few cases to change their exposure group, as most were in the referent group at <0.1 microtesla. Overall, there was a tendency for very slightly higher OR in exposed children who had not moved compared to exposed children who had moved.
The strength of this study is that it is a large registry based study, thus decreasing the possibility for selection bias. Exposure misclassification may have occurred due to analysing only birth address in the Kheifets et al. analysis, and for controls in the Amoon et al. publication. All in all, the results of these two publications, although not significant, are in line with previous analyses showing an increased risk in children exposed to levels >0.4 microtesla and risk of childhood leukaemia.

2.1.2. Adult cancer

In the INTEROCC study, Turner et al. (2017) re-analysed the previously detected association between recent (1-4 years prior to diagnosis) occupational ELF-MF exposure and brain tumours. In this analysis, the authors looked at a possible interaction between ELF-MF exposure and chemicals, so the

question whether ELF-MF exposure results in different risk estimates if workers were also exposed to other compounds. Cases of meningioma (n=1 822) and glioma (n=1 939) and controls (n=5 404) matched on sex and age, originally recruited for the INTERPHONE study from Australia, Canada, France, Germany, Israel, NZ and UK were included. Using conditional logistic regression, they found no clear evidence for an interaction for either glioma or meningioma with chemical exposures and ELF-MF. However, they did see significant positive interaction between metal and ELF-MF, but this was attributable to a reduced OR in the group with low ELF and ever metal exposure.
This could result from chance, bias or exposure misclassification. A limitation of the study is that exposure misclassification from the job exposure matrix (JEM) may have attenuated risk estimates. At the same time, the large number of performed analyses increased the risk of chance findings. In addition, the numbers of exposed cases in several of the sub analyses were very low.

Carlberg et al. (2017) investigated lifetime occupational exposure to ELF-EMF and risk for glioma and meningioma (reported separately and discussed below) in their Swedish case-control studies on use of mobile phones. Adult cases (n=1 346) were recruited from oncology departments during 1997-2003 and 2007-2009. Randomly selected controls (n=3 485) were provided by the Swedish Population Registry. Reported participation rate for both groups was 86%. Exposure was assessed by means of a questionnaire and the same JEM used as in the INTEROCC study (Turner et al., 2014). Data were analysed using logistic regression with adjustment for sex, age and year of diagnosis, and socioeconomic position (self-employed, white- or blue collar). They investigated three categorical exposure metrics, each with cut points at the 25, 50, 75 and 90 percentiles: Cumulative exposure (Cut points: 2.33, 3.79, 5.55, 8.52 µT-years), average exposure (0.11, 0.13, 0.16, 0.24, 0.60 µT) and maximum exposed job (0.13, 0.16, 0.25, 0.60 µT). For cumulative exposure the exposure distribution was similar to the previously published INTEROCC study and this metric did not show an association with glioma risk. Contrary to the INTEROCC study, exposure in the time window 1-4 years before diagnosis was not associated with an increased risk of glioma. For astrocytoma grade IV (n=687) exposure above the first quartile (>0.27 µT-years) in the strata 5-9 and 15-19 years prior to diagnosis was associated with a statistically significant elevated OR. The highest exposure level in both time windows were associated with the highest OR (1.9 and 1.7), the OR across the three intermediate exposure levels were almost constant (≈1.4) with no evidence of exposure-response relationships. The authors conclude that the study showed an increased risk in late stage (promotion/progression) of astrocytoma grade IV for occupational ELF-MF exposure.
All in all, the evidence on occupational ELF-MF exposure and glioma is heterogeneous, with some studies reporting increased risks and others do not (Kheifets et al., 2008, Baldi et al., 2011, Turner et al., 2014, Sorahan, 2014). Studies published over the past few years indicate that it may be informative to further investigate time windows of exposure, or brain tumour subtypes although multiple testing will increase the likelihood for chance findings. Problematic factors in all analyses likely include that the exposure time windows prior to diagnosis will show some correlation with calendar time, which may relate to changes in exposure or in cancer diagnoses.

In the same study Carlberg et al. (2018) assessed occupational ELF-MF exposure and risk of meningioma using the same control population as above. They identified 1 592 meningioma cases and 3 485 controls that had provided at least one job code in the questionnaire on occupational histories. They found no association between meningioma and cumulative, average or maximum exposure to ELF-EMF. Regardless of exposure metric, they found no evidence of increased risk.
Exposure misclassification inherent to JEMs is likely to be non-differential, and could hence mask an effect by reducing exposure contrast.

Huss et al. (2018c) investigated occupational exposure to ELF-MF from JEMs and mortality from hematolymphopoietic cancer in the Swiss national cohort from 1990 to 2008. The exposure of the 3.1 million workers in the cohort was classified as ever high (≈52 µT), only low (≈11 µT), only medium (≈19µT)) based on job titles from censuses in year 1990 and 2000. Using Cox-models accounting for age, sex, nationality, educational level, civil status and language region they did not find clear exposure response relationships with either level or duration of exposure. In men ever holding high exposed jobs the HR for myeloid leukaemia was 1.31 (95% CI: 1.02-1.67) and for acute

myeologenous leukemia (AML) it was 1.26 (95% CI: 0.93-1.70). For both outcomes the risk estimates increased when restricting to men high exposed at both censuses (2.24, 95% CI 0.91–5.53 and 2.75, 95% CI 1.11–6.83, respectively). This was however based on very small numbers. In a meta-analysis, the authors combined their study and pre-existing studies and found a combined risk estimate of 1.21 (95% CI: 1.08-1.37). The authors concluded from this that any association of occupational ELF-MF is likely small and restricted to certain subtypes.

The study had potential exposure misclassification as exposure was only assessed at two points in time and based on a JEM, which did not allow for temporal variation in exposure levels. Also, there was evidence of residual confounding from lifestyle confounders such as smoking where they observed a similar sized risk increase for lung cancer among workers with high ELF-MF exposure.

2.1.3. Neurodegenerative diseases

Amyotrophic lateral sclerosis (ALS) is a rare, usually fatal neurodegenerative disease. The causes of ALS are largely unknown. Epidemiological studies found partially elevated risks for ALS in occupational groups with high exposure to ELF-MF, yet the results are contradictory. It has also been considered that electric shocks, rather than chronic ELF-MF exposure, could be a cause of ALS. (Huss et al., 2018a) conducted a meta-analysis to examine the association between occupational ELF-MF exposure and ALS. The pooled estimate from 20 eligible studies included in the meta-analysis was slightly elevated in those exposed to higher levels of ELF-MF compared to lower levels (RR=1.14 (95% CI: 1.00–1.30) and for workers in electrical occupations (RR: 1.41, CI 1.05–1.92), but with large heterogeneity between studies. In studies that considered the full occupational ELF-MF history, higher risks were found than in studies considering only few points in time, with no heterogeneity between studies. Thus, the authors concluded that study results depend on the quality of the exposure assessment.

Increased risk for workers in electrical occupations could also be due to electric shocks but this was not explicitly analysed in this meta-analysis.

A systematic review on occupational exposure to ELF-MF and Alzheimer's disease was published by Jalilian et al. (2017). 20 articles were included in a meta-analysis, and random-effects meta-analysis resulted in a summary risk estimate of 1.63 (95% CI 1.08-1.87). Heterogeneity was substantial (I^2=61%). Funnel plot asymmetry indicated some small study effects which may be the consequence of publication bias. Several sensitivity analyses did not provide evidence for differences in effects across sex, exposure levels, study design or if outcomes were assessed from death certificates or medical records.

All in all, this meta-analysis is in line with previous reports that there may be an association between high workers' ELF-MF exposure and an increased risk of Alzheimer's disease, although the high between study heterogeneity is of concern and may suggest other relevant factors influencing the study results.

Pedersen et al. (2017) published an update of a Danish utility worker cohort. The cohort consists of employees of all 99 Danish public utility companies that supplied Denmark with electricity between 1900 and 1993. Employees were identified via employment as well as pension fund records, including a total of 45 188 persons. Excluding persons who had died before entering the cohort, who had emigrated or who had had a pre-existing disease of interest (e.g. Parkinson, ALS, dementia), about 40 000 persons remained, of which 32 006 men were included in the current analysis. Exposure to ELF-MF was assigned to job titles using a job exposure matrix. Individuals hospitalized with a central nervous system disease were identified using the Danish National Patient Register. Entry into the cohort was defined as January 1982 and lasted until December 2010. Both internal (low exposed utility workers as referent group) and external (persons who had never worked in a utility company as referent group) comparison groups were used. Exposed workers had non-significantly increased risks for motor neuron disease (IRR 1.78, 95% CI 0.93-3.34 for external and 2.65, 95% CI 0.98-7.13 for internal comparison groups). Highly exposed utility workers were also at higher risk for dementia compared to non-utility workers but not compared to internal controls. Risk estimates for Parkinson's

disease were below unity for workers in the medium and high exposure category.

This is a well performed study with near-complete registration of workers and occurring cases. The external comparison group was assigned to the unexposed group although this group will have likely included some occupationally high ELF-MF exposed workers. All in all, the results are in line with previous meta-analyses indicating no associations of ELF-MF exposure with Parkinson's disease, a possible association with ALS/motor neuron disease, and also possibly slightly increased risks of dementia.

Within the prospective Netherlands Cohort Study (NLCS) Koeman et al. (2017) investigated the association between ALS and various occupational exposures including solvents, pesticides, metals, ELF-MF and electrical shocks. The cohort consists of 58 279 men and 62 573 women aged 55–69 years at enrolment in 1986, who were followed up for 17.3 years on ALS mortality. Out of this cohort, a random sub cohort (2 092 men and 2 074 women) and all ALS deaths (76 men and 60 women) were used for the present analysis. Occupational exposures were estimated by means of job exposure matrices. In gender stratified analyses adjusting for age and educational level and mutually adjusted for all occupational exposures, males ever occupationally exposed to ELF-MF were found to be at increased risk for ALS (HR: 2.19, 95% CI: 1.02 to 4.73) with approximately linearly increasing risk in terms of cumulative work exposure (p=0.02). No associations were observed for electrical shocks and the other occupational exposures under analyses.

This study supports an association between ELF-MF exposure and ALS but could not replicate earlier associations with other occupational exposures. The study is of high quality with detailed and systematic exposure assessment and a prospective design. ALS is a rare disease and thus number of exposed cases is relative low in this study. Meta-analyses allow enhancing the statistical precisions of risk estimates from various similar good quality studies.

Vinceti et al. (2017) investigated the ALS risk in Italy in relation to residential ELF-MF exposure from high voltage power lines with a voltage of 132 kV or higher. They identified all ALS cases diagnosed between 1998 and 2011 in Northern Italy (Emilia Romagna) and Sicily (Catania) as well as comparable healthy controls. The mean ELF-MF exposure in 2001 of all study participants was modelled. A total of 703 patients and 2 737 control subjects were included in the study. Only six patients and 35 controls had an ELF-MF of 0.1 μT or higher at their place of residence. There was thus no increased risk (relative risk: 0.65 with a confidence interval of 0.27-1.55).

Limitations of the study include that the selection of the controls is not described, ELF-MF exposure at the workplace was not taken into account and the number of exposed persons is very small. On the other hand, this is the first study on ALS and ELF-MF exposure at the place of residence carrying out exposure modelling. The previous four studies from Switzerland, Denmark, the Netherlands and Brazil only considered distance to power lines as a measure of exposure. None of these five studies found any indication that ELF-MF from power lines might cause ALS, but all studies suffered from very low numbers of higher exposed cases, or cases living close to high-voltage power lines. This suggests that ELF-MF of high voltage power lines is rather not a risk factor for ALS.

2.1.4. Other outcomes

Sudan et al. (2017) investigated residential ELF-MF exposure from overhead power lines as a risk factor for childhood asthma. They used the Danish National Birth Cohort (n=92 675) containing around 30% of all children born in Denmark from pregnancies during the years 1996 to 2002 (Olsen et al., 2001). Magnetic field exposure was established from information on the geographical location of all power lines >132kV (132 kV lines are described both as included and not included). Based on historical power loads, line configuration, phasing and direction of current flow the utility companies provided estimated corridors around each line beyond which the field strength from the power line would not exceed 0.2, 0.1 and 0 μT (i.e. no contribution to ELF-MF exposure from the power lines). Using geocoded address histories each child was then assigned exposure based on the highest exposure corridor of any of their addresses. This was estimated for the pregnancy period and for the period from conception until end of follow-up. Cases were identified from the maternal report in the 7-

year questionnaire, and from national registers on prescriptions and hospitalizations. The two primary outcome definitions required a child to be in all three sources (n=2 082, "definite case") or to be in at least one (n=20 097, "probable case"). Data where analysed with the Cox proportional hazard model with adjustment for child's sex, environmental tobacco smoke in the home, birth order, breastfeeding, early life respiratory infections, other early life infections, vaccinations, maternal age, family socioeconomic status, exposure to animals outside home or during pregnancy and parental asthma histories. Only 38 "probable" case children had any exposure and 13 cases were exposed to levels of at least 0.2 µT. Among "probable" cases, the adjusted hazard ratio was 0.59 (95% CI 0.08-4.20) among those exposed to >0.2 µT and 1.98 (95% CI 0.64-6.15) among those exposed to 0.1-0.2 µT when compared to those with <0.1 µT at any time until end of follow-up. When including "definite" cases the corresponding hazard ratios were 0.69 (95% CI 0.36-1.34) and 0.93 (95% CI 0.55-1.58), respectively. Analyses stratified by the source of outcome information (questionnaire, patient or medication registry) did not provide materially different results. Due to the low number of exposed cases, results for higher exposure levels were not presented.

This is a large study with several strengths, including the prospective design, the possibility to access health data from registries and the modelling of the exposures. A weakness of the study is the low number of exposed cases, which limits the power to detect a potential effect, should one exist. One of the stated aims of the authors was to overcome limitations of an earlier report on ELF-MF and asthma in children (Li et al., 2011) pertaining to the definition of asthma. Interestingly, in the analysis by Sudan et al, the overlap of identified cases across the three data sources was low, indicating that maybe these different data sources capture different information, which may be relevant for future investigations. It remains unclear if limitations regarding the definition of asthma were mitigated with the applied strategy.

Overall, the study does not support the hypothesis that residential exposure to ELF-MF is associated with asthma risk in 7-year old children.

Sadeghi et al. (2017) performed a case-control study in Babol, North Iran. 155 mothers with spontaneous preterm birth as registered in a local hospital were recruited into the study. 20 mothers were excluded due to inaccurate addresses. Control mothers were selected with random digit dialling, but the response rate was not reported. For all addresses, it was determined whether the closest overhead power line was within 600 m or not. After adjustment for e.g. parity and educational status, women living within 600 m of a power line had an Odds Ratio of 3.28 (95% CI 1.52-16.78) to have had spontaneous preterm birth.

This report lacks detail for many relevant aspects. Response rate was not reported, random digit dialling may have only reached a specific subpopulation (not everybody is enlisted in a telephone book any more), voltage levels of the power lines were not described. Patients and controls may have originated from different catchment areas. Usually, magnetic field levels fall to background levels within about 200 m distance from a power line, so it is unclear why a distance of 600 m was evaluated here or what it means for exposure levels. This study does not contribute to the understanding of presence or absence of a possible effect of magnetic field exposures on spontaneous preterm birth.

Migault et al. (2018) evaluated pregnancy outcomes in the French prospective ELFE cohort. In 2011, mothers giving birth to a child born after at least 33 weeks of gestation were enrolled from 320 maternity wards throughout France. Multiple birth (3 or more), mothers younger than 18 years, or who planned to move abroad within 3 years were excluded. 18 040 families participated, corresponding to a response rate of 51 %. During enrolment at the maternity ward, mothers were interviewed and among other data, also occupational information and job status was collected. Occupations were assigned ISCO-88 (International Standard Classification of Occupations, version 1988) codes and magnetic field exposure levels were assigned to these job codes. Exposures were expressed as cumulative microtesla-days and categorized in quartiles and the 90th percentile. Anthropometric data and health data of the children was retrieved from medical files. The authors evaluated moderate prematurity (33-37 weeks of gestation) and being small for gestational age (SGA); analyses were adjusted for a range of potential confounders. Overall, 734 (4 %) children were born moderately preterm, and 1 284 (8 %) were SGA. Analyses using exposure in categories or as a continuous variable did not provide evidence for an effect of occupational magnetic field exposure on moderately

preterm birth or SGA, with all risk estimates very close to unity.

Some exposure misclassification may have been introduced by using a job exposure matrix that was developed primarily using measurements in men, but that was subsequently applied to women. Women may be exposed slightly differently within similar occupations compared to men, due to the use of different equipment or other tasks (Forssen et al., 2004). Nevertheless, this is a large, well performed and well reported study that does not indicate that occupational exposure to magnetic fields increases the risk of moderately preterm birth or SGA, although the proportion of highly exposed mothers (≥41µT-days corresponds to a mean of 0.15 µT during pregnancy) was small (6.8%).

Li et al repeated an earlier study (Li et al., 2002) on ELF-MF exposure and miscarriage. Pregnant patients of the Kaiser Permanente Northern California hospital were invited to participate in the study if their pregnancy had not yet completed 10 weeks of gestational age. 1 054 women agreed to participate, corresponding to a 65 % response rate. Women were asked to perform a 24 hr measurement and to fill in a diary of activities during the measurement day. In total, 138 measurement files had to be excluded either because of non-compliance or because less than 90 % of the 24 hr measurement period was covered. The 99 % percentile of the exposure distribution was used for the evaluation, and results were stratified by whether women had experienced a "typical" or "non-typical" day. The upper 75% of exposure was compared to the lower 25%. Miscarriage before 20 completed weeks of pregnancy was determined using the electronic medical records of the hospital. Associations with miscarriage were evaluated using Cox regression, adjusting for potential confounders. Results indicated an increased HR among the exposed women with a HR of 1.48 (95% CI 1.03-2.14), which increased to 2.72 (95% CI 1.42-5.19) among women who had experienced a typical day. Risks among women who had had a non-typical day were not elevated. No exposure-response relationship was observed and the highest HR was observed in the second lowest exposure group.

A strong aspect of this study is its prospective design, where women performed an ELF-MF measurement before they had a miscarriage. The study base is not clearly defined with respect to the previous paper and it is thus not clear whether there is an overlap of cases included in both analyses. The measurement period of just 24 hours may be on the short side to actually capture all potentially relevant exposures. In a previous study with a similar design, maximum exposure levels cut into tertiles were evaluated and it would have been informative to see the same analysis reported here, which was unfortunately not the case. Strikingly, in all papers from this replication study, and the publications of the previous cohort addressing various outcomes, different exposure cut-offs are used but no explanation is given for this. Thus, a data driven analysis is of concern. The absence of an exposure-response relationship raises the question if there are other factors that determine the lower risk of miscarriage in the low exposed group. For example, work status (having a job or not) could be associated with magnetic field levels as well as with the risk of miscarriage, but was not taken into account. The literature on ELF-MF as a potential risk factor for miscarriage is highly heterogeneous, but only very few studies have actually performed measurements among pregnant women prospectively.

2.1.5. Conclusions on ELF epidemiological studies

Three new studies on ALS suggest an association with occupational ELF-MF exposure. One study did not identify increased risks of ALS with respect to residential exposure, but the study included only very few exposed cases. One of the studies also evaluated occupational risk of electric shocks but did not observe associations with ALS risk. Overall, whether it is exposure to electric shocks or ELF-MF (or another factor) that is involved in increased risks for workers still remains unclear. A meta-analysis on this topic indicates that the chance to observe an association with ELF-MF exposure depends on the quality of the exposure assessment, with higher quality exposure assessment studies more likely to observe increased risks, which speaks for a possible association. Another meta-analysis on Alzheimer's disease found an overall increased risk but with substantial heterogeneity between studies, which could not be explained by study characteristics. Two other original studies addressed adult cancer risk in relation to occupational ELF-MF exposure. Overall the results of occupational studies on adult cancer are inconsistent and no firm conclusions can be made on this subject. A large

French study did not find a link between maternal ELF-MF exposure during pregnancy and various pregnancy outcomes, not supporting the hypothesis that ELF-MF exposure during pregnancy is a health risk for the foetus. One study evaluating residential ELF-MF exposure and leukaemia risk of children observed slightly elevated risks, in line with previous reports. An analysis stratified over the two decades of observation period did not indicate strongly differing risks by time period, thus not confirming two earlier reports that had observed strongly decreasing risks over time.

2.2. Human studies

As in the previous reporting period only one human experimental study investigating effects of extremely low frequency (ELF) fields was published in the current reporting period. While the investigated endpoint in the study considered for the last report was short-term memory, the present study, Davarpanah Jazi et al. (2017), investigated ELF-MF effects on tremor and the EEG activity in the mu-rhythm frequency range in a small sample of 10 young subjects (5 females, age: mean ± SD: 23.8 ± 4 years). EEG was recorded with a MRI-compatible EEG-cap (64 EEG-channels). The authors focussed on EEG effects at electrodes covering the left primary motor cortex: M1 (C1, C3, and C5) and the left primary somatosensory cortex: S1 (CP1, CP3, and CP5). Five validated tremor characteristics (amplitude, drift, dominant frequency, median frequency and power in the 8-12 Hz frequency range) were recorded with a Class II laser diode from the tip of the right index finger. 60 Hz MF exposure varied between 0 and 50 mT_{rms} delivered in 5 mT_{rms} increments resulting in 11 exposure levels. Each condition was repeated 5 times resulting in 55 exposure periods, each lasted for 5 s with a 5 s exposure free interval between periods. The order of delivery for the 55 repetitions of exposure conditions was randomized. A head exposure system designed and built by Lawson Health Research Institute was used. No significant main exposure effect was observed for the tremor outcome variables except for two of the six EEG my-rhythm (8-12Hz) power spectra values related the somatosensory cortex (CP3 and CP5). This, however, was not confirmed by Bonferroni corrected pairwise comparisons.

Due to the small sample size results are difficult to interpret. The postulated subtle effects on the brain region involved in tactile perception certainly need to be investigated in a sound study with a sample size derived on the basis of a thorough consideration of expected effects, as well as predefined significance and power level.

2.2.1. Conclusions on human studies

Since human experimental studies are very scarce, the only conclusion that can be drawn is that there is no substantial new information on effects of extremely low frequency (ELF) magnetic fields in humans.

2.3. Animal studies

During this reporting period, again studies on brain, behaviour and physiology were identified. A third paper of the mega-experiments, compare 12th report (Soffritti et al., 2016, Sokolovic et al., 2015), addressing the endpoint cancer was presented by researchers of the Ramazzini Institute (Italy), now presenting some tumour data of the ELF-MF mono-exposures. Finally, two studies in non-mammalians are presented.

2.3.1. Brain, behaviour and analgesia

Jadidi et al. (2017) tested the ELF-MF influence (30 min/day; 50 Hz, 1, 50, and 100 µT or 0.5, 6, 12, and 30 Hz at 100 µT) on rats after daily injection of morphine (10 mg/kg sc) over a period of 8 days. Sham controls received daily sc saline injections. Groups of n= 8 male Wistar rats were used. Antinociceptive responses were determined by the hot-plate test (day 1, 4 and 8). Experiment 1

assessed the effects of exposure to ELF-MF (50 Hz, 1, 50, and 100 µT) before morphine injection, experiment 2 shortly after, and experiment 3 thirty min after morphine injection. Experiment 4 should give information if exposure to 100 µT MF at different frequencies (0.5, 6, 12, and 30 Hz) before morphine injection could prevent morphine tolerance. Over the 8-day period of morphine injection analgesic tolerance without ELF-MF exposure was confirmed. Exposure of saline controls to ELF-MF did not significantly increase response latencies on the hot-plate. Compared to control, 50 Hz, 1 µT and 30 Hz, 100 µT before, as well as 50 Hz, 100 µT ELF-MF shortly after morphine injection "prevented" development of morphine tolerance. However, ELF-MF exposure (50 Hz, 1, 50, and 100 µT) 30 min after injection (experiment 3) of morphine did not maintain morphine analgesia. A clear dependency on frequency and/or field strength of the applied ELF-MF on the morphine tolerance was not demonstrated.

Therefore, the authors' conclusion that exposure to ELF-MF "may be a possible method for treating the development of tolerance to the analgesic effect of morphine" is somehow speculative.

Ozdemir et al. (2017) exposed 78 saline and morphine tolerant male Wistar rats to 50 Hz - 0 (sham), 1, 5, 10 mT ELF-MF for in total 2 h/d (4x 30 min on, 4 x 15 min off) over 15 days. Groups of 6 males were allocated to following treatments: Saline, morphine tolerance + sham, ELF-MF (1, 5, 10 mT), and morphine tolerance +ELF-MF (1, 5, 10 mT). Morphine tolerance was induced by a 3-day cumulative dosing regimen of up to 120 mg/kg twice on day 3. On day 4 tolerance was assessed by using the tail-flick (TF) and hot-plate (HP) tests as measures for baseline latencies. Post-drug latency for each rat 30 min after the challenge dose (5 mg/kg) of morphine were evaluated by other TF and HP tests. On days 1, 4, 7, 11, and 15 TF and HP tests were performed. TF and HP latencies were obtained at 30-min intervals (0, 30, 60, 90, 120 min). Analgesic effects of ELF-MF were seen on days 4, 7, 11, and 15 in all ELF-MF-exposed rats with a maximum on day 7, especially after 5 mT and at the 90 min timepoint. Compared to the other groups the additional ELF-MF exposures in morphine-tolerant rats led to significantly higher maximal antinociceptive effects with a maximum at 60 min after termination of ELF-MF exposures.

Unfortunately, the study lacks suffers from some incomplete and inconsistent descriptions. For instance, doses for the induction of morphine tolerance were stated as 50 mg/kg [*para.* abstract] vs. acumulative dosing of up to 2x 120 mg/kg [*para.* methods].

Mastrodonato et al. (2018) exposed groups of 6-10 male, 4-5 weeks old C57BL/6 mice to 50 Hz, 1 mT ELF-MF for 3.5 h/d over 12 days. Corresponding controls were sham-exposed. Thirty days after termination of exposure, a complex setting for the behavioural tests and molecular biology analysis demonstrated that ELF-MF increased olfactory short and long-term memory and neurogenesis in the subventricular zone (SVZ) possibly via enhanced WNT/β-catenin signaling in the SVZ.

The authors interpreted ELF-MF "as a promising tool for enhancing SVZ neurogenesis and olfactory function."

Zhang et al. (2017a) exposed 3-week old male ICR mice to 50 Hz, 8 mT ELF-MF, 4 h/d for 28 days and analysed effects on calcium ion signalling in the hippocampus. In continuation to previous studies of the research group, subgroups (n=10) of mice were administered daily (0.2 mL i.g.) at doses of 30, 60, and 90 mg Lotus seedpod procyanidins (LSPCs) for 15 days. At the beginning of ELF-MF exposure this daily gavage-treatment (ig) was continued for 4 weeks. The experiment consisted of 5 groups: 1) Saline ig + sham-exposure, 2) Saline ig + ELF-MF exposure, 3) LSPC30 + ELF-MF, 4) LSPC60 + ELF-MF, 5) LSPC90 + ELF-MF. At termination of exposure, mice were killed by decapitation under ether anaesthesia. The hippocampus was quickly dissected from the brain and deep-frozen until analysis. The relative density of brain derived neurotrophic factor (BNDF) decreased after 8 mT ELF-MF exposure but increased dose-dependently when LSPCs was given in parallel (groups 3-5); BDNF density in the group LSPC90 +ELF-MF (5) was close to control levels. ELF-MF exposure only (group 2) led to increased levels of (Ca^{2+}mediating) Gi protein, IP3 (inositol-triphosphate, which is the dominant 2nd messenger molecule for release of intracellular Ca^{2+}), DAG (diacylglycerol), PKA (proteinkinase) and PKC beta, calcium and calmodulin-dependent protein phosphatase calcineurin (PP2B), and intracellular Ca^{2+}, whereas Calcium/calmodulin-dependent proteinkinase II (CaMK II)

and PKC alpha were decreased. Again, concurrent gavage of LSPCs (especially 90 mg/kg) significantly changed these values to the range of control levels.

Despite the protective or recovery effects of high-dosed LSPCs, consequences of the described molecular changes are not obvious. Furthermore, some impreciseness in experimental description should be mentioned; e.g., 23±2g body weight of 3-weeks old ICR mice is doubtful, further the animals' age at the beginning of LSPCs gavage as well as at starting of ELF-MF exposures is missing.

2.3.2. Oxidative stress

Kuzay et al. (2017) tested oxidative stress and antioxidant capacity of testis tissue in diabetic and non-diabetic Wistar rats following a 20 min/d, 5 d/week, 1 month-exposure to 50 Hz, 8.2 mT ELF-MF or to 2100 MHz GSM-modulated RF (0.23 W/kg SAR$_{wb}$). Ten groups consisted of n= 6 male rats each: 1) Healthy Control (C), 2) Healthy Sham (S), 3) RF Healthy (RF), 4) ELF Healthy (ELF), 5) RF + ELF Healthy (RF+ELF), 6) Diabetic Control (DC), 7) Diabetic Sham (DS), 8) Diabetic RF (D-RF), 9) Diabetic ELF (D-ELF), 10) Diabetic RF+ ELF (D-RF+ELF). Diabetes (blood glucose level ≥250 mg/dL) was induced by a single intraperitoneal (ip) dose of streptozotocin (STZ) of 65 mg/kg bw. After humanely killing, testicular tissues were frozen until biochemical determination of MDA (malondialdehyde), NOx, and GSH (glutathione) levels. Compared to (non-exposed) healthy rats, diabetics showed slightly higher MDA and NOx levels and a lower GSH level. In both, healthy and diabetic rats, ELF-MF and RF radiation caused significant increases in MDA and NOx levels and a decrease in GSH levels of testicular tissue. The most significant effect was observed in group 10 that was both, diabetic and exposed to ELF-MF and RF.

Summarizing, both non-ionizing radiations increased oxidative stress in testicular tissue while causing a decrease in antioxidant (GSH) level which was more distinctive in diabetic rats. The authors conclude "that diabetic subjects are more adversely affected by radiation when compared to healthy subjects."

2.3.3. Cancer

In addition to the papers of Soffritti et al. (2016a,b), already commented in the previous (12th) report, Bua et al. (2018) published the overall cancer results of the ELF-MF exposure alone. Sprague-Dawley rats were exposed from day 12 post-conception (pc) until death, 19 h/d to sinusoidal 50 Hz MF. Groups of approximately 500 females and males each were continously exposed to 0, 2, 20, and 100 µT. Further 250-270 female and male rats each were either exposed to continous or intermittent (30 min on / 30 min off) 50 Hz MF. The observation period over the entire rats' life span of up to three years did not result in significant differences of specific (adenocarcinomas of the mammary gland, malignant Schwannomas of the heart, thyroid C-cell carcinomas, hemolymphoreticular neoplasias) and total malignant tumor incidences between the groups.

Unfortunately, the complete tumor tabulation is missing also in this publication. As already stated in the 12th SSM report, only selective reporting of tumor data limit the interpretation of the results.

2.3.4. Physiology

Erdem et al. (2018) determined the effects of 50 Hz, 1.5 mT ELF-MF on trace element (Cu, Mg, Zn, Ca) levels in guinea pigs. Four groups of n= 6 adult male guinea pigs were either 4h continuously or intermittently (2 h on – 2 h off – 2 h on – 18 h off) exposed for 4 or 7 days. The fifth group (n=5), "kept under the same conditions", served as control. Overall, after both ELF-MF exposure regimens, Cu and Mg levels increased in blood serum, femur, liver, and kidneys but not in brain tissue. Zn and Ca levels were mostly not significantly affected. Other endpoints than the trace elements mentioned above were not investigated.

It remains unclear if a real sham control was used. The authors' statement "exposure to EMF may cause disturbances in homeostasis of bioelements" is reflecting the high variability of the few parameters studied.

Sato et al. (2017) investigated potential effects of (high frequency) continuous pulsed magnetic stimulation (pMS) in female Sprague-Dawley rats. The experiment consisted of 3 treatment groups: 1) magnetic stimulation (pMS), n= 2x7; 2) sham, n= 2x5; 3) cage control, n= 2x5. MS rats received magnetic stimulation at max. output level (560 mT peak) at 10 Hz for sessions of 25 min once daily, 5d/wk. Seven rats were exposed for 12 consecutive days, further n= 7 for 36 days. Sham rats (n= 5 each) were not stimulated but exposed to sounds of stimulation. After 12 and 36 days lasting pMS sessions no changes were seen in clinical health status, body and organ weights among the 3 groups. Also histopathology did not demonstrate adverse effects on the main organ and tissues examined. Finally, no significant intragroup changes were detected between the three groups for blood cell counts, adrenocorticotropic hormone (ACTH), estrogen (E2) and progesterone levels.

In summary, no adverse effects were observed in female rats, which were (according to the authors) pMS-treated in sessions three times longer than used for a clinical study in humans.

2.3.5. Other endpoints

Li et al. (2017) exposed male (5-6 weeks old) BALB/c mice to pulsed EMF (field strength, 35 kV/m; rise-time, 120.0 ps; pulse-width, 1.02 ns; repetitive rate, 50 Hz) for 2 weeks before mating. Fifty males were daily exposed to 10 000 pulses for 2 weeks. Another 50 males were sham-exposed. After two weeks of daily pEMF (pulsed electromagnetic field) exposure, males were randomly subdivided into five groups each (0 d, 7 d, 14 d, 21 d and 28 d after pEMF exposure). Animals were mated (1 male with 2 females) at 7 PM on the 0 d, 7 d, 14 d, 21 d and 28 d after termination of pEMF exposure, below referred to as D0, D7, D14, D21, and D28. After 7-day mating, male mice were humanely killed for determination of male reproductive endpoints (sperm count and abnormalities, histopathology of the testes, serum levels of sex hormones). On gestation day 20 all females were euthanized, embryos were collected, counted and cryopreserved. Numbers of pregnant females, total embryos and absorbed embryos were recorded; pregnancy ratio, average embryo number and absorption were calculated. Since male embryos show both Sry and GAPDH gene, while the female embryos show the absence of Sry gene, sex ratio of embryos was precisely determined by PCR and agarose gel electrophoresis. Compared to sham-exposed group the pregnancy rate of D14 pEMF was significantly higher whereas the pregnancy rate of D21 pEMF-exposed group was significantly decreased. No differences were found in average numbers of embryos and fetal absorption rates. The fetal sex ratio [no. of ♀/ (no. of ♂ + no. of ♀) × 100%] of D0, D21 and D28 pEMF-exposed groups increased significantly. In males body weight, testes relative weight, and sperm count was not affected. Sperm anomalies were observed in D0, D7 and D14 males, decreased in diameter of seminiferous tubules in D21 and D28 paternal mice. Serum testosterone increased significantly in D0, D14, D21, and D28 exposed compared to sham males. GnRH (gonadotropin-releasing hormone) was increased in the D28 exposed mice wheras serum levels of LH (luteinizing hormone) in D14 and D28 pEMF males were decreased. No statistically significant differences were found between the pEMF- and sham-exposed groups regarding the level of FSH (follicle-stimulating hormone).

The authors' discussion "paternal pEMF exposure might affect the offspring sex ratio" in conjunction with "paralleled" increased testerone (T) levels is of some interest. Nevertheless, such effect (affected sex ratio concurrent to lowered T levels) should have occurred at all mating time-points.

Yang et al. (2018) stimulated osteoarthritis (OA) knees of rats with pulsed EMF (pEMF). Non-traumatic OA was induced by a single dose of 0.2 mg monosodium iodoacetate (MIA) injected through the infrapatellar ligament of the right knee of 3-months old SD male rats. Physiologic saline was used for sham injections. pEMF waves (duty ratio, 10 %; pulse width, 1.33 ms; pulse-off duration, 12 ms) were repeated at 75 Hz, and peak MF within the Helmholtz coils was 1.6 mT. pEMF and sham exposure was applied for 2 h/day for 4 weeks. Three groups of male rats (n= 24 per group) were assigned to the follwing treatments: 1) OA, 2) OA+pEMF, 3) control (shamOA + sham-exposure). After 4 weeks μCT demonstrated a reduction in trabecular number, trabecular area, and trabecular connectivity in tibia and femur of OA rats compared to control, whereas pEMF "partially preserved subchondral trabecular bone microarchitecture." In the right tibia of OA+pEMF rats subchondral gene

expression of WNT3a, β-catenin, and OPG (osteoprotegerin) was increased, but mRNA levels of LRP5 (Low-density lipoprotein receptor-related protein 5) and RANKL (receptor activator of NF-κB ligand) were not (significantly) altered compared to the OA group. (Wnt proteins prevent apoptosis of both uncommitted osteoblast progenitors and differentiated osteoblasts by β-Catenin-dependent and - independent signaling cascades). Immunohistochemistry revealed similar results for WNT3a, β-catenin, OPG, LRP5, and RANKL protein expressions.

Summarizing, pEMF "preserved the structural integrity of subchondral bone in knee OA rats by promoting the activation of Wnt/β-catenin signaling and OPG/RANKL/RANK signaling."

2.3.6. Studies in non-mammalians

Khoshroo et al. (2018) exposed common carp fingerlings once for 2 h to 50 Hz, 0 (sham), 0.1, 0.5, 1 and 2 mT ELF-MF. Three replicates of 8 fish each were used per sham and exposure groups, i.e. n= 24/group. After 15 and 60 days a significant mostly MF-dependent increase in serum enzyme levels of alanine (ALT), aspartate aminotransferase (AST) and alkaline phosphatase (ALP) was described. Also compared to sham-exposed controls the levels of complement factors C3 & C4 and serum lysozyme activity were significantly lowered indicating some immunosuppression. After 60 days lysozyme levels only decreased in a MF-dependent manner.

Taken as a whole, an impact of acute (2 h) ELF-MF exposure on immunophysiology of young fish was detected above 0.1 mT.

Valadez-Lira et al. (2017) exposed *Trichoplusia ni* (cabbage looper) larvae to 60 Hz, 0 (sham) or 2 mT ELF-MF for 24 or 72 h. Life cycle and fertility in exposed organisms were not different to shams after 24-h exposure. After 72-h exposure of third-instar larvae hemolymph was collected when larvae reached the fourth instar. Hemolymph total protein and hemocyte cells were decreased (48 h). After 72-h exposure, apoptotic-like cells and cellular immune response, granulocyte number and oenocytes were increased. Finally, four antimicrobial peptides were downregulated whereas two peptides (attacin and defensin) were upregulated.

The authors discussed their findings in the context of potential future use of ELF-MF on pest species but did not describe any specific application.

Remark: The above mentioned 48-h exposure is described in the *para.* abstract only, but not in the main text or in the figures.

2.3.7. Summary and conclusions on ELF animal studies

For this reporting period fewer animal studies were identified, but similar to the previous Council reports, several studies used one exposure level only and often in the 1 mT range at 50 or 60 Hz. Four brain and behavioural studies did not provide insight on potential ELF-MF mechanism(s). The very same holds true for the single studies addressing oxidative stress, (immune) physiology and fertility.

In addition to the two large Italian co-carcinogenicity studies reported in the previous 12th Council report, the group reported now the corresponding cancer study after ELF-MF mono-exposures, however, again, on single tumour types only, including hemolymphoreticular neoplasias (HLRN). Various magnetic field strengths did not result in significant differences of specific (adenocarcinomas of the mammary gland, malignant Schwannomas of the heart, thyroid C-cell carcinomas, hemolymphoreticular neoplasias) and total malignant tumor incidences. Includig this cancer study none of the animal studies directly addressed childhood leukaemia which is still of relevance in view of the results of epidemiological studies.

Table 2.3.1. Animal studies on exposure to ELF magnetic fields

Endpoint	Reference	Exposure ELF - MF	Duration	Effect
Rodents studies (mostly)				
Brain, behaviour and analgesia	Mastrodonato et al. (2018)	50 Hz, 1mT	3.5 h/d, 12d	Increased olfactory memory and SVZ neurogenesis
	Jadidi et al. (2017)	50 Hz, 1, 50, 100 µT + 10 mg/kg morphine	30min/d, 8d before, simul-taneously, after ELF-MF	Overall inconclusive results regarding the ELF effect(s) on morphine tolerance (in rats)
		0.5, 6, 12, 30 Hz, 100µT + 10 mg/kg morphine	30min/d, 8d after ELF-MF	
	Ozdemir et al. (2017)	50 Hz, 1, 5, 10 mT + 5 mg morphine/kg bw	2h/d, 15d	All ELF-MFs show analgetic effects; max. antinociceptive effects in morphine tolerant + ELF-MF exposed rats
	Zhang et al. (2017)	50Hz, 8 mT	4h/d, 28 d	BDNF↓, Ca²⁺↑ & of Ca²⁺ related gene expression in hippocampus 1↓
		+ 30, 60, 90 mg LSPCs /kg ig	Daily, 15d before + concurenct to ELF-MF	BDNF, Ca²⁺ & Ca²⁺ related gene express. dose-dep. changed to control level
Oxidative stress	Kuzay et al. (2017)	50 Hz, 8.2 mT	20min/d, 5d/wk 1 mo	Increased oxidative stress (MDA↑, NOx↑) & decreased anti-oxidant capacity (GSH↓) in testicular tissue of healthy and diabetic rats (for both exposures)
		2100 MHz GSM	20min/d, 5d/wk 1 mo	
Cancer	Bua et al. (2018)	50 Hz, 0, 20, 100, 1000 µT	19h/d, d12 pc -- (up to 3 years)	No different incidences in HLRN, mammary carcinomas, malignant (heart) Schwannomas and total malignant tumors
Physiology	Erdem et al. (2017)	50 Hz, 1.5 mT	4h/d continuous or 4h/d intermittent, 4d & 7d	Cu & Mg levels in serum, femur, kidneys liver increased; not in brain
	Sato et al. (2017)	pMS (10 Hz, max 560 mT peak, 300 µs pulse width); sham cc	25 min/d, 5d/wk a) 12x, b) 36x	No adverse effect on health, bw, organ w, hematology, ACTH, E2, progesterone, and organ (histo)pathology
Immunology	Koshroo et al. (2018)	50 Hz, 10 µT	2h once 15d, 60d post exposure observation dates	1wk only: Leukocytes (neutrophils, CD8+ lymphocytes) increased dose-dep., ACTH & POMC
Other endpoint: Fetal Sex ratio	Li et al. (2017)	50 Hz pEMF: 35 kV/m, 120ps rise-time, 1.02ns pulse-width	10⁴pulses/d, 2wk (parental mice only)	Fetal sex ratio ↑ (on 3/5 (D0, 21, 28); post-exposure mating days)
Other endpoint: Knee OA rats	Yang et al. (2016)	75 Hz, 1.6 mT pEMF	2h/d, 4wk	Structural integrity preserved by Wnt/β-catenin signaling
Studies in non-mammalians				
Immunophysiology in common carp fingerlings	Koshroo et al. (2018)	50 Hz, 0.1, 0.5, 1, 2 mT	2h once (15d, 60d post exposure observation dates)	MF-dependent increase in serum AST, ALT, ALP; Decrease in C3, C4, serum lysozyme

Fertility and Immunity in Trichoplusi *ni*	Valadez-Lira et al. (2017)	60 Hz, 2 mT	24h	Life cycle & fertility not affected
			48h	Hemocytes &-lymph ↓
			72h	Apoptotic-like cells & immune response ↑

<u>Abbreviations:</u> ↑=increase(d); ↓=decrease(d); 5-HIAA: 5-hydroxindolacetic acid; ACTH: adrenocorticotropic hormone; AD: Alzheimer disease; ALP: alkaline phosphatase; ALT: alanine aminotransferase; AST: aspartate aminotransferase; BDNF: brain-derived neurotrophic factor; bw: body weight; C3, C$: complement factors 3 & 4; E2: 17β-estradiol; ELF-MF: extremely low frequency magnetic field; EF: electric field; GSH: glutathione; HLRN: hemolymphoretical neoplasisia(s); ig: intra gastric (oral gavage); iv: intravenously; MDA: malondialdehyde; OVX: ovarectomized; pc: post conception; RBC: red blood cell count; ROS: Reactive oxygen species; SMF: static magnetic field; SVZ: subventricular zone; w: weight.

2.4. Cell studies

Eight papers are described in this section, dealing with the effect of ELF-MF exposure, given alone or in combination with chemical agents. Eleven more studies have been recognized but are not presented since ten of them lack of sham-exposed controls and one dealt with biomedical applications of ELF fields.

2.4.1. Epigenetic stability

In two papers, modification of epigenetic stability was investigated in cell cultures. Epigenetic changes refer to external modifications that do not change the DNA sequence, but may indirectly influence the expression of the genome.

Manser et al. (2017) examined the potential of 72 hours intermittent (5 min on/10 min off cycles) exposure to 50 Hz, 1 mT, to induce epigenetic modifications in leukaemic Jurkat cells and in human CD34+ haematopoietic stem cells undergoing in vitro differentiation into granulocytes. ELF-MF exposure did not induce alterations in the active and repressive status of histone H3 nor in DNA methylation, as assessed in three independent experiments carried out in blind conditions. At variance, treatments with trichostatin A, a well-known epigenetic modulator, induced consistent changes. In addition, the effect of ELF-MF exposure was also evaluated in terms of proliferation, cell cycle progression and apoptosis, three parameters that may influence epigenetic modifications. Also in this case no effects were detected. Similar results were obtained when CD34+ haematopoietic stem cells were tested, although in this case slight but not statistically significant differences between exposed and sham-exposed cultures were recorded, depending on the exposure condition adopted. The authors concluded that the exposure does not affect in a deterministic manner the epigenetic landscapes of the cells investigated, but it may influence the robustness of histone modification and DNA methylation during neutrophilic differentiation, without compromising the granulopoiesis efficiency.

A study was conducted by Consales et al. (2017) to evaluate if prolonged exposure (up to 72 hours) to 50 Hz, 1 mT affects epigenetic modulation in neuronal cells. To this purpose, the expression of selected microRNA (miRNA; molecules that post-transcriptionally regulate gene expression) was investigated. The authors selected miR-34b and miR-34c since they mediate cell cycle arrest, apoptosis and metabolic regulation and act as potential tumour suppressors. In addition, they are dysregulated in major neurodegenerative diseases, such as Parkinson's disease and Alzheimer's disease. The experiments were carried out on a SH-SY5Y human neuroblastoma cell line as well as on mouse primary cortical neurons. The results obtained in both cell types (three independent experiments) showed that the exposure induced a significant decrease in both miRNAs examined. DNA methylation was involved in the process since it was significantly increased upon ELF-MF exposure. Although such results have to be validated in animal models, they suggest a role of ELF-MF exposure in promoting a set of molecular events that may promote a degenerative phenothype in neuronal cells.

2.4.2. Cell proliferation

Cell proliferation was investigated in four studies.

Rat adipose tissue-derived mesenchymal stem cells (rADSCs) were employed by Fathi and Farahzadi (2017) to evaluate the effect of 30 min exposure/day for 21 days to 50 Hz, 20 mT. The experiments were carried out in presence and in absence of zinc (Zn) as an antioxidant and anti-inflammatory agent, also known to be involved in the regulation of cell growth and proliferation. In three independent experiments, cell proliferation was increased in Zn-treated cultures and decreased in EMF-MF-exposed cultures compared to sham ($p < 0.05$). Cultures co-exposed to EMF-MF and Zn showed an increase in proliferation compared to EMF-MF-treated samples ($p < 0.05$), indicating that Zn is able to reduce the effect of EMF-MF on cell proliferation. In a further study, by employing the same experimental conditions (cell type, exposure conditions and exposure time) the authors analyzed cell viability, the expression of telomerase reverse transcriptase (TERT) and senescence. Telomeres, the terminal part of chromosomes, are strictly related to genomic integrity and aging, and TERT is involved in the synthesis of telomeric DNA. Senescence was evaluated as increase of ß-galactosidase activity. The results of three experiments indicated that the exposure induced a decrease in the expression of the TERT gene and an increase in the percentage of senescent cells ($p < 0.05$). Treatments with Zn significantly increased the TERT gene expression ($p < 0.01$) and decreased the ELF-MF-induced senescence ($p < 0.05$).

In a preliminary study conducted by Koziorowska et al. (2018) the effect of ELF-MFs on the viability of four human cell lines was investigated. In particular, healthy cells, i.e. skin fibroblasts (BJ) and embryonic kidney 293 cells (HEK-293), and cancer cells, i.e. glioblastoma (U87_MG) and bone osteosarcoma cells (143B), were employed. The exposure was carried out in a frequency range from 2 to 60 Hz, at different field-shapes (sinusoid, triangle or square), at different field intensities (from 2 to 6 mT) and for different durations (from 0.5 to 3 h). Three sets of experiments were carried out and each condition was tested in quintuplicate.
In the first set of experiments cells were exposed for 2 h to 2, 20, 30 40, 50 and 60 Hz at 2, 2.5, 3, 4 and 6 mT. Concerning cancer cells, viability of 143B cells was increased at 2 Hz for all the field intensities tested, and decreased at 20 Hz up to 60 Hz, except at 20 Hz, where decrease was statistically significant only at 6 mT ($p < 0.01$). U87_MG cell viability was significantly decreased at 2, 30, 50 and 60 Hz for all the field intensities tested, while at 20 and 40 Hz only 2 mT affected cell proliferation ($p < 0.05$). Healthy cells always exhibit increase in cell viability, although it did not reach significance at 2 Hz (BJ and HEK-293 cells), at 20, 40 and 50 Hz (HEK-293 cells).

In a second set of experiments, cells were exposed for 2 h to 50 Hz (2-6 mT) by using sinusoid, triangle or square waveforms. Increased cell viability was detected in healthy cells, which in most cases was statistically significant. Instead, in cancer cells it was significantly decreased in the majority of the experimental conditions adopted.

In a third set of experiments cells were exposed to 50 Hz (2-6 mT) for 0.5, 1, 2 or 3 h. The results confirmed an increase in cell viability in healthy cells and a decrease in cancer cells.
On the whole, these findings evidenced a different effect of exposure in the cell viability in the cancer and healthy cells.

Falone et al. (2017) exposed SH-SY5Y human neuroblastoma cells for five or 10 days to 50 Hz, 1 mT, and evaluated either cell growth and the cell vulnerability to reactive oxygen species (ROS)-producing agents. They confirmed the hyperproliferation induced by ELF-MF exposure, as reported in their previous investigations and detected the same effect following exposure to 0.1 mT flux density. Moreover, they found statistically significant increased enzymatic antioxidant defense (glutathione-peroxidase, GPX, catalase, CAT, superoxide-dismutase, SOD) and in the protein level of sirtuin 1 and 3, which control the cellular redox environment in exposed cultures compared to sham ($p < 0.05$) at both exposure durations tested. In addition, a cytoprotective response was also detected in cultures treated with ELF-MF and hydrogen peroxide or doxorubicin (DOXO, a chemotherapeutic drug). In the latter case, 0.1 mT flux density was also effective. These results indicate that the adaptation induced

by ELF-MF exposure may provide a mechanism of resistance to anticancer treatments that acts on a redox basis.

Biochemical and metabolic changes induced by repetitive magnetic stimulation were investigated by Hong et al. (2018) in neuronal cells. In six independent experiments, a rat neuroblastoma B50 cell line was exposed to a continuous stimulation for 10 min to 1 Hz and 10 Hz and the level of selected metabolites was measured immediately after stimulation by applying metabolomic techniques. Among 18 reproducible intracellular metabolites identified from the technique, a significant decrease was observed at 1 Hz in 12 metabolites with respect to sham-exposed cultures, including seven amino acids ($p < 0.05$), cholesterol, glycylglutamic acid, inositol, pyroglutamate and succinate ($p<0.01$). At 10 Hz, significant decreases were observed in a total of nine metabolites, all of which were also significantly decreased at 1 Hz. Measured as a fold change, the decrease observed at 1 Hz was greater than at 10 Hz for all 12 significantly different metabolites.
These interesting results suggest the possibility that repetitive magnetic stimulation could modulate neural tissues. However, due to the absence of organized neural circuits, they cannot be extrapolated to the human brain.

Su and co-workers (Su et al. (2017)) also employed mammalian nervous cells to investigate the effect of ELF-MF exposure on DNA damage as well as on several cell functions. Six neurogenic cell types were investigated, both tumor cell lines (U251, A172, SH-SY5Y) and primary cells from rats (astrocytes, microglia, cortical neurons). The exposure was carried out at 50 Hz, 2 mT for different durations on the bases of the biological endpoint investigated. In particular, the frequency of γ-H2AX (H2A histone family, member X) foci formation (an early marker of DNA double-strand breaks) was measured immediately after 1, 6 and 24 h exposure in all the cell types. Cell cycle, proliferation and viability were tested soon after 24 hours exposure and following 24 and 48 hours in neurogenic tumor cells (U251, A 172 and SH-SY5Y) and in primary rat cortical neurons. Release of cytokines was measured in astrocytes and microglia cells soon after 24 hour exposure. Furthermore, microglia phagocytic activity was also evaluated. In addition, primary cortical neurons were exposed 1 hour per day up to 14 days and neural morphology was evaluated after three days (axon morphology), seven days (dendrites morphology) and 14 days (synapses density) of exposure. The results obtained in three to four independent experiments indicated that in all the six different neurogenic cells and for all the experimental conditions investigated the exposure to a 50 Hz did not affect the endpoints investigated, as assessed by comparing exposed and sham exposed cultures. For each parameter investigated, positive controls were provided and worked properly.

2.4.3. Summary and conclusions for cell studies

The ELF *in vitro* studies evaluated several biological endpoints, including proliferation, viability, senescence, antioxidant defences and DNA damage. As for the previous report, the results are not univocal, with increase, decrease or no difference compared to sham controls. Moreover, also in this case, several studies lack sham-controls and have been excluded because they are thus difficult to interpret.

Table 2.4.1. *In vitro* studies on exposure to ELF magnetic fields

Cell type	Endpoint	Exposure conditions ELF-EMF	Effect	References
Jurkat cells haematopoietic stem cells	Epigenetic modification	50 Hz, 1 mT 72 h (5'on/10'off cycles)	No effect in histone H3 status and DNA methylation; no effect on proliferation, cell cycle and apoptosis.	Manser et al. (2017)

Human neuroblastoma cells (SH-SY5Y) mouse primary cortical neurons	Epigenetic modification	50 Hz, 1 mT up to 72 h	Significant decrease in miR-34b and -34c; significant increase in DNA methylation.	Consales et al. (2017)
Rat adipose tissue-derived mesenchymal stem cells (rADSCs)	Proliferation	50 Hz, 20 mT 30 min/day for 21 days	Decrease in cells treated with EMF alone. Effect of EMF reduced by treatment with Zn.	Fathi and Farahzadi (2017)
Rat adipose tissue-derived mesenchymal stem cells (rADSCs)	Viability, TERT expression, aging	50 Hz, 20 mT 30 min/day for 21 days	Decreased expression of TERT and increased % of senescent cells. Effect of EMF reduced by treatment with Zn.	Fathi et al. (2017)
Human healthy (BJ and HEK-293) and cancer (U87_MG and 143B) cells	Viability	2, 20, 30, 40, 50, 60 Hz 2, 2.5, 3, 4 and 6 mT Sinusoid, triangle and square wave 0.5, 1, 2 and 3 h	Viability increased in healthy cells and decreased in cancer cells in the majority of the conditions investigated.	Koziorowska et al. (2018)
Human neuroblastoma cells (SH-SY5Y)	Proliferation, redox state	50 Hz, 0.1 and 1 mT 5 and 10 days	Increased cell proliferation and resistance to DOXO; 1 mT: increased antioxidant defense and increased resistance to H_2O_2 and DOXO	Falone et al. (2017)
Rat neuroblastoma cells (B50)	Selected metabolites	1 and 10 Hz 10 min	Decrease in 12 metabolites at 1 Hz and 9 metabolites at 10 Hz	Hong et al (2018)
U251, A172, SH-SY5Y tumor neurogenic cells and primary astrocytes, microglia cells and cortical neurons from rats	DNA damage, proliferation and neuronal functions	50 Ha, 2 mT 24 h 1 h/day up to 14 days	No effects on γ-H2AX foci formation, cell cycle, proliferation, viability, cytokine release, phagocytic activity and morphology	Su et al. (2017)

Abbreviations: DOXO: doxorubicin; ; γ-H2AX (H2A histone family, member X); H_2O_2: hydrogen peroxide; miR: microRNA; TERT: telomerase reverse transcriptase; Zn: Zinc

3. Intermediate frequency (IF) fields

Despite increasing use of intermediate frequency magnetic field (IF-MF) emitting sources such as induction cooking and anti-theft devices used in shops, scientific evaluation of potential health risks is still scarce. For some of these sources, exposure assessment especially of induced internal (electric) fields remains challenging.

3.1. Epidemiological studies

Khan et al. (2018) investigated intermediate magnetic field exposures among Finnish cashiers working near electronic article surveillance (EAS) systems and potential effects on birth outcomes. The authors set up a cohort of 4 157 women working in stores with ("exposed") or without ("unexposed") EAS between 2008 and 2015. Exposure was assessed in a previous study and indicated little difference in exposure values at the position of the cashier's seat. Elevated exposures would only occur when cashiers pass between gates of the EAS. Surveillance systems were working at a frequency of 8.2 MHz in all stores. Birth outcomes were matched to cashier records from the national health registry. A total of 536 birth and 38 miscarriages occurred. There were not statistically significant differences between "exposed" and "unexposed" cashiers in terms of risk if miscarriage, difference in birth weight, being small for gestational age or gestational age.

This is a relatively small study where it is uncertain if there were any meaningful exposure contrasts between women classified as exposed or unexposed. No information was available if women worked close to the EAS gates or how often they would pass them. This study is therefore limited in its ability to determine presence or absence of potential risks from intermediate field exposure on miscarriage or other birth outcomes.

3.2. Human studies

No human studies have been identified.

3.3. Animal studies

Within the European GERoNiMo project three animal studies were run by the same Finnish research group.

3.3.1. Brain, learning and behaviour

Kumari et al. (2017b) exposed two groups of 20 two months old male C57BL/J mice for 5 weeks (24 h/d) to 7.5 kHz MF at 12 µT or 120 µT. Thirty male mice were sham exposed. Motor functions, anxiety, aggression, learning and memory were assessed 3 weeks after termination of exposure. During the fourth week after end of exposure the animals were humanly killed and samples of the hippocampus were taken for immunohistochemistry and quantitative polymerase chain reaction PCR analysis. Compared to controls no effects were observed on body weight, spontaneous activity, motor coordination, level of anxiety or aggression. Mice exposed to 120 µT MF showed moderate impairment of spatial learning and memory in the Morris swim task and in the passive avoidance task. Immunohistochemistry of the hippocampus did not indicate astroglial activation or neurogenesis. The mRNA expression of brain-derived neurotrophic factor (BDNF) was not impaired whereas the proinflammatory tumor necrosis factor alpha (TNFα) was significantly increased after exposure to 120 µT.

The obtained results fully support the authors conclusion "that exposure to a 7.5 kHz, 120 MHz µT MF may lead to mild learning and memory impairment possibly through an inflammatory reaction in

the hippocampus." In addition, it should be noted that 120 µT exceeded the ICNIRP reference level (100 µT for frequencies of 3 kHz – 10 MHz) for occupational exposure.

3.3.2. Reproduction and fertility

Using the same exposed male C57BL/6J mice, Kumari et al. (2017a) investigated male fertility indicators. The Finish researchers obviously obtained epididymidal sperm from the males humanely killed during week 4 after termination of exposure. They did not observe exposure-related differences in sperm counts or sperm head abnormalities. Increased sperm motility, detected in the 120 µT group, may be confirmed in further studies.
Similar to two previous studies of other research groups in rats (Nishimura et al., 2012, Dawson et al., 1998), no adverse effects on fertility indicators were seen. Together these 3 studies are covering 4 frequencies (7.5, 10, 20, 60 kHz) and flux densities between 12 to 950 µT.

Using the same exposures, Kumari et al. (2018) conducted a third study addressing "behavioural teratology". The study aimed on detecting possible effects on the developing nervous system of male offspring. Starting on gestational day 1 pregnant dams and their male offspring till weaning (postnatal day [PND] 28) were continuously (24 h/d) exposed to 7.5 kHz MF at 12 µT (n= 22 males) or 120 µT (n= 20 males) or sham exposed (n= 20 males). Between PND-60 and PND-77 behavioural tests were performed. On PND-77 histological sampling of hippocampal specimen was done. No exposure-related differences in body weight development, spontaneous motor activity, anxiety, spatial learning and memory were seen. Histopathology did not show effects on astroglial reactivity or hippocampal neurogenesis.
Concluding, 7.5 IF-MF had no effects on spatial learning and memory and histological markers of brain tissue reaction. The observation of an improved performance in the Rotarod task in the 12 µT group and the more slowly swimming in the Morris swim navigation task were interpreted (by the authors) as chance findings, as no consistent dose-dependency was measured.
Unfortunately, several dams of in total 22 females ate their new-born pups. To obtain n= 20 male offspring per group, dams were rebred three times. This is somehow unusual and should be questioned in terms of external stress to the dams. Nevertheless the reporting of that problem is quite fair.

3.3.3. Summary and conclusions on IF animal studies

In the 7.5 kHz range the three mouse studies did not result in adverse effects on fertility, reproduction, learning and behaviour. In this context it should be noted that the upper magnetic field strength (120 µT) is about twice of nowadays cashiers' work place-exposures.

Table 3.3.1. Animal studies on exposure to intermediate frequency fields

Endpoint in rodents	Reference	Exposure IF - MF	Duration	Effect
Brain & Behaviour	Kumari et al. (2017b)	7.5kHz, 12,120µT	24h/d, 5wk	No adverse effects at 12 µT. 120µT: learning and memory mildly impaired, TNFα ↓
Reproductions & Fertility	Kumari et al. (2017a)	7.5kHz, 12,120µT	24h/d, 5wk	No abnormalities in sperm count and sperm heads at 12 & 120µT. 120µT: sperm motility ↑
	Kumari et al. (2018)	7.5kHz, 12,120µT	d1 pc – D28 (weaning)	No effects on bw, spontaneous motor activity, anxiety, spatial learning & memory.

Abbreviations: ↑=increase(d); ↓=decrease(d); BDNF: pc: post conception; bw: body weight; d=D: day; IF: intermediate frequency, MF: magnetic field; TNFα: tumor necrosis factor alpha

3.4. Cell studies

No cell studies have been identified.

4. Radiofrequency (RF) fields

4.1. Epidemiological studies

In the previous Council reports it was concluded that no, or at most small, indications were found for a brain tumour risk up to approximately 15 years of mobile phone use based on case-control and cohort studies as well as analyses of incidence time trends. Studies on symptoms and behaviour do not indicate an association with exposure from fixed-site transmitters but with mobile phone use. However, associations were not restricted to calling with mobile phones, but also to other aspects of mobile phone use such as using them for entertainment. This indicates that other factors than RF-EMF exposure may be relevant in that context. Several studies observed decreased semen quality of mobile phone users. However, studies are uninformative due to lack of appropriate exposure assessment and lack of confounding control in most studies.

In the latest SSM report it was also noted that study quality has been quite heterogeneous with a substantial proportion of low quality and only a few high quality studies.

4.1.1. Adult cancer

In the last year several meta-analyses on mobile phone use and brain tumours have been published.

In a systematic review and meta-analysis, Bortkiewicz et al. (Bortkiewicz, 2017, Bortkiewicz et al., 2017) investigated case-control studies on use of mobile phones and intracranial and salivary-gland tumours, published until March 2014. They investigated a range of potential associations and reported positive associations for intracranial tumours: a) Regular use of any mobile phone for 10 or more years (OR:1.46 95% CI: 1.07-1.98 based on 9 studies), b) Ten or more years since first regular use of mobile phones (OR: 1.25 95% CI: 1.04-1.52 based on 14 studies) and c) Regular ipsilateral mobile phone usage of any duration (OR: 1.29 95% CI: 1.06-1.57 based on 11 studies). They did not find positive associations for specific tumour types or for analogue phone usage only.

The authors conclude that the results support the association between long-term mobile phone use and risk of intracranial tumours but point to the need for further studies.

Prasad et al. (2017) conducted a meta-analysis on use of mobile phones and risk of brain tumours based on 14 studies published between 1999 and 2014. They found no evidence of increased risk with ever-use of mobile phones for any brain tumour, or for meningioma, glioma or acoustic neuroma analysed separately. For more than 10 years of mobile phone use, the OR for any brain tumour risk was 1.33 (95% CI 1.07-1.66, based on 7 studies). They also assessed the funding source and quality of all studies to investigate if these factors influenced results. The authors concluded that higher study quality translated into higher risk estimates.

Wang and Guo (2016) conducted a meta-analysis of 11 studies published between 2001 and 2008 on use of mobile phones and risk of glioma. They found no overall association whereas more than 5 years of use was associated with an OR of 1.35 (95% CI: 1.09-1.62).

This is a brief report where it is unclear why only studies until 2008 were taken into account. Large heterogeneity between studies was not discussed.

Yang et al. (2017) conducted a meta-analysis of mobile phone use and risk of glioma including 11 studies published between 2001 and 2015. They found that more than 10 years of use was associated with increased risk of glioma. Both ever and long use was associated with low-grade glioma whereas they did not find an association with ever use, ipsilateral use or for high-grade tumours. They found considerable heterogeneity between studies, and noted that the current evidence was of low quality.

None of the meta-analyses above have generated new knowledge and share to a great extent the same challenges. Limitations include: 1) not reconciling the proposed risk increases with lack of such an increase in the incidence time trend studies, 2) use of so called "quality scores" that do not enable to identify which underlying factors actually impact observed risk estimates, 3) no discussion of

encountered heterogeneity and/or influential studies driving risk estimates with respect to their limitations which includes selection and recall bias. What would be more informative at this stage were new studies that improve on the design and overcome the shortcomings of existing studies rather than repetitive (re-) meta-analyses of existing study reports.

In an update of parts of an earlier paper, summarized in a previous SSM report (SSM 2016) Hardell and Carlberg (2017) compared incidence trends of brain tumours of unknown type (ICD10 D43, Tumour of unknown type in the brain or CNS) from the Swedish national inpatient register and brain tumours (ICD7: 193.0, brain tumour including brain, meninges and CNS nerves) from the Swedish cancer register. As in the previous report, joinpoint regression analysis detected the incidence trend of D43 to change in year 2007 with an annual incidence increase of more than 4% after that time for both men and women, the numbers where not standardized by age. In analyses of sex combined by 20-year age group, no joinpoint was detected for any age group. The highest average annual increase (2.71% per year) over the full period was seen in people diagnosed at 20-39 years of age. For any brain tumours from the Swedish cancer register they observed the age standardized incidence rate in men to increase 0.49% per year (95% CI: 0.05-0.94); in women the corresponding rate was 0.33 (95% CI: -0.29-0.93). In neither sex was there any joinpoint identified when looking at all ages. The authors concluded that there was a clear contrast between the observed results from the two registers. The data from the two sources, however, differs, as the data from the inpatient register were not age-standardized whereas the data from the cancer register were. Also, data in cancer registries are likely to have been inspected differently than data from administrative registers. A minor difference is that the cancer registry includes also tumours of the meninges. Changes in diagnostic practices (such as changes in autopsy rates) may have caused an increase in tumours classified as "unknown type" D43. The authors argue that their results suggest underreporting of brain tumours to the Swedish cancer registry, and that such underreporting might conceal a possible effect of mobile phones. This requires that the underreporting somehow matched the proposed risk increase relatively closely and that similar underreporting occurred in other countries where the incidence trends have also been monitored. This does not appear to be very likely.

Using data from the UK Office of National Statistics, Philips et al. (2018) investigated incidence trends of brain tumours (ICD10: C71 as well as D43, supratentorial malignant tumours without histology/morphology) in England. They calculated age and gender-standardised incidence trends and reported an increasing incidence starting around 1973 until around 2000 after which time only a small increase was observed. When looking at types of glioma for the years 1995 to 2015, the incidence rate of glioblastoma multiforme (GBM) increased on average 5.2% (95% CI: 3.7-6.6,%) per year. The rise in GBM appeared to occur mostly in the frontal and temporal lobes. The apparent increase in GBM was quite constant over the study period from 1995. During that time incidence for glioma and astrocytic non-GBM decreased resulting in relatively stable incidence rates for all cases of brain tumour between 1995 and 2015. The authors suggest that environmental factors may be the cause of the observed trend for GBM. They list a range of potential risk factors including mobile phones. Given the opposite time trends for glioma and GBM, changes in diagnostic practise seems the most plausible explanation for the change in case mix over time. The authors state that "there were no material classification changes over the analysis period that might explain the findings, though multidisciplinary team working was strengthened (2005 onwards) and better imaging has resulted in improved diagnosis along with a more complete registration of brain tumours in the elderly". The paper also shows that all type of brain cancer (C.71) mostly increased before 1995 (due to improved diagnosis with MRI and CT) and stayed rather constant after 1995. But the paper did not show time trends of GBM incidence before 1995. Thus, it is not clear, whether the increase started in 1995 or already before that time point. In any case, the observed rather monotonic increase in GBM does not match the more exponential increase in mobile phone use. In summary, the paper does not provide plausible arguments how widespread mobile phone use could be related to increasing GBM rates and decreasing glioma and astrocytic non-GBM rates at the same time.

Satta et al. (2018) investigated environmental RF exposure and risk of lymphoma in an Italian case-control study with 322 cases and 444 controls, frequency-matched on sex, age group and geographical

area. The response rates among all eligible cases and controls can be calculated as 71% and 53% respectively. Residential history was obtained from questionnaires. The study included four measures of exposure: 1) self-reported distance (<50 m, 51-100 m and >100 m) to fixed radio-television transmitters and mobile phone base stations for the three addresses held the longest. 2) The actual distance from the home to the closest mobile phone base station, calculated from GIS data for subjects living within 500 m of a base station and classified into <=100 m 101-200, 200-300, 300-500 and >500 m. 3) RF-EMF-fields around mobile phone base stations as modelled by regional environmental protection agencies (>1.74V/m, 1.5-1.74V/m,1.24-1.50 m, 0.01-1.23V/m: <0.01V/m). 4) Front door measurements for a subset of longest-held addresses within 250 m of a base station. Available confounders were level of education and traffic intensity. No associations were observed with measured RF-EMF front-door exposure, or with modelled exposure. Also no associations emerged from the analysis of distance category of the home to the next transmitter, with the exception of self-reported distance of the home address within 50 m of a radio-television transmitter and the risk for any lymphoma (OR 2.7, 95% CI 1.5-4.6). Similar ORs where seen for subtypes of lymphoma, although these were based on smaller numbers and not always statistically significant. The study provided evidence that self-reported distance to mobile phone base stations was biased, as cases were more likely to underestimate distance to nearest base-station. The authors concluded that their results do not support an association of mobile-phone base stations and lymphomas.
In general the study suffered from low numbers and had relatively poor exposure assessment, further augmented by the incomplete address histories and not having included exposure from personal communication devices such as mobile and cordless phones. These factors by themselves could drive results towards the null, however as evidenced for base stations the reliance on retrospective self-reported data can lead to overestimation of exposure among cases and introduce possible false associations.

Gonzalez-Rubio et al. (2017) reported an ecological study of all inhabitants of the Spanish city Albacete (population= 166 383). They investigated associations between residential RF-EMF exposure and incidence of lymphoma (n= 65), glioma (n= 12) and meningioma (n= 18) over the period January 2012 to May 2015, ascertained from the only oncology hospital in the city. For each of the city's 110 administrative area units, mean night-time exposure (14 bands: 88 MHz to 6 GHz) was assessed in early 2015 by means of biking all streets in an area with a mounted exposimeter (Satimo, EME spy 140). Outdoor measured electric field strength (V/m) levels were subsequently averaged per area. The authors calculated Spearman correlations between area-level outdoor electric field exposures and incidence of the different tumour types. Compared with 390 random control addresses, cases followed a random distribution across city areas (all p-values: >0.31 from Morans I test). They found low correlations between electric field levels and incidence of tumour types ranging from -0.03 (p=0.04) for lymphoma to 0.28 (p=.003) for any brain tumours. Overall, the authors concluded that they observed no evidence of associations due to the random distribution of cases across the city. The study is primarily a methodological demonstration of concept. However, the authors do not address the question whether outdoor averaged electric field strength taken at ground level (or the height of the exposimeter on the bike) determines personal exposure levels. Therefore, it remains uncertain if the suggested study design is able to answer research questions as to potential health effects from RF-EMF exposure in a meaningful way. As an epidemiological study in its own right, it has the general limitations of ecological studies and is also limited by the very low number of cases and the lack of control for confounding. Overall, the study is not informative regarding the association between RF-EMF exposure and the incidence of brain tumours or lymphoma.

Peleg et al. (2018) revisited a case series of 47 cancer patients that all had occupational or military exposure to RF-EMF or ELF-MF from power lines and likely chemical exposures (e.g. solvents) in the period 1987 to 2003 and that self-referred to an Israeli occupational and environmental medicine clinic. The authors calculated the percentage of total cancers in the dataset that were hematolymphatic cancers (40 %) which was significantly different from the expected percentage of 23 % for that age and gender group. They performed similar calculations for three other studies as well, all showing the proportion of hematolymphatic cancers to be higher than expected. The authors conclude that the data suggest that there exist a cause-effect relationship between RF-EMF and hematolymphatic cancers in

military/occupational settings.

The study suffers from several shortcomings, including the weak exposure metric, no incidence data, small numbers and former military personnel that is likely to differ from the general population in many aspects, which may bias and confound the results. In addition, even if the percentages of tumour distribution was different in this group it would still beunclear that it was due to an excess of hematolymphatic tumours and not a reduced risk of other tumours. It is also unclear why the observed difference is interpreted as attributable to RF-EMF exposure, given the occurrence of other exposures reported by the authors. Also, the results are very dependent on equal diagnostic intensity for each tumour site and type among both exposed and reference populations. All in all the study seems very weak.

4.1.2. Reproduction

In a retrospective analysis of 468 men attending an infertility clinic from 1993–2007 in Austria, the associations between mobile phone use including storage fashion, semen quality, serum testosterone, luteinizing hormone (LH) and follicle stimulating hormone (FSH) were assessed (Schauer and Mohamad Al-Ali, 2018). Mobile phone storage in trouser pockets was positively correlated with the percentage of normal sperm morphology and negatively with LH concentration (both p < 0.001). No covariates were considered in these analyses.

This study is limited as it is a highly selective sample, mobile phone use was assessed retrospectively by interviews and no confounding factors were considered in the analyses. Thus, it remains unclear whether observed associations are due to RF-EMF or due to other lifestyle factors related to the preference to store the own mobile phone in trouser pockets.

4.1.3. Self-reported electromagnetic hypersensitivity (EHS) and symptoms

Wang et al. (2017b) conducted a systematic review and meta-analyses on cross-sectional studies analysing mobile phone use and headache. In total 7 cross-sectional studies were included in the meta-analysis, which yielded a 38 % (95 % CI 18 %–61 %) increased headache risk in mobile phone users compared to non-users with some indications for increasing risk with increasing exposure.

All papers included in this meta-analysis were based on self-reported mobile phone use, which is subject to recall bias. Available studies with operator recorded data would have been more informative but they were not included in this paper. The meta-analysis did not consider longitudinal studies and thus the study is not informative in terms of causality.

Martens et al. (2017) studied the interplay between perceived and modelled exposure by mobile phone base stations, nonspecific symptoms and sleep disturbances in the AMIGO cohort study from the Netherlands. They modelled the exposure from mobile phone base stations at the home addresses of the study participants. In addition, perceived exposure to mobile phone base stations, radio and TV, nonspecific symptoms and sleep disturbances were assessed by questionnaire. Exposure was modelled for two points in time (2011/2012 and 2013). Ten percent of the study sample were exposed >0.14 V/m and thus were considered to be highly exposed. The subjective appraisal of exposure as well as the assessment of nonspecific symptoms and sleep disturbances took place at three different points in time in 2011/2012, 2013 and 2014. Cross-sectional analyses of the 2011/2012 data with 14 829 study participants aged between 31 and 65 years, and longitudinal analyses after one (n=2 228) and two years (n=1 740) did not show any correlations between modelled RF-EMF exposure and occurrence of nonspecific symptoms and sleep disturbances. However, the authors found an association between the participants' own perception of exposure and the occurrence of health problems. The observed correlation might indicate a nocebo phenomenon among participants who were aware of the presence of mobile phone base stations in their vicinity, and assessed their own exposure as relatively high. The authors' interpretation of the overall findings is that exposure from mobile phone base stations at the residential location does not lead to substantial adverse effects on health.

This is one of the few longitudinal studies on the topic. The number of study participants is high, and exposure was modelled using a validated approach. The standardised questionnaire allows good comparability of the data. Nevertheless, a weakness of the study is that the perceived exposure included radio and TV, which was not the case regarding modelled exposure, and this may have contributed to the lack of correlation between these two exposure measures. Furthermore, the differences in exposure levels were small and RF-EMF exposure by own use of communication devices was not considered. The latter is usually considerably higher than RF-EMF of fixed site transmitters. The authors state that they cannot exclude the possibility that total RF-EMF exposure is associated with symptoms.

A cross-sectional study explored the associations between mobile phone use, RF-EMF exposure at school and 23 self-reported symptoms of Turkish high school students (Durusoy et al., 2017). A total of 87 classes were included in the study with 2 240 out of 2 466 students being present in the classroom during data collection and all of them participating in the study. RF-EMF at school was measured between November 2009 and April 2011 using a portable Aaronia Spectran HF-4060 device. Multivariate regression analyses were adjusted for gender and school type only. Exposure-response associations were observed for many symptoms such as fatigue, sleep disturbances, headache, concentration difficulties, visual disturbances and depressive symptoms in relation to various mobile phone usage characteristics including number of calls per day, total duration of calls per day, total number of text messages per day, position and status of mobile phone at night and making calls while charging. Only very few associations were observed between symptoms and measured exposure at school.

This cross-sectional survey cannot differentiate between cause and effects. Associations were seen with mobile usage behaviour only marginally related to EMF exposure (e.g. sending text messages, position at night), which may indicate that observed associations are due to other reasons than EMF exposure. Many factors could have affected the analyses since only few confounders were considered in the analyses. Given that information on potential confounders was available, it is not clear why they were not considered in the analyses.

The relationship between mobile phone use and mental health was evaluated in a cross-sectional study of 785 students from two universities in Serbia and Italy between March and May 2016 (Visnjic et al., 2018). Mobile phone use and various symptoms including depression, anxiety and stress were inquired by questionnaire. Logistic models for the three main outcomes included various predictors, age, gender and country. Anxiety was positively correlated with sending text messages (OR = 1.15, 95% CI: 1.11–1.31), and negatively with browsing the internet (OR = 0.84, 95% CI: 0.73–0.95) and playing games (OR = 0.79, 95% CI: 0.68-0.92). Stress was positively correlated with time spent on the phone (OR = 1.28, 95% CI: 1.12–1.56) and negatively correlated with call frequency (OR = 0.79, 95% CI: 0.64–0.97). The strongest predictor of high stress levels was keeping the mobile phone less than 1 m away during sleeping (OR = 1.48, 95% CI: 1.12–2.08). Depression was positively correlated with number of text messages per day (OR=1.31, 95% CI: 1.12-1.54) but negatively correlated with number of calls per day (OR = 0.70, 95% CI: 0.55 0.8) and browsing the internet (OR=0.85, 95% CI: 0.73-0.99).

In summary, positive and negative correlations between mobile phone use and mental health symptoms were observed, which suggests other causal factors than RF-EMF exposure. The cross-sectional design and the fact that the mobile phone usage variables are expected to be correlated with each other limits interpretability of this study. Participation rate was high (95%) and thus selection bias is not of concern whereas generalizability beyond a university student sample is uncertain.

In a survey performed in Taiwan in 2012/2013, Huang et al. (2018) assessed the prevalence of EHS. Participants were selected stratified from 25 different geographic regions from Taiwan, if they had a landline telephone. Prevalence rate and odds rations were weighted according to age, sex and educational level distributions of the respective geographic areas. Overall, 1 251 individuals were interviewed, corresponding to a response rate of 24%. EHS was identified with the question "While being near EMF sources such as mobile phone, electrical devices, or computer, do you feel allergic or sensitive?" Results were compared to a previous survey from Taiwan from 2007, and to previous

reports in the scientific literature. EHS prevalence was close to 5%, decreasing from 13% in 2007. Heterogeneity across studies was very high (I^2=99%), with prevalence rates across countries varying between 1 and 13 % (pooled 5 %). There was some indication that EHS prevalence may be decreasing over time.

Overall, this study confirmed an overall estimation of EHS prevalence below 10 %, in line with many previous reports. The low participation rate may mean that some selection bias could be at work. In addition, comparison to previous studies is hampered by the fact that most studies appear to ask with different kinds of questions.

Karvala et al. (2018) investigated the prevalence of environmental intolerances towards chemicals, certain buildings, noise and electrical devices in age and gender stratified samples of Swedes and Finns to participate. The Swedish response rate was 40% with 3 406participants. The corresponding numbers for Finland were 33.3% and 1 535. Regarding EMF intolerance the question was "Are you getting symptoms from certain switched-on electrical devices that you believe other people are not getting symptoms from?". In both countries slightly more than 21% reported any intolerance. However, the prevalence of each specific intolerance was significantly different between countries. The prevalence of EMF-intolerance was the lowest of the investigated intolerances with 2.7 % and 1.6 % in Sweden and Finland respectively. The authors suggest that the constant total prevalence but differing levels for each factors may result from nocebo effects where people are more likely to attribute their symptoms to factors featured prominently in the media in their country.

A causal link between exposure to electromagnetic fields and development of symptoms in electromagnetic hypersensitive (EHS) individuals has not been established so far but previous research relied on comparison of group means and could not exclude that a few sensitive individuals were masked by a heterogeneous group of people claiming to be sensitive to electromagnetic field exposure. In individual case studies, Verrender et al. (2018) tested exposure detection and symptom severity in three participants aged 44–64 during a series of sham and active exposure trials (2 open-label trials; 12 randomized, double-blind, counterbalanced trials). The RF-EMF exposure had a frequency of 902–928 MHz with an average incident power density of 0.3 W/m^2 at the participant. In the double-blind trials, no significant difference in symptom severity or exposure detection was found for any of the three participants between the two conditions. However, belief of exposure strongly predicted symptom severity score for all participants.

This study confirms previous findings from provocation studies with EHS individuals. However, generalizability is limited given the small number of EHS individuals tested.

Heuser and Heuser (2017b) performed functional MRI (fMRI) brain scans on 10 persons reporting EHS. Of all 10 cases, a very brief case description was provided. Half of the cases also reported a history of head injury, and 9 out of ten were reported to have experienced chemical exposure, although details on the head injuries or the other mentioned chemical exposures were not provided. All brain scans of the patients were described as abnormal, and the authors describe that they had suggested their patients to undergo the fMRI exam to document potential abnormalities. In a corrigendum (Heuser and Heuser, 2017a), the authors explain how they had derived a control fMRI picture in healthy participants.

The results of this study cannot prove any association of EMF exposure with health problems, simply because EMF exposure as such was not analysed. In addition, it is unclear how the 10 presented patients were selected from all patients, which raises questions regarding the generalizability. All in all, the results of this study cannot be interpreted as presenting a useful diagnostic procedure for EHS persons.

4.1.4. Other outcomes

A study by Birks et al. (2017) addressed the question whether mobile phone use by women during pregnancy leads to behavioural problems of their children. The authors based their analysis on cohort data from five countries (Denmark, The Netherlands, Norway, Spain and South Korea), with a total of

more than 80 000 participating mother-child pairs. Both maternal mobile phone use and child behavioural problems were assessed through questionnaires filled in by the mothers. With regard to mobile phone use, data were collected prospectively in three of the cohorts, thus before the children were born. For the remaining two cohorts, data on mobile phone use were collected retrospectively at the same time when assessing potential behavioural problems at the age of five to seven. Children whose mothers used their mobile phone often during pregnancy (more than 4-6 times or more than one hour per day) had a 22 % higher risk of having hyperactivity or inattention problems. No increased risk was found with regard to general behavioural or emotional problems. The analysis took account of several potential confounders, such as civil status, education, history of psychopathology, smoking and alcohol consumption during pregnancy, body mass index and height. The results were robust in a multitude of sensitivity analyses, and independent of whether mobile phone use was assessed prospectively or retrospectively.

The large database is a strength of the study, but there are also some weaknesses. The questions related to mobile phone use, behavioural problems and co-factors varied in the different countries, and no assessment was made about the actual strength of the children's RF-EMF exposure during pregnancy. Although the association as such has been established rather consistently, it remains unclear whether mobile phone use of the mothers during pregnancy was actually the cause of the observed behavioural problems of the children. Other factors related to maternal mobile phone use could have played a role as well. It is also quite likely that mothers who frequently used a mobile phone during pregnancy have continued doing so in the following years, which potentially also had an effect on later mother-child interaction.

Maternal mobile phone use in pregnancy and child's language, communication and motor skills at 3 and 5 years was investigated in a Norwegian prospective cohort study consisting of 45 389 mother-child pairs recruited at midpregnancy from 1999 to 2008 (Papadopoulou et al., 2017). Maternal frequency of cell phone use in early pregnancy was assessed by a questionnaire administered at the 17th week of gestation. Early language development of the children at 3 years was assessed by the Dale and Bishop Grammar rating, motor skills at 3 years and communication skills at 3 and 5 years were assessed by the "Ages and Stages" questionnaire. Children of mobile phone using mothers (90% of the sample) had a 17% (95% CI: -23 to -11%) lower adjusted risk of having low sentence complexity at 3 years, compared to children of non-users. The risk was 13%, 22% and 29% lower by low, medium and high maternal mobile phone use. Additionally, children of mobile phone users had lower risk of low motor skills score at 3 years, compared to children of non-users, but this association was not found at 5 years. Communication skills were not related to maternal mobile phone use. The authors speculate that observed improvements in motor and language skills in relation to prenatal mobile phone use might be explained by enhanced maternal-child interaction among mobile phone users.

This large study is of high quality. A particular asset is the prospective exposure assessment at the time of pregnancy, which precludes from differential exposure misclassification. However, the study does not make any attempt to differentiate between mobile phone use and RF-EMF exposure which limits the interpretability of the findings. As acknowledged by the authors, residual confounding may be an explanation for the observed associations, although a number of relevant confounders were considered in the analysis (e.g parity, maternal age, education, year of delivery, maternal extrovert personality score).

Choi et al. (2017) evaluated maternal mobile phone use and blood lead levels in the Korean prospective birth cohort study MOCEH. Starting in 2006, 1 751 women were included at baseline and filled in a questionnaire that inquired, among other things, about mobile phone use. After excluding mothers who did not report on their mobile phone use, did not provide information on their child's development (Bayley Scales of Infant Development-Revised) or for whom no blood lead levels were available, 1 198 mother-child pairs were included in the analysis. For a subgroup of 210 participants, RF-EMF levels were measured with a personal exposimeter, the EME-SPY 100. Bayley tests were performed when children were aged 6, 12, 24 and 36 months respectively, and the authors evaluated the Mental as well as Psychomotor Development Index. Analyses were adjusted for a numerous sociodemographic and co-exposures (e.g. urinary cotinine levels). Maternal mobile phone use was not associated with the Mental Development Index, but more frequent maternal mobile phone use during

pregnancy was associated with higher Psychomotor Development Index at ages 12 and 24 months of the children. Measured RF-EMF levels were not associated with either of the scales, but the authors noted a potential modifying effect of blood lead levels.

Strength of the study includes the prospective design, where mothers were asked about their mobile phone use during pregnancy and developmental outcomes were assessed afterwards. However, residual confounding is a concern for the associations with maternal mobile phone use as this may be a proxy for many aspects of education and lifestyle, which might affect psychomotor development of children.

Potential effects of mobile and cordless phone use on cognitive function were investigated in 412 primary school children (10-11 years) from the Australian ExPOSURE cohort study (Bhatt et al., 2017). Cognitive functions were evaluated with the CogHealth™ test and Stroop Color-Word test, and data on children's socio-demographics, use of mobile and cordless phones were collected by questionnaire at baseline and follow-up one year later. Change in cognitive functions over one year was compared between children with an increase in call frequency vs. decrease or no change in call frequency between baseline and follow-up. Analyses were adjusted for age, sex, ethnicity, socioeconomic position, lag time between baseline and follow-up, handedness, and total weekly screen time. Out of 26 tests, 4 significant results were observed pointing to decreased (2 tests) and increased (1) reaction time as well as increased accuracy for children with an increase in exposure. In conclusion, the study found no evidence that increase in mobile and cordless phone use of primary school children had a negative impact on cognitive functions.

The longitudinal approach and considerations of confounding factors are assets of this study. The exposure range was, however, small: On average, study participants made only two mobile and two cordless phone calls per week. There was quite some discrepancy between mobile phone ownership as reported by the parents or children themselves. This indicates the presence of exposure misclassification in this study using self-reported exposure data. Also given the number of test performed, some chance findings are expected.

Baby et al. (2017) conducted a cross-sectional study on the use of mobile phones and thyroid function at a medical college in South India. They invited 100 undergraduate students (age 18 to 25 years) required to be active mobile phone users and free from known thyroid conditions, 83 fulfilled these criteria and returned a questionnaire on family history of thyroid conditions and their use of mobile phones. 75 underwent clinical examination of their serum thyroid-stimulating hormone (TSH) levels. 80% of the participants had clinically normal thyroid function and 70% had no family history of thyroid diseases. 53% of the participants talked around 30 minutes a day while eight students reported talking on their phones for more than 3 hours a day. Exposure was calculated as daily seconds spent talking on a phone times the phone specific SAR-value as reported by the manufacturer. A statistically significant Pearson correlation between this metric and serum TSH level was found (p=0.025) also when excluding subjects with a family history of thyroid conditions (p=0.038).

This is an insufficiently reported study with problems especially regarding the exposure assessment: SAR values do not determine actual exposure levels. It is unclear if students held phones to their heads during calling or used e.g. hands-free equipment, which would greatly reduce exposure received by the pituitary gland. It is also unclear which time frame the mobile phone use questions pertain to, on average per day or on the day of testing? This is relevant due to the short half-life of THS of about an hour. The analysis was not corrected for potential confounders although this information was collected. Finally, apparently, no effort was done to mask the purpose of the study to the participants, meaning that possibly students with thyroid problems and high mobile phone use might have been more interested in participating. All in all, this study is not informative regarding a potential effect of mobile phone use on TSH.

The cause for most cases of sudden sensorineural hearing loss (SNHL) is unknown and Sagiv et al. (2018) hypothesized that it might "somehow" be related to use of mobile phones. They identified 160 adult patients from their clinic that had developed unilateral SNHL between 2014 and 2016 and reporting daily use of a mobile phone. In a case-only analysis, they compared lateral agreement between the ear with SNHL and the dominant hand or the dominant ear, as proxies for the ear most

exposed to RF-EMF. Using chi-square and t-test they found no correlation.

The study suffered from low-numbers, statistical methods that did not allow adjustment for potential confounders and a very crude proxy for exposure which may all have driven estimates towards the null. In this context, reverse causality is also of concern: hearing loss on the ipsilateral side with respect to mobile phone use may be detected quicker. The study is uninformative.

Zothansiama et al. (2017) performed a cross-sectional study in 2015 and 2016 Aizawl city, Mizoram, India. 80 healthy volunteers participated, of which 40 lived within 80 m of a mobile phone base station ("exposed"), and 40 lived further than 300 m away ("unexposed"). Additional information regarding age, sex, smoking, alcohol consumption and mobile phone use was collected by means of questionnaires. A range of blood parameters were measured, such as glutathione, superoxide dismutase, catalase or lipid peroxidation; which were compared between exposed and unexposed volunteers. RF-EMF measurements were taken in homes of 23 volunteers and showed clear differences between exposure groups. Response rate was not reported, also not how the unexposed group was selected and how homes were selected for measurements. Power density was associated with all measured blood parameters, also after correction for age, sex, smoking, alcohol consumption and daily mobile phone use.

Unfortunately, many details of this study are insufficiently described, e.g. when and where (outside of the home, inside, bedroom?) the measurements were performed and for how long, how measurements were summarized, how volunteers were recruited, and if volunteers were aware of the study hypothesis and may have self-selected into the study. Blood parameter values presented between "high" and "low" measured RF-exposed based on measurements do not indicate strong differences among volunteers exposed to levels > 4 or ≤ 4mW/m^2, but are reported as statistically highly significant differences. It is unclear if other, unmeasured or unreported, factors could have contributed to the observed results. Due to the many unreported characteristics, the study results remain difficult to interpret.

Nanjannawar et al. (2017) evaluated the hypothesis that mobile phone use releases nickel ion and affects the pH of saliva in patients with fixed orthodontic appliances. To do so, they analyzed saliva samples of 42 healthy patients aged 12 to 25 years who had fixed orthodontic appliances in their mouth for a duration of 6 to 9 months. Nickel ion concentration and pH was compared between a group of mobile phone users (n=21) and a group of non-mobile phone users (n=21). The latter group mainly included children and women from rural areas, who did not have mobile phones of their own and/or rarely used a mobile phone. Data were analyzed using unpaired t-tests. No statistically significant differences between the two groups were found.

Limitations of this study include the small sample size, the low number of samples per person and lack of confounding adjustment. It seems that the two groups were quite different.

4.1.5. Conclusions on epidemiological studies

Several new meta-analyses on brain tumour risk in relation to mobile phone use were published. However, these papers do not contribute to a better understanding as essentially the identical underlying study base was re-analysed several times. Overall, time trends of brain tumour incidence stay rather constant over time. Increases have been reported for specific subtypes of tumours and decreases in some others. Most likely changes in coding praxis are responsible for shifting number of cases between different diagnoses. Thus, future incident studies should carefully report results for all diagnoses and locations within a disease entity to allow better interpretation of the data.

Two studies on mobile phone use during pregnancy found positive and negative effects and suggested that other factors than RF-EMF exposure may be at play. In terms of symptoms, several studies reported associations with self-reported mobile phone use but not for exposure from transmitters. These studies may indicate that other aspects related to frequent mobile phone use (e.g. distraction or stress) than RF-EMF exposure may have an impact on health-related quality of life.

4.2. Human studies

Contrary to other exposure types the number of studies investigating RF-EMF effects in human experimental studies is relatively constant. While all studies considered in the previous report refer to effects in healthy subjects, the current reporting period also covers a study in subjects who declared themselves to be electrohypersensitive (Andrianome et al., 2017). The other two studies investigated effects of radiofrequency electromagnetic field exposure on the activity of the waking brain in healthy subjects (Dalecki et al. (2018); Hinrikus et al. (2017)), which was also the main outcome parameter in the previous report.

Two other studies that did not meet the quality criteria to be included in the Council report are listed in the Appendix.

Furthermore, two reviews were published. Zhang et al. (2017b) published a review on acute effects of radiofrequency electromagnetic field emitted by mobile phone on brain function. Since their search terms always included the word phone or mobile phone they missed other studies investigating effects of RF exposure on the brain. Based on (selected) 16 studies covering various endpoints they come up with the conclusion "several inconsistent findings exist, and (that) conclusions regarding adverse effects of EMF exposure are currently limited".
There are inconsistent results with regard to "brain function", which is partly due to the fact, that different outcomes have been considered together (e.g. results from imaging studies, electrophysiological studies during wake and sleep, etc.). However, so far there is no evidence of effects that are harmful to health.

The other review addressed effects of exposure from mobile phone-like signals, on attention in humans (Curcio, 2018). The author selected laboratory volunteer studies with at least one verum and a sham exposure condition. Out of the 43 studies, 31 indicated no exposure effect on attention; nine indicated an improvement of attention, while three showed inconsistent results or a worsening of performance. Although the author emphasizes that the studies are quite heterogeneous with regard to methodology, dosimetry and statistical analyses, he concludes that there is a substantial lack of evidence about a negative effect of non-ionizing radiations on attention.
This conclusion is consistent with the overall picture, which emerged from the Council reports of the past years.

4.2.1. Brain Activity

Dalecki et al. (2018) investigated effects of a GSM-like exposure (920 MHz, peak spatial SAR values, averaged over 10 g ($psSAR_{10g}$) of 1 W/kg and 2 W/kg, and sham) in 36 healthy subjects (18 females, age range: 18-52 years; mean $\pm$ SD: 24.4 $\pm$ 6.3 years). The study comprised four study visits separated by at least one week. The first visit was a calibration session to practise the cognitive tasks. In study visits two to four exposures were delivered in a double-blind, counterbalanced, cross-over design. The assessments were performed at an individually fixed time of the day (09:00 or 13:00). The cognitive task was a visual discrimination task with altogether 360 trials comprising non-targets, easy targets and difficult targets. The difficulty of the task was individually calibrated on the basis of the performance in the first session. Each experimental session comprised two blocks. In the first 30 min block subjects were tested under the condition "RF ON", followed by 30 min testing under the condition "RF OFF". Performance parameters are not reported. The authors analysed amplitudes and latencies for seven components of a visually evoked potential. Exposure was delivered using the xXh920 planar exposure system designed and distributed by IT'IS Zurich. All experiments were performed with the subjects wearing a thermosuit to ensure that the external environment and prior activity did not interfere with the experiment. There is, however, no information about a possible interference of the EEG recording device and exposure. The authors controlled carefully for artefacts due to eye movements. Analyses were performed 1) for amplitudes and latencies comparing sham exposure to the average of the event-related potentials (ERPs) observed under both exposure conditions, and 2) for low vs high real exposure. Both analyses were performed separately for easy

and difficult targets (resulting in 56 tests: (7 amplitudes + 7 latencies)*2 target situations (easy and difficult) * 2 exposure comparisons (sham vs exposure or-, high vs low exposure, respectively). None of the comparisons between high and low exposure led to significant results. For the comparison sham vs exposure two significant results were observed, one amplitude was affected in the easy target condition and one latency in the difficult target condition. Since the differences were not obvious in the comparison between real exposures and given the multiple testing situations the results were considered to be due to chance.

Hinrikus et al. (2017) investigated whether different modulation frequencies (7, 40, and 1000 Hz) of a 450 MHz microwave signal affected EEG activity in 15 healthy volunteers (21-24 years, 7 females). Modulation frequencies were chosen to reflect lower (7 Hz) and higher (40 Hz) activity of the normal EEG spectrum. A much higher modulation of 1000 Hz served as a kind of control. The peak spatial SAR averaged over 1g was calculated to be 0.303 W/kg. EEG was recorded with subjects lying in a relaxed position with closed eyes. Sessions with randomly assigned different exposures were scheduled on different days between 9 am and noon. Each recording session lasted for 30 min and consisted of three experimental series with a constant modulation frequency. Each experimental series consisted of five 2-min exposure cycles with 1-min exposure on and 1-min exposure off. Two of the three 10-min sessions were with RF exposure and one without. EEG was recorded from nine electrodes, covering frontal (Fp1, Fp2), temporal (T3, T4), parietal (P3, P4) and occipital (O1, O2) brain regions with Cz as reference. For evaluation EEG was averaged over exposure cycles, EEG channels and subjects. While modulation frequencies of 7 Hz and 1000 Hz did not affect EEG power under exposure, a 40 Hz modulation resulted in significant increases in the power of EEG in the alpha and beta frequency ranges. The authors conclude that these results are in good agreement with their theory of parametric excitation of the brain bioelectric oscillations caused by the periodic alteration of neurophysiologic parameters and that the data support the proposed mechanism.

4.2.2. Heart rate variability (HRV) and skin conductance

Effects of exposure to various EMF signals (GSM 900, GSM 1800, DECT, and Wi-Fi) on the autonomic nervous system (ANS) in subjects who declared to be electrohypersensitive (EHS) were investigated by Andrianome et al. (2017). In a first assessment, which was not related to any exposure, they investigated differences in heart rate variability parameters, blood pressure, skin conductance, and skin conductance response in a sample of 30 EHS subjects (18-65 years, mean ± SD: 47 ± 9 years) as compared to 25 non-EHS subjects, which were matched for age, body mass index, and sex. None of the parameters differed significantly between EHS and non-EHS subjects. The experiment, which was related to possible exposure effects was performed in 10 of the 30 EHS subjects from the first assessment, who agreed to be exposed to different EMF signals in a double-blind cross-over experiment. Subjects were exposed in two different sessions (sham and real exposure) starting at 10 AM separated by an interval of at least one week. In the real exposure condition, subjects were exposed consecutively to GSM 900, GSM 1800, DECT and Wi-Fi for a duration of 5 min each with an exposure-free interval of 10 min between exposures. Symptoms were assessed in these exposure-free intervals. Information about dosimetry and delivery of exposure is missing. None of the investigated parameters (respiratory rate, blood pressure, heart rate variability parameters, skin conductance and skin conductance reactivity) differed significantly between exposure conditions. The authors conclude that exposure did not have an effect on the ANS parameters they explored. This conclusion is certainly limited by the small sample size, which is due to the fact that only 10 out of the 30 EHS subjects agreed to participate in the exposure-related experiment.

4.2.3. Conclusion on human studies

The studies on effects of RF-EMF exposure address endpoints other than the studies covered in the last reporting period. One study concludes that there is no effect on visually evoked potentials, the other underlines that a 40 Hz modulation of the RF signal affects EEG power. The conclusion, that RF

does not affect the autonomous nervous system in subjects who declared themselves to be electrohypersensitive is certainly limited by the small sample size and the related small power.

4.3. Animal studies

This year, the Council focuses on animal studies on carcinogenesis and on effects on brain and behaviour.

4.3.1. Carcinogenesis

Recently, results from a major carcinogenesis study conducted by the National Toxicology Program (NTP) in the USA were published in two reports (NTP, 2018a, 2018b). A Peer Review Panel has made remarks, which will be used to formally finalize these reports. Therefore, they have not yet been published in the peer-reviewed scientific literature, but in view of their importance they are discussed here. Sprague Dawley rats were exposed to 900 MHz GSM- or CDMA-modulated signals at whole-body specific absorption rates (SAR) of 1.5, 3 or 6 W/kg (NTP, 2018a), and B6C3F1/N mice to 1900 MHz GSM- or CDMA-modulated signals at whole-body SARs of 2.5, 5 or 10 W/kg (NTP, 2018b). Exposure was for 10 minutes on, then 10 minutes off, repeated for a total of 18 hours and 20 minutes daily. Exposure of rats started in utero (on gestation day 5) and continued after birth for up to 107 weeks. In mice, it started at 5-6 weeks of age and continued for 106 and 108 weeks in males and females respectively.

For GSM exposures, in male mice, there was "equivocal evidence" of carcinogenicity, based on incidences of skin fibrosarcoma, sarcoma, or malignant fibrous histiocytoma, alveolar/bronchiolar adenoma or carcinoma and malignant lymphoma. No evidence of neoplastic lesions was noted in female mice. In male rats they found "some evidence of carcinogenic activity" based on malignant schwannoma in the heart. They also concluded that there is "equivocal evidence of carcinogenicity" based on incidences of tumours (benign, malignant, or complex combined) in the prostate gland, brain, pituitary gland, adrenal medulla and pancreas. They found no evidence of carcinogenic activity in female rats.

For CDMA exposures, they concluded that there was "equivocal evidence of carcinogenic activity" in male and female mice based on incidences of hepatoblastoma and malignant lymphoma, respectively. In rats they found "some evidence of carcinogenic activity" in males based on malignant schwannoma in the heart and equivocal evidence based on malignant glioma in the brain, adenoma in the pituitary gland and adenoma or carcinoma in the liver. In females the evidence was equivocal based on malignant glioma in the brain and pheochromocytoma in the adrenal medulla.
There is considerable discussion on how to interpret these results. One problem is the lack of tumours in the controls in the experiment, while there were tumours in the historical control groups. This may have to do with the fact that the controls in the experiment lived shorter than the historical controls and then the RF-exposed animals. When the historical controls are used to assess the tumour incidence, no significantly increased incidence is found, while with the controls from the experiment this is the case for the highest exposure level (6 W/kg) in the male rats for the cardiac schwannoma. The researchers showed that at this exposure level the subcutaneous temperature was increased with approximately 0.5 °C (Wyde et al., 2018). However, the core temperature is likely to have increased more, since that is less dependent on heat loss trough the superficial tissue layers. Possible effects on reproduction and development of tumours should have been discussed in this context. Altogether there is considerable uncertainty about how to interpret the results of this study.

(Falcioni et al., 2018) exposed male and female Sprague-Dawley rats prenatally from the 12th day of gestation until their natural death for 19 h/day to a 1800 MHz GSM far field signal at whole-body SARs of 0.001, 0.03 or 0.1 W/kg. They reported a significant increased incidence of Schwannomas in the heart of male rats exposed at the highest SAR (0.1 W/kg), as well as increased incidence of heart

Schwann cell hyperplasia (in males and females) and malignant glial tumours (in females only), but these were not statistically significant. The results are not consistent with the results of the NTP study, where no increased tumour incidences were found with the exposure level of 1.5 W/kg. They also only reported on tumours in the heart and brain, and not in other tissues. Selective reporting of specific tumours is not state of the art.

4.3.2. Behaviour and cognition

Obajuluwa et al. (2017) exposed male albino rats in groups of 6 to a 2.5 GHz WiFi signal for 24 h per day during 4, 6 or 8 weeks at an E field level of 11 V/m [no SAR is provided]. At the end of each exposure period analysis of behavioural parameters was performed and acetylcholinesterase gene expression in the brain was assessed. In the Rotarod test (measuring anxiety) a reduction in the latency of falling was observed in the exposed groups. In the open field test, the exploratory activity decreased with increasing exposure duration. Acetylcholinesterase activity in the cerebral cortex was reduced with all exposure durations, but an increased acetylcholinesterase gene expression level was found only after 6 and 8 weeks of exposure.

Son et al. (2018) explored the effects of long-term exposure on behaviour using the 5xFAD mouse model, which is transgenic for a rapid development of amyloid β plaques, thus being a model for the development of Alzheimer's disease (AD). Female mice (n= 8) were exposed at a whole-body SAR of 5 W/kg to a 1950 MHz RF field for 2 h per day, 5 days per week for 8 months. After the exposures, sham-exposed animals exhibited increased activity levels in an open field test and had a much-reduced preference for a novel object in an object recognition test, compared to age-matched, unexposed wild-type female mice. Significant decreased activities were shown by the exposed transgenic animals, and their behaviour was similar to that of the wild-type animals. Thus long-term exposure appeared to have attenuated the decline in cognitive ability shown by the transgenic animals at 9.5 months of age.

Zhang et al. (2017c) exposed juvenile C57BL/6 mice (n= 7 or 10) to 1800 MHz at a brain SAR of 2.2 W/kg for 6 h per day during 28 days. No effect on spatial learning or memory as assessed in a Morris water maze was observed, but exposure increased levels of anxiety. Depression-like behaviour was not affected. In both the hippocampus and the cortex a decreased level of γ-aminobutyric acid (GABA) and aspartic acid was observed, but no effect on glutamic acid, glycine and acetylcholinesterase.

In an extension of a study published in 2015, Shahin et al. (2018) exposed 12 week old Swiss albino mice to a 2.45 GHz CW field for 2 h per day for 15, 30 or 60 days at an average whole body SAR of 0.0146 W/kg. Animals (n= 20) were trained to perform a food-reinforced task in an 8-arm radial maze to assess spatial learning and memory. With increasing exposure time they made more working and reference memory errors. They also spent less time in the 4 previously-baited arms of the maze during a probe trial. This effect was larger with increasing exposure periods. Additional biochemical and molecular studies identified the classical hippocampal memory formation pathway to be involved in these changes. The authors suggest that local stress was induced that suppressed signalling mechanism(s) of hippocampal memory formation.

Van Eeghem et al. (2017) exposed NMRI mice (n=7) to 10 GHz fields amplitude modulated at 2 or 8 Hz. The brain SAR was 0.3 W/kg and the exposure was 24 hours per day during 6 days. Exposure had no significant effect on motor coordination, spatial working memory, anxiety or depressive-like behaviour, except for an immediate reduction in spontaneous activity in the open field with 2 Hz modulation. They found no difference between exposed and sham-exposed animals in the levels of dopamine, 3,4-dihydroxyphenylacetic acid (a metabolite of dopamine) and glutamate in the brain.

Sharma et al. (2017) exposed 14 day-old Swiss mice (n= 6) to a 10 GHz field for 2 h per day during 15 days. Spatial memory was investigated using a Morris water maze about 2 weeks after exposure. Significant deficits were reported in learning during acquisition trials and in memory during the probe trial indicating exposure had a sustained effect on behaviour.

Tan et al. (2017) exposed Wistar rats to pulsed 2.856 GHz and/or 1.5 GHz Exposure was for 6 minutes to each frequency only, or for 6 minutes to one, followed by 6 minutes to the other frequency. Two exposure levels were employed. With the low level, the whole-body SARs were 1.8 (1.5 GHz) and 1.7 (2.856 GHz) W/kg, with the high levels they were respectively 3.7 and 3.3 W/kg. Temperature, measured at the rat's surface increased less than 1 °C (n= 4). Place learning was assessed using the water maze on days 1, 2, 7, 14 and 28 after exposure. Exposure increased escape latency only at the higher SAR, irrespective of frequency, on all days.

Bodera et al. (2017) exposed Wistar rats (n=8 per group) to 1800 MHz for 15 minutes per day during 5 days, with a whole-body SAR of 0.024–0.028 W/kg. They found no effect on the expression in the brain of N-methyl-d-aspartate receptor subunit NR1 (NMDA-R1; a transmembrane protein that, when activated by binding of glutamate and glycine (or D-serine), allows positively charged ions to flow through the cell membrane; it is very important for controlling synaptic plasticity and memory function).

Wang et al. (2017a) exposed male Wistar rats (n=15) for 6 min per day, 5 days per week, during 6 weeks. Brain SARs were 1.75, 3.5 and 7 W/kg. After the 7 W/kg exposures, no effect was found on NMDAR1; NMDAR2A and p-NMDAR2B were decreased at 1 day after the last exposure, but not at 1, 6, 9 and 12 months; NMDAR2B was decreased at 1 day, 1 and 6 months, but not at the later times. Place learning was assessed using a water maze. Only exposure at 7 W/kg caused deficits in learning and memory at 7 days and at 1, 3, and 9 months after exposure. A brain SAR of 7 W/kg could have resulted in thermal effects. No results were reported for the lower SAR levels.

Gokcek-Sarac et al. (2017) exposed Wistar rats (n=13 per group) to 900 or 2100 MHz EMF for 2 h per day, 5 days per week, during 1 or 10 weeks. The brain SAR was 0.66 W/kg (900 MHz) or 0.27 W/kg (2100 MHz). After the exposures, they found increased expression of a number of enzymes in the hippocampus, including PKA, CaMKIIa, CREB, and p44/42 MAPK, all involved in NMDAR-related signalling pathways. The effects were stronger after the longer exposure and with 2100 MHz compared to 900 MHz.

Kim et al. (2017a) exposed C57Bl/6 mice for 5 h per day, 5 days per week during 4 or 12 weeks to 835 MHz at a whole-body SAR of 4 W/kg. In both cases they found a decreased number of synaptic vesicles in the cortex. They also observed an exposure time-related decrease in synapsin in neurons. Synapsin is a key regulator of storage and mobilization of synaptic vesicles at synaptic terminals. So this means that there may be an influence of exposure on neurotransmission.

4.3.3. Apoptosis and oxidative stress

Ertilav et al. (2018a) exposed Wistar rats (n=8 per group) to 900 or 1800 MHz for 1 h per day, 5 days per week during 1 year at a whole-body SAR of 0.15±0.10 W/kg. After the last exposure they extracted hippocampal and dorsal root ganglion neurons and investigated the pronociceptive polymodal receptor sensing transient receptor potential (TRP) vanilloid 1 (TRPV1). They found in both types of cells with both frequencies an increase in TRPV1 currents, intracellular free calcium influx, reactive oxygen species production, mitochondrial membrane depolarization, apoptosis and in caspase 3 and 9 levels. They suggest that this reflects an RF-EMF-induced stress response.

Kerimoglu et al. (2018) exposed male Sprague Dawley rats (n= 8 per group) to 900 MHz fields for 1 h per day during 38 days at a WBA SAR of 0.0093 W/kg. When assessed after the last exposure, the levels of malondialdehyde, catalase and superoxide dismutase were increased in the sciatic nerve, while glutathione was not. There was also marked thickening in the epineurium.

In three papers, Kim and et al. (Kim et al., 2017b; Kim et al., 2018b; Kim et al., 2018a) presented an experiment in which they exposed C57BL/6 mice for 5 h per day, 5 days per week during 12 weeks to

835 MHz at a whole-body SAR of 4 W/kg. They assessed in different brain areas the expression of several genes and proteins related to autophagy. In the first paper, Kim et al. (2017b) found increased expression in the cortex. They also observed induced hyperactivity as measured in an open field arena. In the second paper, Kim et al. (2018b) they also found this in the hippocampus, but not in the brain stem. In the third paper, Kim et al. (2018a) they observed decreased calcium channel expression in the hippocampus, which they assume to indicate altered intracellular calcium homeostasis. They also observed accumulation of autolysosomes in hippocampal neurons and increased expression of autophagy-related genes and proteins. Therefore they suggest that the alterations in calcium homeostasis are influenced by activation of autophagy and inhibition of apoptotic regulation.

In a study also evaluating behaviour, cognition and neurotransmitters (see previous sections) Bodera et al. (2017) exposed Wistar rats (n= 8 per group) to 1800 MHz for 15 minutes per day during 5 days, with a whole-body SAR of 0.024–0.028 W/kg. They found that the oxygen radical absorbance capacity was decreased by ~2/3 (i.e. the level of radicals was increased). There was no effect on the activity of endogenous radical trapping.

Lameth et al. (2017) investigated 14-day and 2-months old Wistar rats that were exposed to 1800 MHz at a local brain SAR of 2.94 W/kg for 2 h. The expression in the cortex of a number of proteins that are induced by acute neuroinflammation was assessed, including TNFα (tumour necrosis factor alpha), IL6 (interleukin 6), IL1β, CCL2 (chemokine (C-C motif) ligand 2), NOS2 (inducible NO synthase) and NOX2 (NOX2-dependent phagocyte NADPH oxidase). Exposure to EMF without neuroinflammation had no effect on the expression of these enzymes.

Sharma et al. (2017), in a study reported under behaviour, exposed 14 day-old Swiss mice (n= 6) to a 10 GHz field for 2 h per day during 15 days. They found increased lipid peroxidation and catalase, and reduced glutathione, superoxide dismutase and protein in the brain, both immediately after the exposure and 6 weeks later.

Tan et al. (2017), in a study reported under behaviour, exposed Wistar rats to pulsed 2.856 GHz and/or 1.5 GHz Exposure was for 6 minutes to each frequency only, or for 6 minutes to one, followed by 6 minutes to the other frequency. Two exposure levels were employed. With the low level, the whole-body SARs were 1.8 (1.5 GHz) and 1.7 (2.856 GHz) W/kg, with the high levels they were respectively 3.7 and 3.3 W/kg. Temperature, measured at the rat's surface increased less than 1 °C (n= 4). Exposure at the low level to either single frequency had no effect on oxidative stress parameters in brain tissue (n= 25). Combined exposure to low-level 2.856 and 1.5 GHz resulted in reduced expression of acetylcholinesterase and cytochrome C oxidase. After exposure at the high levels, they observed reduced expression of acetylcholinesterase, cytochrome C oxidase, and superoxide dismutase. Following combined exposure to both frequencies, reduced expression of acetylcholinesterase, brain derived neurotrophic factor, cytochrome C oxidase and superoxide dismutase were found. In EEG recordings, the combined low-level exposure reduced power of α waves; the single high-level 2.856 GHz exposure reduced the EEG frequency and power of α and β waves, and increased power of θ wave; the single high-level 1.5 GHz exposure reduced the EEG frequency and power of α wave; the combined high-level microwave exposures reduced the EEG frequency and power of α and β waves, and increased power of θ wave. Morphological analyses of the hippocampus carried out at 7 d after exposure (in 5 brains per group) by means of light microscopy and transmission electron microscopy showed no changes vs. controls in rats exposed to single low-level 2.856 GHz or 1.5 GHz exposures, but some aberrations were found in all the other exposure groups (the most in the combined high-level group).

4.3.4. Blood brain barrier
Poulletier de Gannes et al. (2017) exposed groups of 11-16 Wistar-Han rats to GSM 1800 or UMTS 1960 MHz signals at brain-averaged SARs of 0.026, 0.26, 2.6 or 13 W/kg for 2 h or for 2 h/day, 5 days/week for 4 weeks. The animals were restrained and the head was exposed using a loop antenna.

Neither single nor repeated exposure to low level GSM or UMTS signals had any significant effect on degeneration in the rat brain, but repeated exposures that caused local hyperthermia resulted in increased albumin leakage. While fewer degenerating neurons and decreased albumin leakage were observed at some time points after exposure, only repeated exposures to either signal at 13 W/kg caused a significant increase in albumin leakage only after 50 days. The exposure at 13 W/kg caused a temporary increase in the temperature of the cortex of about 0.9 °C.

4.3.5. Brain physiology

Aslan et al. (2017) exposed 21-d old male Sprague Dawley rats (n= 6 per group) to 900 MHz for 1 h per day during 25 days at a WBA SAR of 0.01 W/kg. After the last exposure the cerebellum was dissected and the number of Purkinje cells counted. In the exposed group the number was lower than in the sham-exposed and cage control groups. They also observed alteration of normal Purkinje cell arrangement and pathological changes including intense staining of neuron cytoplasm in the exposed animals.

4.3.6. Conclusions

Two studies on carcinogenesis have a number of positive aspects, including their size and the duration of the exposure and the attempts to provide a comprehensive analysis of the pathology. However, the results are inconsistent between the studies in terms of the exposure levels where increased tumour incidences are observed, and the main endpoint, schwannoma of the heart, is only a very rare tumour in humans and therefore, likely, the public health relevance is not very high. Moreover, it is a tumour that has never been reported in experimental RF cancer studies, so it is peculiar at the least that it now appears in two studies that were published at the same time, and that it shows up only in rats and not in mice. A discussion on the effects of heating at the high exposure level in male rats is missing. Altogether the Council does not feel that these studies can be considered as clear indications for carcinogenicity of RF fields in humans.

Eleven studies of sufficient quality were identified that investigated behavioural and cognitive effects and effects on neurotransmitters of exposure to RF EMF. In most studies some effect was observed, but it is difficult to find a clear overall picture. It is remarkable that both in studies with relatively low (WBA SAR 14-179 mW/kg) and high (brain SAR 7 W/kg) exposure levels effects on memory were observed, while in studies employing WBA SARs of 0.2-3.3 W/kg no effect was found. Anxiety was found to be increased in two out of three studies. Several studies found effects on neurotransmitter / signalling pathways in the cortex or hippocampus, but this was also not clearly related to exposure levels. In one study using animals transgenic for human Alzheimer-related genes, the effects on behaviour of the genetic alterations was annulled by RF EMF exposure.

In eight of the nine studies on apoptosis or oxidative stress, an effect indicative of increased oxidative stress was observed. The one study on blood-brain barrier only found leakage with the very high local brain exposure of 13 W/kg, which might have resulted from heating. Finally, a WBA SAR of 0.01 W/kg was shown to result in changes in Purkinje cells in the cerebellum. In contrast to earlier studies, newer studies indicate possible effects of relatively low-level RF-EMF exposures on oxidative stress. The results are however not conclusive and further studies are needed to confirm if the association occurs in animals and to establish whether and to what extent it may occur in humans.

Table 4.3.1. Animal studies on exposure to RF fields

Endpoint	Authors	Animals, source	Exposure	Effect
Carcinogenesis	NTP (2018a)	Rat, Sprague Dawley 900 MHz, GSM or CDMA	WBA SAR 1.5, 3. 6 W/kg 10 min on/10 min off, 18 h 20 min/day, from gestation day 5 for107 weeks	GSM, males: "some evidence of carcinogenic activity"; females: no evidence CDMA, males: "some evidence of carcinogenic activity", females: "equivocal evidence of carcinogenic activity"
	NTP (2018b)	Mouse: B6C3F1/N 1900 MHz GSM or CDMA	WBA SAR 2.5, 5, 10 W/kg 10 min on/10 min off, 18 h 20 min/day, from age 5-6 wk for 106 (male) or 108 weeks (female)	GSM, males: "equivocal evidence" of carcinogenicity; females: no evidence CDMA, males, females: "equivocal evidence of carcinogenic activity"
	Falcioni et al. (2018)	Rat, Sprague Dawley 1800 MHz, GSM	WBA SAR 0.001, 0.03, 0.1 W/kg 19h/day, prenatal to death	Males, 0.1 W/kg: increased heart Schwannoma.
Behaviour, cognition, neurotransmitters	Obajuluwa et al. (2017)	Rat, albino 2.5 GHz, WiFi	E field 11 V/m 24h/day, 4, 6, 8 weeks	Increased anxiety, decreasing exploration with increasing exposure time. Reduced acetylcholinesterase activity cortex (all times), increased acetylcholinesterase gene expression after 6 and 8 weeks.
	Son et al. (2018)	Mice, 5xFAD (AD transgenic) 1950 MHz	WBA SAR 5 W/kg, 2 h/day, 5 days/week, 8 months	Transgenic sham exposed: increased activity, reduced object recognition. Transgenic exposed: same behavior as wild-type animals
	Zhang et al. (2017c)	Mouse: C57/BL 1800 MHz	WBA SAR 2.7 W/kg, Brain SAR 2.2 W/kg 6 h/day, 28 days	No effects spatial learning, depression-like behavior;i ncreased anxiety. Hippocampus, cortex: decreased GABA, aspartic acid, no effect glutamic acid, glycine, acetylcholinesterase.

Shahin et al. (2018)	Mouse: Swiss 2450 MHz CW	WBA SAR 14.6 mW/kg 2h/day, 15, 30 or 60 days	Exposure-time dependent increase in errors in working and reference memory. Involvement classical hippocampal memory formation pathway.
Van Eeghem et al. (2017)	Mouse: NMRI 10 GHz, amplitude-modulated at 2 or 8 Hz	WBA SAR 0.3 W/kg 24 h/day, 6 days	No effect motor coordination, spatial working memory, anxiety or depressive-like behavior, except reduced activity immediately after exposure with 8 Hz . No effect brain levels of dopamine, 3,4-dihydroxyphenylacetic acid and glutamate.
Sharma et al. (2017)	Mouse: Swiss 1000 MHz	WBA SAR 0.179 W/kg 2 h/day, 15 days	Deficits in learning and memory 2 weeks after exposure.
Tan et al. (2017)	Rat: Wistar 1500 MHz, 2856 MHz or both sequentially	WBA SAR 1.8/1.7 W/kg or 3.7/3.3 W/kg 6 min/frequency	Escape latency increased only at higher SAR (both frequencies). No increased effect with sequential exposure. Acetylcholinesterase expression: low level, single frequency: no effect; low-level, combined exposure, high levels: reduced.
Bodera et al. (2017)	Rat: Wistar 1800 MHz	WBA SAR 2.4-2.8 mW/kg 15 min/day, 5 days	No effect on NMDAR1.
Wang et al. (2017a)	Rat: Wistar 2586 MHz, pulsed	Brain SAR 1.7, 3.5 or 7 W/kg 6 min/day, 5 days/week, 6 weeks	Increased escape latency, impaired memory at 7 W/kg. No effect on NMDAR1; decreased NMDAR2A and p-NMDAR2B at 1 day, not at 1, 6, 9 and 12 months; NMDAR2B decreased at 1 day, 1 and 6 months.

	Gökcek-Sarac et al. (2017)	Rat: Wistar 900, 2100 MHz	Brain SAR 0.66 W/kg (900 MHz) or 0.27 W/kg (2100 MHz) 2 h/day, 5 days/week, 1 or 10 weeks	Hippocampus: increased expression PKA, CaMKIIa, CREB, and p44/42 MAPK, all involved in NMDAR-related signalling pathways. Effects stronger after the longer exposure and with 2100 MHz compared to 900 MHz.
	Kim et al. (2017a)	Mouse: C57Bl/6 835 MHz	WBA SAR 4 W/kg 5 h/day, 5 days/week, 4 or 12 weeks	Cortex: decreased number of synaptic vesicles, exposure time-related decrease in synapsin in neurons.
Apoptosis, oxidative stress	Ertilav et al. (2018b)	Rat: Wistar 900, 1800 MHz	WBA SAR 0.15±0.10 W/kg 1 h/day, 5 days/week, 1 year	In both types of neuronswith both frequencies increase in apoptosis, caspase 3 & 9 in hippocampal and dorsal root ganglion neurons.
	Kerimoğlu et al. (2018)	Rat: Sprague Dawley 900 MHz	WBA SAR 9.3 mW/kg 1 h/day, 38 days	Sciatic nerve: increased malondialdehyde, catalase, superoxide dismutase, not glutathione.
	Kim et al., 2017b	Mouse: C57Bl/6 835 MHz	WBA SAR 4 W/kg 5 h/day, 5 days/week, 12 weeks	Cortex: increased expression several genes and proteins related to autophagy.
	Kim et al. (2018b)	Mouse: C57Bl/6 835 MHz	WBA SAR 4 W/kg 5 h/day, 5 days/week, 12 weeks	Hippocampus: increased expression several genes and proteins related to autophagy, not in brain stem.
	Kim et al. (2018a)	Mouse: C57Bl/6 835 MHz	WBA SAR 4 W/kg 5 h/day, 5 days/week, 12 weeks	Hippocampus: decreased calcium channel expression. Hippocampal neurons: accumulation of autolysosomes, increased expression autophagy-related genes and proteins.
	Bodera et al. (2017)	Rat: Wistar 1800 MHz	WBA SAR 2.4-2.8 mW/kg 15 min/day, 5 days	Decreased oxygen radical absorbance capacity, no effect endogenous radical trapping.

	Lameth et al. (2017)	Rat: Wistar 1800 MHz	Brain SAR 2.94 W/kg 2 h	Cortex: no effect on TNFα, IL6, IL1β, CCL2, NOS2, NOX2 in 14-day and 2-months old rats.
	Sharma et al. (2017)	Mouse: Swiss 1000 MHz	WBA SAR 0.179 W/kg 2 h/day, 15 days	Increased brain lipid peroxidation, catalase, reduced glutathione, superoxide dismutase and protein, immediately and 6 weeks after exposure.
	Tan et al. (2017)	Rat: Wistar 1500 MHz, 2856 MHz or both sequentially	WBA SAR 1.8/1.7 W/kg or 3.7/3.3 W/kg 6 min/frequency	Low level, single frequency: no effect. Low-level, combined exposure: reduced acetylcholinesterase and cytochrome C oxidase. High levels: reduced acetylcholinesterase, cytochrome C oxidase, superoxide dismutase.
Blood-brain barrier	Poulletier de Gannes et al. (2017)	Rat: Wistar-Han 1800 MHz, GSM 1960 MHz, UMTS	Brain local SAR 0.026, 0.26, 2.6 or 13 W/kg 2 h (single) or 2 h/day, 5 days/week for 4 weeks (repeated)	No effects except repeated exposure to either signal at 13 W/kg increased albumin leakage at 50 days.
Brain morphology	Aslan et al. (2017)	Rat: Sprague Dawley 900 MHz	WBA SAR 0.01 W/kg 1 h/day, 25 days	Purkinje cells cerebellum: decreased number, alteration arrangement, pathological changes.

4.4. Cell studies

Eleven papers are described in this section, dealing with the effect of RF exposure, given alone or in combination with chemical or physical agents. Twelve more studies have been recognized but they were excluded because they did not meet the inclusion criteria.

Several biological parameters have been investigated in a large frequency range, from 400 MHz to 60 GHz.

4.4.1. Adaptive response

The phenomenon of the RF-induced adaptive response is under investigation since a decade and in the period of interest two papers have been published.

Sannino and co-workers (Sannino et al., 2017b) exposed Chinese Hamster lung fibroblast cell line (V79) to 1950 MHz, UMTS signal, at four SAR values in the range 0.15 – 1.25 W/Kg for 20 h to evaluate the induction of chromosomal damage (micronucleus frequency) induced by RF exposure alone and given before a treatment with mitomycin-C (MMC), a well-known alkylating agent. The results of four independent experiments indicated that the lower SAR values (0.15 and 0.30 W/Kg) induced a slight but statistically significant increase in MN frequency ($p < 0.05$) compared to sham

exposed samples but such an increase was not recorded in cultures exposed to higher SARs (0.6 and 1.25 W/Kg). In addition, cell cultures were also pre-exposed at 0.3 or 1.25 W/kg, and then treated with MMC and a significant reduction in the frequency of MN was detected in cultures pre-exposed to 1.25 W/kg compared to cultures treated with MMC alone (P<0.05), indicating induction of adaptive response. Such a decrease was not induced by pre-exposure at 0.3 W/kg SAR. Taken together and considering the dependency of RF exposure effects on the cell type, the results indicated that V79 is a sensitive cell model to evidence either adverse or cell-protecting effects of RF exposure, depending on experimental conditions applied.

He et al. (2017) exposed mouse bone marrow stromal cells to 900 MHz, at a calculated SAR of 0.41 mW/kg 3 h per day for five days. After RF exposure, some cultures were exposed to an acute dose of 1.5 Gy gamma radiation. The authors analysed the amount of DNA damage over the course of two hours (0, 30, 60, 90, 120 minutes), evaluated by means of the comet assay and the expression and transcription of poly (ADP-ribose) polymerase 1 (PARP1, a key sensor of DNA damage and regulator of repair mechanisms). In addition, some cultures were also treated with 3-aminobenzamide (3-AB), a potent inhibitor of PARP1. Each condition was tested in three independent experiments. No effects were detected after RF exposure alone in terms of comet, while an increase of PARP1 gene and protein expression was recorded (p<0.05). At variance, in cultures exposed to RF and gamma radiation a decrease in DNA damage was detected compared to cultures exposed to gamma radiation alone (P<0.01), indicating induction of adaptive response. Such a decrease was negated when cells were also treated with 3-AB.
Although the results are very interesting and consistent, it has to be pointed out that the description of the RF exposure system and dosimetry does not completely fullfill the good quality criteria.

4.4.2. Genotoxicity
Genotoxicity and co-genotoxicity have also been addressed by three research groups.

In at least three independent experiments, Herrala and co-workers (Herrala et al., 2018) exposed rat primary astrocytes to 872MHz GSM-modulated or continuous wave (CW) at SAR levels of 0.6 or 6.0 W/kg for 24 h. Cell cultures were also treated for 3 h with Menadione (MQ) and methyl methanesulfonate (MMS) after RF exposure. In addition, induced genomic instability (IGI) was evaluated at 36 days after RF exposure, alone (GSM-modulated) or combined with MQ. No genotoxic effects, evaluated as DNA migration and chromosomal damage, were induced by RF exposure alone. Combined treatments induced increased DNA damage at 6.0 W/kg (p< 0.05) and decreased DNA damage at 0.6 W/kg (p< 0.001) when cells were exposed to GSM-modulated RF radiation and MQ, and increased micronucleus frequency in cells exposed to CW RF exposure at 0.6 W/kg and MMS (p< 0.01). IGI was not induced for all the experimental conditions considered.

Primary cultured neurogenic cells were employed by Su and co-workers to evaluate the effect of 1, 6 and 24 h exposure (5 min on/10 min off) to 1800 MHz, GSM, 4 W/kg SAR, on DNA damage and key cellular functions (Su et al., 2018). DNA damage was evaluated in terms of induction of gamma foci in astrocytes, microglia and cortical neurons; in addition, cytokines detection was evaluated in cultures of astrocytes and microglia and phagocytosis was assayed in microglia cells. In cortical neurons, morphological changes were evaluated at day 3 (axon morphology), day 7 (dendrites morphology) and day 14 (synapses density) through 14 days exposure/sham exposure, carried out 1h per day.
The results of three independent experiments showed that no effects of the RF exposure protocols were induced in all the cell type investigated, except for phagocytic activity in microglia, which resulted significantly decreased with respect to sham exposed controls (p< 0.05), and axon branch length and number in cortical neurons (p< 0.05).

Kohler et al. (2018) examined whether short- and long-term exposure to Terrestrial Trunked Radio (TETRA; carrier frequency: 395 MHz; pulse frequency: 17.64 Hz; differential quaternary phase-shift keying -π/4 DQPSK- modulation) could affect the functional activity of neuronal in vitro networks.

The experiments were performed in cryopreserved primary Sprague Dawley rat cortex neurons (E18); extracellular recordings were carried out by using a microelectrode array (MEA) system. Neither 15 min (1.17 W/kg, n=18; 2.21 W/kg, n=12), nor 18 days TETRA exposure (1.17 W/kg, n=8) affected the functionality of the neuronal network, in terms of spike rate, burst rate, burst duration and network synchrony, compared to sham controls (15 min: n=22; 18 days: n=10).

4.4.3. Oxidative stress

Two studies were carried out by the research group of Marjanovic Cermak to investigate the oxidative stress induced by exposure to 1800 MHz. In a first paper V79 cells were exposed for 10, 30 and 60 minutes at a calculated SAR of 1.6 W/Kg and impairment in cellular oxidation-reduction balance was measured immediately after RF exposure (Marjanovic Cermak et al., 2017). In three independent experiments, by comparing exposed and sham-exposed cultures, an increased level of superoxide radicals was detected after 60-min exposure together with higher glutathione (GSH) level after 10-min exposure ($P < 0.05$) and higher but not significant activity of GSH-Px. Lipid oxidative damage and alterations of cell viability were not detected.

In the further study (Marjanovic Cermak et al., 2018) human neuroblastoma cells (SH-SY5Y) were exposed for 10, 30 and 60 minutes in the same experimental conditions to evaluate Reactive Oxygen species (ROS) formation, lipid and protein oxidative damage, by means of malondialdehyde and protein carbonyls concentration, and antioxidant activity by means of total GSH content. For each exposure duration, the ROS level was higher in exposed samples compared to sham-exposed ones ($P < 0.05$). After 60 min of exposure, a significant lipid and protein damage was also detected ($P < 0.05$), and the highest GSH concentration was found after 10 min exposure ($P < 0.05$). Cell viability was unaffected.
In both studies the characteristics of the RF signal (continuous wave or modulation) are not reported.

4.4.4. Fertility

Three studies addressed the possible effects of RF exposure on fertility.

Suzuki et al. (2017) investigated the effects of 1950 MHz, WCDMA, on mice spermatozoa and oocytes exposed/sham-exposed to 2W/Kg for 1 h and evaluated rates of fertilization, embryogenesis (8-cell embryo, blastocyst), and chromosome aberration. In particular, they exposed spermatozoa and oocytes separately and fertilization was investigated by considering: a) exposed spermatozoa/not exposed oocytes; b) exposed oocytes/not exposed spermatozoa; c) exposed spermatozoa and oocytes; d) not exposed spermatozoa and oocytes. The results, obtained on 5 to 6 batches of cells indicated no effect of RF exposure for all the parameter investigated and for all the conditions tested.

Lin et al. (2017) exposed mouse Leydig cells to 1950 MHz, GSM-talk, at 3 W/Kg for 24 h and measured proliferation, cell cycle, apoptosis, ROS formation and testosterone secretion at 0, 1, 2, 3, 4, and 5 days after exposure. Leydig cells are the interstitial testis cells with a crucial role for supporting spermatogenesis and male reproductive function, including testosterone secretion. For each endpoint, the experiments were conducted in triplicate. By comparing exposed and sham-exposed cultures, no differences were found in terms of ROS formation and apoptosis. On th other hand, a reduction in cell proliferation at 3, 4 and 5 days after RF exposure ($p < 0.01$) and an arrest in S phase of the cell cycle at all time-points after exposure ($p < 0.05$) was detected. Testosterone content was decreased in the supernatant (day 1, 2 and 4 after exposure) and in the cell lysate (day 1 and 2) ($p < 0.05$ vs. sham). In addition, the mRNA expression level of the steroidogenic acute regulatory protein (StAR) and of the cholesterol side-chain cleavage enzyme (P450scc) also resulted decreased, although differences between the exposed and sham-exposed group resulted significant only for P450scc from day 2 to day 5 following exposure ($p < 0.05$).

In the study by Zhang et al. (2017d) mouse spermatocyte-derived (GC-1) cells were exposed for 24 h to 1950 MHz, 3 W/kg SAR, in presence and in absence of 6 Gy X-ray, delivered after RF exposure, to evaluate apoptosis at day 3 and cell proliferation at days 1, 2, 3 and 4 after treatments. In at least three independent experiments, no effect was detected after RF exposure alone with respect to sham-exposed samples but, compared with the X-ray group, the proliferation level significantly decreased at days 2 to 4 ($p < 0.05$) and the apoptotic rate significantly increased ($p < 0.01$) in the RF+X-ray group. The authors also showed the involvement of B-cell lymphoma-2 (Bcl-2) and Bcl-2 associated X protein (Bax) expression in the observed effect ($p < 0.05$).

4.4.5. Other cellular endpoints

In a study carried out by Soubere Mahamoud et al. (2016) the microarray-based approach was used to analyse modifications of the whole genome and to evaluate the effect on cell metabolism, the ATP content in human keratinocytes exposed for 3 h at 60.4 GHz MMW at 20 mW/cm². In addition, they tested the effect of co-exposures with a glycolysis-inhibitor, 2-deoxyglucose (2dG) for 3 h.
The results from four to six independent experiments indicated that the MMW exposure alone did not induce modification compared to sham-exposed samples. Co-exposure with 2dG did not alter the ATP content, but a slight alteration in the transcriptome was detected (P<0.05). In particular, six genes were identified, involved in the cytokine pathway. The authors stressed the importance of investigating the impact of MMW-long term or chronic exposure on metabolically stressed cells.

4.4.6. Summary and conclusions for cell studies

Also in this period a large number of papers have been published on the effect of RF on cell cultures, given alone or in combination with other chemical or physical agents but about 50% of them have not been included in the analysis due to scanty quality criteria of the research. Most of the studies considered do not indicate effects of RF exposure. In addition, they confirm that RF is able to modify (by increasing or decreasing) the effect induced by chemical or physical agents.

Table 4.4.1. *In vitro* studies on exposure to RF fields

Cell type	Endpoint	Exposure conditions	Effect	References
Chinese Hamster lung fibroblast cell line (V79)	MN frequency	1950 MHz, UMTS 0.15, 0.3, 0.6, 1.25 W/Kg 20 h Co-exposure with MMC	Increased MN frequency in cells exposed at 0.15 and 0.3 W/Kg; Reduced MMC-induced MN in cells pre-exposed to 1.25 W/Kg	Sannino et al. (2017)
Mouse bone marrow stromal cells	DNA migration, PARP1 expression	900 MHz 0.41 mW/kg 3 h per day for five days. Co-exposure with 1.5 Gy gamma radiation	No effects on DNA migration. Increased PARP1 gene and protein expression. Reduced gamma radiation-induced DNA migration; such reduction was negated in cultures treated with 3-AB.	He et al., (2017)
Rat primary astrocytes	DNA migration, MN frequency, IGI	872MHz, GSM, CW 0.6, 6 W/kg 24 h Co-exposure with MQ or MMS	No effect of RF alone. Increased DNA damage at 6.0 W/kg and decreased DNA damage at 0.6 W/kg in cells co-exposed to GSM and MQ; increased MN frequency in cells co-exposed to CW at 0.6 W/kg and MMS	Herrala et al. (2017)
astrocytes, microglia and cortical neurons	Gamma foci, cytokines, phagocytosis, morphological changes	1800 MHz, GSM 4 W/kg 1, 6, 24 h; 1h/day for 7 days (5 min on/10 min off cycles)	No effect on Gamma foci and cytokines. Reduced phagocytotic activity of microglia; inhibited axon branch length and number of cortical neurons.	Su et al. (2018)

Primary rat cortex neurons from Sprague Dawley rat cortex	spike rate, burst rate, burst duration and network synchrony	395 MHz, TETRA, carrier frequency; pulse frequency 17.64 Hz; differential quaternary phase-shift keying -π/4 DQPSK-modulation; 1.17 or 2.21 W/kg: 15 min 1.17 W/kg: 18 days	No effects	Kohler et al., (2018)
Chinese Hamster lung fibroblast cell line (V79)	Oxidative stress, cell viability	1800 MHz, 1.6 W/Kg 10, 30, 60 min	Increased level of superoxide radicals and GSH; no effects on lipid oxidative damage cell viability	Marjanovic Cermak et al. (2017)
human neuroblastoma cells (SH-SY5Y)	Oxidative stress, cell viability	1800 MHz, 1.6 W/Kg 10, 30, 60 min	Increased ROS formation and lipid and protein damage after 60 min exposure; increased GSH concentration after 10 min exposure). No effects on cell viability.	Marjanovic Cermak et al. (2018)
Mouse spermatozoa and oocytes	Fertilization, embryogenesis and chromosomal aberration	1950 MHz, WCDMA 2 W/Kg 1 h	No effect	Suzuki et al. (2017)
Mouse Leydig cells	Proliferation, cell cycle, apoptosis, ROS formation and testosterone secretion measured 0, 1, 2, 3, 4, and 5 days after exposure	1950 MHz, GSM-talk 3 W/Kg 24 h	No effect on ROS formation and apoptosis. Reduced cell proliferation at 3, 4 and 5 days after RF and arrest in S phase at all time-points after exposure. Decreased testosterone content and mRNA expression of P450scc from day 2 to day 5 after exposure.	Lin et al. (2017)
mouse spermatocyte-derived cells (GC-1)	Proliferation, apoptosis	1950 MHz, UMTS 3 W/Kg 24 h Co-exposure: 6 Gy X-rays	No effect of RF alone. Increased X-ray induced apoptosis and decreased X-ray induced proliferation rate	Zhang et al. (2017)
human keratinocytes	modifications of the whole genome and ATP content	60.4 GHz, 20 mW/cm2 3 h Co-exposure: 2dG	No effects of MMW alone; Co-exposure induces a slight alteration in the transcriptome; no effect on ATP.	Soubere Mahamoud et al. (2016)

Abbreviations: 2dg: 2-deoxyglucose; 3-AB: 3-aminobenzamide; ATP: ATP: adenosine triphosphate acid; GSH: glutathione; GSM: Global System for Mobile Communication; IGI: induced genomic instability; MMC: mitomycin-C; MMS: methyl methanesulfonate; MMW: millimeter waves; MN: micronuclei; MQ: menadione; P450scc: cholesterol side-chain cleavage enzyme; PARP1: poly(ADP-ribose) polymerase 1; ROS: Reactive oxygen species; TETRA: Terrestrial Trunked Radio; UMTS: universal mobile telecommunications system; differential quaternary phase-shift keying -π/4 DQPSK- modulation; W-CDMA: Wideband Code Division Multiple Access

5. Recent expert reports

This chapter briefly summarizes two expert reports published since the previous Council report. The summaries are directly edited from the executive summaries of these reports. The Council do not evaluate or comment any of the reports.

5.1. Power Lines and Health, Part I: childhood cancer.

Health Council of the Netherlands: Power Lines and Health, Part 1: childhood cancer, The Hague, The Netherlands, 2018, Publication 2018/08.

Indications that the risk of getting childhood leukaemia is higher in children living near high voltage power lines than in other children exist for some time. It is possible that there is an association with the magnetic fields generated by the power lines. The Health Council concludes from the currently available data that a causal relation with magnetic fields has not been proven, but that there are indications for such relation. It remains therefore necessary to continue the precautionary policy with high voltage power lines. The council gives the state secretary for Infrastructure and Water Management into consideration to expand the precautionary policy to underground electricity cables and other sources of prolonged exposure to magnetic fields from the electricity grid, because magnetic fields are not blocked by soil and building materials.

Summary
In the Netherlands, on average approximately 135 new cases of childhood leukaemia are diagnosed each year. There are indications that the risk of getting this disease is twice as high in children living near overhead power lines than in other children. This means that one case of childhood leukaemia every two years may be associated with the presence of overhead power lines. Exposure to the magnetic fields generated by the power lines could be responsible for this, although other (unknown) factors and chance cannot be excluded. Motivated by a Health Council report published in 2000, the Netherlands Government recommends local and provincial authorities and electric power transport companies to apply a precautionary policy. The aim is to prevent as much as possible that new situations will arise with long-term exposure of children to magnetic fields from overhead high-voltage power lines that exceed an annual average level of 0.4 microtesla.

Childhood leukaemia
Overall, the results indicate an increasing risk of childhood leukaemia with decreasing distance and increasing magnetic field strength. The risk estimate is higher when the magnetic field strength is assessed more accurately. The most representative exposure estimate is the assessment of the magnetic field strength in all residences of a child between birth and diagnosis. Based on these data, the estimated leukaemia risk seems to be more than two and a half times higher in children that have been long-term exposed to an average magnetic field strength of 0.3 to 0.4 microtesla or higher compared to children that are exposed at background level. There is considerable uncertainty in this risk estimate, but the Committee considers it highly unlikely that in reality there is no increased risk.

These new analyses confirm the earlier conclusions of the Health Council.

Other types of cancer
For other types of cancer in children only data are available on brain tumours and lymphomas. Only for brain tumours sufficient data are available to carry out analyses. In studies using distance as a measure of exposure, no indications for a association with brain cancer in children have been found. In studies using the magnetic field strength as an exposure metric, the risk of brain cancer seems almost 1.5 times higher in children that have been long-term exposed in their homes to magnetic field strengths averaging 0.4 microtesla or more. There is considerable uncertainty in this risk estimate and

the Committee considers it more likely that the increase is a chance finding than in the case of leukaemia.

Conclusions
The analyses of the Committee provide indications of an association between exposure to magnetic fields around overhead power lines and the incidence of childhood leukaemia and possibly brain tumours. When the results are summarized in terms of the framework for assessing causality of the US Environmental Protection Agency, the Committee concludes that they are 'suggestive of a causal relationship' between magnetic field exposure and both leukaemia and brain tumours. However, the indications are weaker for brain tumours than for leukaemia. For both cancer types there is insufficient evidence for the qualification of a 'likely' or 'proven causal relationship', also because there is no supporting evidence from animal studies.

Regarding the risk of childhood lymphomas, there is insufficient data to infer on causality.

An influence of other factors that are associated with the presence of overhead power lines cannot be excluded. However, this has not been shown in research to date. It can also not be excluded that the observations, in particular those concerning brain tumours, are chance findings.

Recommendations
The current scientific knowledge does not give the Committee reason to recommend the State Secretary for Infrastructure and Water Management to reconsider the current policy regarding overhead power lines. Since there are indications for a causal relationship between exposure to magnetic fields and increased risks of childhood leukaemia and brain tumours, and magnetic fields are not blocked by soil or construction materials, the Committee suggests the State Secretary from a public health perspective to consider extending the precautionary policy to underground power cables and other sources of long-term exposure to magnetic fields from the electricity grid, such as transformer stations and transformer houses.

5.2. OPINION of the French Agency for Food, Environmental and Occupational Health & Safety regarding the expert appraisal on "electromagnetic hypersensitivity (EHS) or idiopathic environmental intolerance attributed to electromagnetic fields (IEI-EMF)"

ANSES Opinion Request No 2011-SA-0150, 13 March 2018

https://www.anses.fr/en/system/files/AP2011SA0150EN.pdf

ANSES's conclusions and recommendations
First of all, regarding the exposure of individuals to electromagnetic fields, ANSES reiterates the recommendation it formulated in its Opinion of October 2013 on the exposure of individuals to electromagnetic fields: "Considering the current or future deployment of new mobile communication technologies […], in parallel with the existing services, and the uncertainties concerning the long-term effects of exposure to radiofrequencies, the Agency emphasises the need for these technological developments to go hand in hand with limitation of individual exposure, whether exposure is environmental or related to devices".

Regarding the need to undertake a collective expertise appraisal on the topic of EHS, ANSES reiterates that in its Opinion of October 2013 it indicated that: "Considering on the one hand the

number of recent publications and the expected publication of results from on-going studies, and on the other, the need to grant particular attention to the issue of hypersensitivity to electromagnetic waves, ANSES decided to postpone assessment of this issue, to be dealt with in a special report by the Working Group".

With regard to this expert appraisal, the Agency endorses the conclusions and recommendations of its Expert Committee on Physical agents, new technologies and development areas, set out above (see Section 3).

It reiterates that this expert appraisal was undertaken between 2014 and 2017 by a dedicated multidisciplinary working group, together with the Expert Committee on "Physical agents, new technologies and development areas". This expert appraisal work drew on all the available scientific literature, as well as on numerous hearings with hospital and general practitioners, researchers and associations, in connection with electrohypersensitive (EHS) individuals. The Agency underlines the fact that the expert appraisal report was available for public consultation between July and October 2016 and that it takes into account the numerous comments (more than 500) collected. This made it possible, among other things, to supplement the references and enhance several parts of the report (see Annex 17 on the review of the consultation and the main changes made to the report, as well as the table of responses to the comments in the electronic Annex).

The expert appraisal showed the great complexity of the issue of electrohypersensitivity. First of all, there are currently no validated diagnostic criteria for EHS, and the expert appraisal found that it is only possible to define EHS on the basis of self-reporting by people. In the end, in the current state of knowledge, there is no solid experimental evidence enabling a causal relationship to be established between exposure to electromagnetic fields and the symptoms described by EHS individuals. However, the Agency emphasises that the complaints (pain, suffering) expressed by EHS individuals are a reality of life and that they have to adapt their daily lives to cope with it.

The symptoms experienced by EHS individuals, as well as the psycho-social isolation suffered by some of them, require and justify the provision of suitable care by health and social service professionals (see the CES's recommendations for health and social service professionals). As such, the Agency underlines the relevance of asking the French National Authority for Health to investigate guidelines on the care of EHS individuals intended for health professionals. In particular, the Agency recommends developing training for health and social service professionals in supporting and counselling EHS individuals, as well as taking their questions and expectations into account in their practices, especially in terms of quality of life. In addition, the Agency stresses the need to continue research work on EHS, in accordance with the following recommendations:

• strengthen interactions between scientists and associations of EHS individuals (see recommendations for research institutions and organisations);

• support the establishment of research infrastructures suitable for investigating EHS, mainly in order to conduct long-term follow-up studies, while ensuring that the experimental conditions are controlled and take into account the circumstances of EHS individuals;

• continue financing research work, in particular fundamental research, on the health effects of radiofrequencies (see recommendations for the public authorities).

References

AMOON, A. T., OKSUZYAN, S., CRESPI, C. M., ARAH, O. A., COCKBURN, M., VERGARA, X. & KHEIFETS, L. 2018. Residential mobility and childhood leukemia. *Environ Res,* 164**,** 459-466.

ANDRIANOME, S., GOBERT, J., HUGUEVILLE, L., STEPHAN-BLANCHARD, E., TELLIEZ, F. & SELMAOUI, B. 2017. An assessment of the autonomic nervous system in the electrohypersensitive population: a heart rate variability and skin conductance study. *J Appl Physiol (1985),* 123**,** 1055-1062.

ASLAN, A., IKINCI, A., BAS, O., SONMEZ, O. F., KAYA, H. & ODACI, E. 2017. Long-term exposure to a continuous 900 MHz electromagnetic field disrupts cerebellar morphology in young adult male rats. *Biotech Histochem,* 92**,** 324-330.

BABY, N. M., KOSHY, G. & MATHEW, A. 2017. The Effect of Electromagnetic Radiation due to Mobile Phone Use on Thyroid Function in Medical Students Studying in a Medical College in South India. *Indian J Endocrinol Metab,* 21**,** 797-802.

BALDI, I., COUREAU, G., JAFFRE, A., GRUBER, A., DUCAMP, S., PROVOST, D., LEBAILLY, P., VITAL, A., LOISEAU, H. & SALAMON, R. 2011. Occupational and residential exposure to electromagnetic fields and risk of brain tumors in adults: a case-control study in Gironde, France. *Int J Cancer,* 129**,** 1477-84.

BHATT, C. R., BENKE, G., SMITH, C. L., REDMAYNE, M., DIMITRIADIS, C., DALECKI, A., MACLEOD, S., SIM, M. R., CROFT, R. J., WOLFE, R., KAUFMAN, J. & ABRAMSON, M. J. 2017. Use of mobile and cordless phones and change in cognitive function: a prospective cohort analysis of Australian primary school children. *Environ Health,* 16**,** 62.

BIRKS, L., GUXENS, M., PAPADOPOULOU, E., ALEXANDER, J., BALLESTER, F., ESTARLICH, M., GALLASTEGI, M., HA, M., HAUGEN, M., HUSS, A., KHEIFETS, L., LIM, H., OLSEN, J., SANTA-MARINA, L., SUDAN, M., VERMEULEN, R., VRIJKOTTE, T., CARDIS, E. & VRIJHEID, M. 2017. Maternal cell phone use during pregnancy and child behavioral problems in five birth cohorts. *Environ Int,* 104**,** 122-131.

BODERA, P., MAKAROVA, K., ZAWADA, K., ANTKOWIAK, B., PALUCH, M., SOBICZEWSKA, E., SIRAV, B., SIWICKI, A. K. & STANKIEWICZ, W. 2017. The effect of 1800MHz radio-frequency radiation on NMDA receptor subunit NR1 expression and peroxidation in the rat brain in healthy and inflammatory states. *Biomed Pharmacother,* 92**,** 802-809.

BONGERS, S., SLOTTJE, P. & KROMHOUT, H. 2018. Development of hypertension after long-term exposure to static magnetic fields among workers from a magnetic resonance imaging device manufacturing facility. *Environ Res,* 164**,** 565-573.

BONGERS, S., SLOTTJE, P., PORTENGEN, L. & KROMHOUT, H. 2016. Exposure to static magnetic fields and risk of accidents among a cohort of workers from a medical imaging device manufacturing facility. *Magn Reson Med,* 75**,** 2165-74.

BORTKIEWICZ, A. 2017. Erratum to Bortkiewicz et al. "Mobile phone use and risk for intracranial tumors and salivary gland tumors - A meta-analysis" (Int J Occup Med Environ Health 2017;30(1):27-43). *Int J Occup Med Environ Health,* 30**,** 685.

BORTKIEWICZ, A., GADZICKA, E. & SZYMCZAK, W. 2017. Mobile phone use and risk for intracranial tumors and salivary gland tumors - A meta-analysis. *Int J Occup Med Environ Health,* 30**,** 27-43.

BUA, L., TIBALDI, E., FALCIONI, L., LAURIOLA, M., DE ANGELIS, L., GNUDI, F., MANSERVIGI, M., MANSERVISI, F., MANZOLI, I., MENGHETTI, I., MONTELLA, R., PANZACCHI, S., SGARGI, D., STROLLO, V., VORNOLI, A., MANDRIOLI, D. & BELPOGGI, F. 2018. Results of lifespan exposure to continuous and intermittent extremely low frequency electromagnetic fields (ELFEMF) administered alone to Sprague Dawley rats. *Environ Res,* 164**,** 271-279.

CARLBERG, M., KOPPEL, T., AHONEN, M. & HARDELL, L. 2017. Case-control study on occupational exposure to extremely low-frequency electromagnetic fields and glioma risk. *Am J Ind Med,* 60**,** 494-503.

CARLBERG, M., KOPPEL, T., AHONEN, M. & HARDELL, L. 2018. Case-Control Study on Occupational Exposure to Extremely Low-Frequency Electromagnetic Fields and the Association with Meningioma. *Biomed Res Int,* 2018**,** 5912394.

CHOI, K. H., HA, M., HA, E. H., PARK, H., KIM, Y., HONG, Y. C., LEE, A. K., HWA KWON, J., CHOI, H. D., KIM, N., KIM, S. & PARK, C. 2017. Neurodevelopment for the first three years following prenatal mobile phone use, radio frequency radiation and lead exposure. *Environ Res,* 156**,** 810-817.

CONSALES, C., CIROTTI, C., FILOMENI, G., PANATTA, M., BUTERA, A., MERLA, C., LOPRESTO, V., PINTO, R., MARINO, C. & BENASSI, B. 2017. Fifty-Hertz Magnetic Field Affects the Epigenetic Modulation of the miR-34b/c in Neuronal Cells. *Mol Neurobiol*.

CURCIO, G. 2018. Exposure to Mobile Phone-Emitted Electromagnetic Fields and Human Attention: No Evidence of a Causal Relationship. *Front Public Health,* 6**,** 42.

DALECKI, A., LOUGHRAN, S. P., VERRENDER, A., BURDON, C. A., TAYLOR, N. A. S. & CROFT, R. J. 2018. Does acute radio-frequency electromagnetic field exposure affect visual event-related potentials in healthy adults? *Clin Neurophysiol,* 129**,** 901-908.

DAVARPANAH JAZI, S., MODOLO, J., BAKER, C., VILLARD, S. & LEGROS, A. 2017. Effects of A 60 Hz Magnetic Field of Up to 50 milliTesla on Human Tremor and EEG: A Pilot Study. *Int J Environ Res Public Health,* 14.

DAWSON, B. V., ROBERTSON, I. G., WILSON, W. R., ZWI, L. J., BOYS, J. T. & GREEN, A. W. 1998. Evaluation of potential health effects of 10 kHz magnetic fields: a rodent reproductive study. *Bioelectromagnetics,* 19**,** 162-71.

DERKACZ, A., GAWRYS, J., GAWRYS, K., PODGORSKI, M., MAGOTT-DERKACZ, A., POREBA, R. & DOROSZKO, A. 2018. Effect of electromagnetic field accompanying the magnetic resonance imaging on human heart rate variability - a pilot study. *Int J Inj Contr Saf Promot,* 25**,** 229-231.

DURUSOY, R., HASSOY, H., OZKURT, A. & KARABABA, A. O. 2017. Mobile phone use, school electromagnetic field levels and related symptoms: a cross-sectional survey among 2150 high school students in Izmir. *Environ Health,* 16**,** 51.

ERDEM, O., AKAY, C., CEVHER, S. C., CANSEVEN, A. G., AYDIN, A. & SEYHAN, N. 2018. Effects of Intermittent and Continuous Magnetic Fields on Trace Element Levels in Guinea Pigs. *Biol Trace Elem Res,* 181**,** 265-271.

ERTILAV, K., USLUSOY, F., ATAIZI, S. & NAZIROGLU, M. 2018a. Long term exposure to cell phone frequencies (900 and 1800 MHz) induces apoptosis, mitochondrial oxidative stress and TRPV1 channel activation in the hippocampus and dorsal root ganglion of rats. *Metab Brain Dis*.

ERTILAV, K., USLUSOY, F., ATAIZI, S. & NAZIROGLU, M. 2018b. Long term exposure to cell phone frequencies (900 and 1800 MHz) induces apoptosis, mitochondrial oxidative stress and TRPV1 channel activation in the hippocampus and dorsal root ganglion of rats. *Metab Brain Dis,* 33**,** 753-763.

FALCIONI, L., BUA, L., TIBALDI, E., LAURIOLA, M., DE ANGELIS, L., GNUDI, F., MANDRIOLI, D., MANSERVIGI, M., MANSERVISI, F., MANZOLI, I., MENGHETTI, I., MONTELLA, R., PANZACCHI, S., SGARGI, D., STROLLO, V., VORNOLI, A. & BELPOGGI, F. 2018. Report of final results regarding brain and heart tumors in Sprague-Dawley rats exposed from prenatal life until natural death to mobile phone radiofrequency field representative of a 1.8GHz GSM base station environmental emission. *Environ Res*.

FALONE, S., SANTINI, S., JR., CORDONE, V., CESARE, P., BONFIGLI, A., GRANNONICO, M., DI EMIDIO, G., TATONE, C., CACCHIO, M. & AMICARELLI, F. 2017. Power frequency magnetic field promotes a more malignant phenotype in neuroblastoma cells via redox-related mechanisms. *Sci Rep,* 7**,** 11470.

FATHI, E. & FARAHZADI, R. 2017. Zinc Sulphate Mediates the Stimulation of Cell Proliferation of Rat Adipose Tissue-Derived Mesenchymal Stem Cells Under High Intensity of EMF Exposure. *Biol Trace Elem Res*.

FORSSEN, U. M., MEZEI, G., NISE, G. & FEYCHTING, M. 2004. Occupational magnetic field exposure among women in Stockholm County, Sweden. *Occup Environ Med,* 61**,** 594-602.

GOKCEK-SARAC, C., ER, H., KENCEBAY MANAS, C., KANTAR GOK, D., OZEN, S. & DERIN, N. 2017. Effects of acute and chronic exposure to both 900 MHz and 2100 MHz electromagnetic radiation on glutamate receptor signaling pathway. *Int J Radiat Biol,* 93**,** 980-989.

GONZALEZ-RUBIO, J., ARRIBAS, E., RAMIREZ-VAZQUEZ, R. & NAJERA, A. 2017. Radiofrequency electromagnetic fields and some cancers of unknown etiology: An ecological study. *Sci Total Environ,* 599-600**,** 834-843.

HARDELL, L. & CARLBERG, M. 2017. Mobile phones, cordless phones and rates of brain tumors in different age groups in the Swedish National Inpatient Register and the Swedish Cancer Register during 1998-2015. *PLoS One,* 12**,** e0185461.

HE, Q., ZONG, L., SUN, Y., VIJAYALAXMI, PRIHODA, T. J., TONG, J. & CAO, Y. 2017. Adaptive response in mouse bone marrow stromal cells exposed to 900MHz radiofrequency fields: Impact of poly (ADP-ribose) polymerase (PARP). *Mutat Res,* 820**,** 19-25.

HERRALA, M., MUSTAFA, E., NAARALA, J. & JUUTILAINEN, J. 2018. Assessment of genotoxicity and genomic instability in rat primary astrocytes exposed to 872 MHz radiofrequency radiation and chemicals. *Int J Radiat Biol***,** 1-7.

HEUSER, G. & HEUSER, S. A. 2017a. Corrigendum to: Functional brain MRI in patients complaining of electrohypersensitivity after long term exposure to electromagnetic fields. *Rev Environ Health,* 32**,** 379-380.

HEUSER, G. & HEUSER, S. A. 2017b. Functional brain MRI in patients complaining of electrohypersensitivity after long term exposure to electromagnetic fields. *Rev Environ Health,* 32**,** 291-299.

HINRIKUS, H., BACHMANN, M., KARAI, D. & LASS, J. 2017. Mechanism of low-level microwave radiation effect on nervous system. *Electromagn Biol Med,* 36**,** 202-212.

HONG, I., GARRETT, A., MAKER, G., MULLANEY, I., RODGER, J. & ETHERINGTON, S. J. 2018. Repetitive low intensity magnetic field stimulation in a neuronal cell line: a metabolomics study. *PeerJ,* 6**,** e4501.

HUANG, P-C., CHENG, M-T. & GUO, H-R. 2018. Representative survey on idiopathic environmental intolerance attributed to electromagnetic fields in Taiwan and comparison with the international literature. *Environ Health,* 17:5

HUSS, A., PETERS, S. & VERMEULEN, R. 2018a. Occupational exposure to extremely low-frequency magnetic fields and the risk of ALS: A systematic review and meta-analysis. *Bioelectromagnetics,* 39**,** 156-163.

HUSS, A., SCHAAP, K. & KROMHOUT, H. 2017. MRI-related magnetic field exposures and risk of commuting accidents - A cross-sectional survey among Dutch imaging technicians. *Environ Res,* 156**,** 613-618.

HUSS, A., SCHAAP, K. & KROMHOUT, H. 2018b. A survey on abnormal uterine bleeding among radiographers with frequent MRI exposure using intrauterine contraceptive devices. *Magn Reson Med,* 79**,** 1083-1089.

HUSS, A., SPOERRI, A., EGGER, M., KROMHOUT, H. & VERMEULEN, R. 2018c. Occupational extremely low frequency magnetic fields (ELF-MF) exposure and hematolymphopoietic cancers - Swiss National Cohort analysis and updated meta-analysis. *Environ Res,* 164**,** 467-474.

JADIDI, M., KHATAMI, M. S., MOHAMMAD-POUR, F., BANDAVI, A., RASHIDY-POUR, A., VAFAEI, A. A., TAHERIAN, A. A. & MILADI-GORJI, H. 2017. Effects of extremely low frequency magnetic field on the development of tolerance to the analgesic effect of morphine in rats. *Bioelectromagnetics,* 38**,** 618-625.

JALILIAN, H., TESHNIZI, S. H., ROOSLI, M. & NEGHAB, M. 2017. Occupational exposure to extremely low frequency magnetic fields and risk of Alzheimer disease: A systematic review and meta-analysis. *Neurotoxicology.*

KARVALA, K., SAINIO, M., PALMQUIST, E., NYBACK, M. H. & NORDIN, S. 2018. Prevalence of various environmental intolerances in a Swedish and Finnish general population. *Environ Res,* 161**,** 220-228.

KERIMOGLU, G., GUNEY, C., ERSOZ, S. & ODACI, E. 2018. A histopathological and biochemical evaluation of oxidative injury in the sciatic nerves of male rats exposed to a continuous 900-

megahertz electromagnetic field throughout all periods of adolescence. *J Chem Neuroanat,* 91**,** 1-7.

KHAN, M. W., ROIVAINEN, P., HERRALA, M., TIIKKAJA, M., SALLMEN, M., HIETANEN, M. & JUUTILAINEN, J. 2018. A pilot study on the reproductive risks of maternal exposure to magnetic fields from electronic article surveillance systems. *Int J Radiat Biol***,** 1-7.

KHEIFETS, L., CRESPI, C. M., HOOPER, C., COCKBURN, M., AMOON, A. T. & VERGARA, X. P. 2017. Residential magnetic fields exposure and childhood leukemia: a population-based case-control study in California. *Cancer Causes Control,* 28**,** 1117-1123.

KHEIFETS, L., MONROE, J., VERGARA, X., MEZEI, G. & AFIFI, A. A. 2008. Occupational electromagnetic fields and leukemia and brain cancer: an update to two meta-analyses. *J Occup Environ Med,* 50**,** 677-88.

KHOSHROO, M. M., MEHRJAN, M. S., SAMIEE, F., SOLTANI, M. & SHEKARABI, S. P. H. 2018. Some immunological responses of common carp (Cyprinus carpio) fingerling to acute extremely low-frequency electromagnetic fields (50 Hz). *Fish Physiol Biochem,* 44**,** 235-243.

KIM, J. H., KIM, H. J., YU, D. H., KWEON, H. S., HUH, Y. H. & KIM, H. R. 2017a. Changes in numbers and size of synaptic vesicles of cortical neurons induced by exposure to 835 MHz radiofrequency-electromagnetic field. *PLoS One,* 12**,** e0186416.

KIM, J. H., SOHN, U. D., KIM, H. G. & KIM, H. R. 2018a. Exposure to 835 MHz RF-EMF decreases the expression of calcium channels, inhibits apoptosis, but induces autophagy in the mouse hippocampus. *Korean J Physiol Pharmacol,* 22**,** 277-289.

KIM, J. H., YU, D. H., HUH, Y. H., LEE, E. H., KIM, H. G. & KIM, H. R. 2017b. Long-term exposure to 835 MHz RF-EMF induces hyperactivity, autophagy and demyelination in the cortical neurons of mice. *Sci Rep,* 7**,** 41129.

KIM, J. H., YU, D. H., KIM, H. J., HUH, Y. H., CHO, S. W., LEE, J. K., KIM, H. G. & KIM, H. R. 2018b. Exposure to 835 MHz radiofrequency electromagnetic field induces autophagy in hippocampus but not in brain stem of mice. *Toxicol Ind Health,* 34**,** 23-35.

KOEMAN, T., SLOTTJE, P., SCHOUTEN, L. J., PETERS, S., HUSS, A., VELDINK, J. H., KROMHOUT, H., VAN DEN BRANDT, P. A. & VERMEULEN, R. 2017. Occupational exposure and amyotrophic lateral sclerosis in a prospective cohort. *Occup Environ Med,* 74**,** 578-585.

KOHLER, T., WOLFEL, M., CIBA, M., BOCHTLER, U. & THIELEMANN, C. 2018. Terrestrial Trunked Radio (TETRA) exposure of neuronal in vitro networks. *Environ Res,* 162**,** 1-7.

KOZIOROWSKA, A., ROMEROWICZ-MISIELAK, M., SOLEK, P. & KOZIOROWSKI, M. 2018. Extremely low frequency variable electromagnetic fields affect cancer and noncancerous cells in vitro differently: Preliminary study. *Electromagn Biol Med,* 37**,** 35-42.

KUMARI, K., CAPSTICK, M., CASSARA, A. M., HERRALA, M., KOIVISTO, H., NAARALA, J., TANILA, H., VILUKSELA, M. & JUUTILAINEN, J. 2017a. Effects of intermediate frequency magnetic fields on male fertility indicators in mice. *Environ Res,* 157**,** 64-70.

KUMARI, K., KOIVISTO, H., CAPSTICK, M., NAARALA, J., VILUKSELA, M., TANILA, H. & JUUTILAINEN, J. 2018. Behavioural phenotypes in mice after prenatal and early postnatal exposure to intermediate frequency magnetic fields. *Environ Res,* 162**,** 27-34.

KUMARI, K., KOIVISTO, H., VILUKSELA, M., PALDANIUS, K. M. A., MARTTINEN, M., HILTUNEN, M., NAARALA, J., TANILA, H. & JUUTILAINEN, J. 2017b. Behavioral testing of mice exposed to intermediate frequency magnetic fields indicates mild memory impairment. *PLoS One,* 12**,** e0188880.

KUZAY, D., OZER, C., SIRAV, B., CANSEVEN, A. G. & SEYHAN, N. 2017. Oxidative effects of extremely low frequency magnetic field and radio frequency radiation on testes tissues of diabetic and healthy rats. *Bratisl Lek Listy,* 118**,** 278-282.

LAMETH, J., GERVAIS, A., COLIN, C., LEVEQUE, P., JAY, T. M., EDELINE, J. M. & MALLAT, M. 2017. Acute Neuroinflammation Promotes Cell Responses to 1800 MHz GSM Electromagnetic Fields in the Rat Cerebral Cortex. *Neurotox Res,* 32**,** 444-459.

LI, D. K., CHEN, H. & ODOULI, R. 2011. Maternal exposure to magnetic fields during pregnancy in relation to the risk of asthma in offspring. *Arch Pediatr Adolesc Med,* 165**,** 945-50.

LI, D. K., ODOULI, R., WI, S., JANEVIC, T., GOLDITCH, I., BRACKEN, T. D., SENIOR, R., RANKIN, R. & IRIYE, R. 2002. A population-based prospective cohort study of personal

exposure to magnetic fields during pregnancy and the risk of miscarriage. *Epidemiology,* 13**,** 9-20.

LI, J. H., JIANG, D. P., WANG, Y. F., YAN, J. J., GUO, Q. Y., MIAO, X., LANG, H. Y., XU, S. L., LIU, J. Y. & GUO, G. Z. 2017. Influence of electromagnetic pulse on the offspring sex ratio of male BALB/c mice. *Environ Toxicol Pharmacol,* 54**,** 155-161.

LIN, Y. Y., WU, T., LIU, J. Y., GAO, P., LI, K. C., GUO, Q. Y., YUAN, M., LANG, H. Y., ZENG, L. H. & GUO, G. Z. 2017. 1950MHz Radio Frequency Electromagnetic Radiation Inhibits Testosterone Secretion of Mouse Leydig Cells. *Int J Environ Res Public Health,* 15.

MANSER, M., SATER, M. R., SCHMID, C. D., NOREEN, F., MURBACH, M., KUSTER, N., SCHUERMANN, D. & SCHAR, P. 2017. ELF-MF exposure affects the robustness of epigenetic programming during granulopoiesis. *Sci Rep,* 7**,** 43345.

MAO, L., WANG, H., MA, F., GUO, Z., HE, H., ZHOU, H. & WANG, N. 2017. Exposure to static magnetic fields increases insulin secretion in rat INS-1 cells by activating the transcription of the insulin gene and up-regulating the expression of vesicle-secreted proteins. *Int J Radiat Biol,* 93**,** 831-840.

MARJANOVIC CERMAK, A. M., PAVICIC, I., TARIBA LOVAKOVIC, B., PIZENT, A. & TROSIC, I. 2017. In vitro non-thermal oxidative stress response after 1800 MHz radiofrequency radiation. *Gen Physiol Biophys,* 36**,** 407-414.

MARJANOVIC CERMAK, A. M., PAVICIC, I. & TROSIC, I. 2018. Oxidative stress response in SH-SY5Y cells exposed to short-term 1800 MHz radiofrequency radiation. *J Environ Sci Health A Tox Hazard Subst Environ Eng,* 53**,** 132-138.

MARTENS, A. L., SLOTTJE, P., TIMMERMANS, D. R. M., KROMHOUT, H., REEDIJK, M., VERMEULEN, R. C. H. & SMID, T. 2017. Modeled and Perceived Exposure to Radiofrequency Electromagnetic Fields From Mobile-Phone Base Stations and the Development of Symptoms Over Time in a General Population Cohort. *Am J Epidemiol,* 186**,** 210-219.

MASTRODONATO, A., BARBATI, S. A., LEONE, L., COLUSSI, C., GIRONI, K., RINAUDO, M., PIACENTINI, R., DENNY, C. A. & GRASSI, C. 2018. Olfactory memory is enhanced in mice exposed to extremely low-frequency electromagnetic fields via Wnt/beta-catenin dependent modulation of subventricular zone neurogenesis. *Sci Rep,* 8**,** 262.

MIGAULT, L., PIEL, C., CARLES, C., DELVA, F., LACOURT, A., CARDIS, E., ZAROS, C., DE SEZE, R., BALDI, I. & BOUVIER, G. 2018. Maternal cumulative exposure to extremely low frequency electromagnetic fields and pregnancy outcomes in the Elfe cohort. *Environ Int,* 112**,** 165-173.

NANJANNAWAR, L. G., GIRME, T. S., AGRAWAL, J. M., AGRAWAL, M. S., FULARI, S. G., SHETTI, S. S. & KAGI, V. A. 2017. Effect of Mobile Phone Usage on Nickel Ions Release and pH of Saliva in Patients Undergoing Fixed Orthodontic Treatment. *J Clin Diagn Res,* 11**,** ZC84-ZC87.

NISHIMURA, I., OSHIMA, A., SHIBUYA, K., MITANI, T. & NEGISHI, T. 2012. Absence of reproductive and developmental toxicity in rats following exposure to a 20-kHz or 60-kHz magnetic field. *Regul Toxicol Pharmacol,* 64**,** 394-401.

NTP (2018a). Technical report on the toxicology and carcinogenesis studies in Hsd:Sprague Dawley SD rats exposed to whole-body radio frequency radiation at a frequency (900 MHz) and modulations (GSM and CDMA) used by cell phones., *National Toxicology Program; NTP TR 595.*

NTP (2018b). Technical report on the toxicology and carcinogenesis studies in B6C3F1/N mice exposed to whole-body radio frequency radiation at a frequency (1900 MHz) and modulations (GSM and CDMA) used by cell phones,. *National Toxicology Program; NTP TR 596.*

OBAJULUWA, A. O., AKINYEMI, A. J., AFOLABI, O. B., ADEKOYA, K., SANYA, J. O. & ISHOLA, A. O. 2017. Exposure to radio-frequency electromagnetic waves alters acetylcholinesterase gene expression, exploratory and motor coordination-linked behaviour in male rats. *Toxicol Rep,* 4**,** 530-534.

OLSEN, J., MELBYE, M., OLSEN, S. F., SORENSEN, T. I., AABY, P., ANDERSEN, A. M., TAXBOL, D., HANSEN, K. D., JUHL, M., SCHOW, T. B., SORENSEN, H. T., ANDRESEN, J., MORTENSEN, E. L., OLESEN, A. W. & SONDERGAARD, C. 2001. The

Danish National Birth Cohort--its background, structure and aim. *Scand J Public Health,* 29**,** 300-7.

OZDEMIR, E., DEMIRKAZIK, A., GURSOY, S., TASKIRAN, A. S., KILINC, O. & ARSLAN, G. 2017. Effects of extremely low frequency electromagnetic fields on morphine analgesia and tolerance in rats. *Gen Physiol Biophys,* 36**,** 415-422.

PAPADOPOULOU, E., HAUGEN, M., SCHJOLBERG, S., MAGNUS, P., BRUNBORG, G., VRIJHEID, M. & ALEXANDER, J. 2017. Maternal cell phone use in early pregnancy and child's language, communication and motor skills at 3 and 5 years: the Norwegian mother and child cohort study (MoBa). *BMC Public Health,* 17**,** 685.

PEDERSEN, C., POULSEN, A. H., ROD, N. H., FREI, P., HANSEN, J., GRELL, K., RAASCHOU-NIELSEN, O., SCHUZ, J. & JOHANSEN, C. 2017. Occupational exposure to extremely low-frequency magnetic fields and risk for central nervous system disease: an update of a Danish cohort study among utility workers. *Int Arch Occup Environ Health,* 90**,** 619-628.

PELEG, M., NATIV, O. & RICHTER, E. D. 2018. Radio frequency radiation-related cancer: assessing causation in the occupational/military setting. *Environ Res,* 163**,** 123-133.

PETRI, A. K., SCHMIEDCHEN, K., STUNDER, D., DECHENT, D., KRAUS, T., BAILEY, W. H. & DRIESSEN, S. 2017. Biological effects of exposure to static electric fields in humans and vertebrates: a systematic review. *Environ Health,* 16**,** 41.

PHILIPS, A., HENSHAW, D. L., LAMBURN, G. & O'CARROLL, M. J. 2018. Brain Tumours: Rise in Glioblastoma Multiforme Incidence in England 1995-2015 Suggests an Adverse Environmental or Lifestyle Factor. *J Environ Public Health,* 2018**,** 7910754.

POULLETIER DE GANNES, F., MASUDA, H., BILLAUDEL, B., POQUE-HARO, E., HURTIER, A., LEVEQUE, P., RUFFIE, G., TAXILE, M., VEYRET, B. & LAGROYE, I. 2017. Effects of GSM and UMTS mobile telephony signals on neuron degeneration and blood-brain barrier permeation in the rat brain. *Sci Rep,* 7**,** 15496.

PRASAD, M., KATHURIA, P., NAIR, P., KUMAR, A. & PRASAD, K. 2017. Mobile phone use and risk of brain tumours: a systematic review of association between study quality, source of funding, and research outcomes. *Neurol Sci,* 38**,** 797-810.

SADEGHI, T., AHMADI, A., JAVADIAN, M., GHOLAMIAN, S. A., DELAVAR, M. A., ESMAILZADEH, S., AHMADI, B. & HADIGHI, M. S. H. 2017. Preterm birth among women living within 600 meters of high voltage overhead Power Lines: a case-control study. *Rom J Intern Med,* 55**,** 145-150.

SAGIV, D., MIGIROV, L., MADGAR, O., NAKACHE, G., WOLF, M. & SHAPIRA, Y. 2018. Mobile phone usage does not affect sudden sensorineural hearing loss. *J Laryngol Otol,* 132**,** 29-32.

SANNINO, A., ROMEO, S., SCARFI, M. R., MASSA, R., D'ANGELO, R., PETRILLO, A., CERCIELLO, V., FUSCO, R. & ZENI, O. 2017a. Exposure Assessment and Biomonitoring of Workers in Magnetic Resonance Environment: An Exploratory Study. *Front Public Health,* 5**,** 344.

SANNINO, A., ZENI, O., ROMEO, S., MASSA, R. & SCARFI, M. R. 2017b. Adverse and beneficial effects in Chinese hamster lung fibroblast cells following radiofrequency exposure. *Bioelectromagnetics,* 38**,** 245-254.

SATO, E., YAMANISHI, T., IMAI, Y., KOBAYASHI, M., SAKAMOTO, T., ONO, Y., FUJII, A., YAMAGUCHI, T., NAKAMURA, T. & UEDA, Y. 2017. High-Frequency Continuous Pulsed Magnetic Stimulation Does Not Adversely Affect Development on Whole Body Organs in Female Sprague-Dawley Rats. *Low Urin Tract Symptoms,* 9**,** 102-106.

SATTA, G., MASCIA, N., SERRA, T., SALIS, A., SABA, L., SANNA, S., ZUCCA, M. G., ANGELUCCI, E., GABBAS, A., CULURGIONI, F., PILI, P., MURA, E., CAPPAI, M., ENNAS, M. G. & COCCO, P. 2018. Estimates of Environmental Exposure to Radiofrequency Electromagnetic Fields and Risk of Lymphoma Subtypes. *Radiat Res,* 189**,** 541-547.

SCHAUER, I. & MOHAMAD AL-ALI, B. 2018. Combined effects of varicocele and cell phones on semen and hormonal parameters. *Wien Klin Wochenschr,* 130**,** 335-340.

SCHMIEDCHEN, K., PETRI, A. K., DRIESSEN, S. & BAILEY, W. H. 2018. Systematic review of biological effects of exposure to static electric fields. Part II: Invertebrates and plants. *Environ Res,* 160**,** 60-76.

SHAHIN, S., BANERJEE, S., SWARUP, V., SINGH, S. P. & CHATURVEDI, C. M. 2018. From the Cover: 2.45-GHz Microwave Radiation Impairs Hippocampal Learning and Spatial Memory: Involvement of Local Stress Mechanism-Induced Suppression of iGluR/ERK/CREB Signaling. *Toxicol Sci,* 161**,** 349-374.

SHARMA, A., KESARI, K. K., SAXENA, V. K. & SISODIA, R. 2017. Ten gigahertz microwave radiation impairs spatial memory, enzymes activity, and histopathology of developing mice brain. *Mol Cell Biochem,* 435**,** 1-13.

SOFFRITTI, M., TIBALDI, E., PADOVANI, M., HOEL, D. G., GIULIANI, L., BUA, L., LAURIOLA, M., FALCIONI, L., MANSERVIGI, M., MANSERVISI, F., PANZACCHI, S. & BELPOGGI, F. 2016. Life-span exposure to sinusoidal-50 Hz magnetic field and acute low-dose gamma radiation induce carcinogenic effects in Sprague-Dawley rats. *Int J Radiat Biol,* 92**,** 202-14.

SOKOLOVIC, D., DJORDJEVIC, B., KOCIC, G., STOIMENOV, T. J., STANOJKOVIC, Z., SOKOLOVIC, D. M., VELJKOVIC, A., RISTIC, G., DESPOTOVIC, M., MILISAVLJEVIC, D., JANKOVIC, R. & BINIC, I. 2015. The Effects of Melatonin on Oxidative Stress Parameters and DNA Fragmentation in Testicular Tissue of Rats Exposed to Microwave Radiation. *Adv Clin Exp Med,* 24**,** 429-36.

SON, Y., KIM, J. S., JEONG, Y. J., JEONG, Y. K., KWON, J. H., CHOI, H. D., PACK, J. K., KIM, N., LEE, Y. S. & LEE, H. J. 2018. Long-term RF exposure on behavior and cerebral glucose metabolism in 5xFAD mice. *Neurosci Lett,* 666**,** 64-69.

SORAHAN, T. 2014. Magnetic fields and brain tumour risks in UK electricity supply workers. *Occup Med (Lond),* 64**,** 157-65.

SOUBERE MAHAMOUD, Y., AITE, M., MARTIN, C., ZHADOBOV, M., SAULEAU, R., LE DREAN, Y. & HABAUZIT, D. 2016. Additive Effects of Millimeter Waves and 2-Deoxyglucose Co-Exposure on the Human Keratinocyte Transcriptome. *PLoS One,* 11**,** e0160810.

SSM 2015. Recent research on EMF and Health Risk. Tenth report from SSM's Scientific Council on Electromagnetic Fields, 2015. *SSM Report, 19.* Stockholm: Strålsäkerhetsmyndigheten.

SSM 2016. Recent research on EMF and Health Risk. Eleventh report from SSM's Scientific Council on Electromagnetic Fields, 2016. *SSM Report, 15.* Stockholm: Strålsäkerhetsmyndigheten.

SSM 2018. Recent research on EMF and Health Risk. Twelfth report from SSM's Scientific Council on Electromagnetic Fields, 2018. *SSM Report, 09.* Stockholm: Strålsäkerhetsmyndigheten.

SU, L., YIMAER, A., WEI, X., XU, Z. & CHEN, G. 2017. The effects of 50 Hz magnetic field exposure on DNA damage and cellular functions in various neurogenic cells. *J Radiat Res,* 58**,** 474-486.

SU, L., YIMAER, A., XU, Z. & CHEN, G. 2018. Effects of 1800 MHz RF-EMF exposure on DNA damage and cellular functions in primary cultured neurogenic cells. *Int J Radiat Biol,* 94**,** 295-305.

SUDAN, M., ARAH, O. A., BECKER, T., LEVY, Y., SIGSGAARD, T., OLSEN, J., VERGARA, X. & KHEIFETS, L. 2017. Re-examining the association between residential exposure to magnetic fields from power lines and childhood asthma in the Danish National Birth Cohort. *PLoS One,* 12**,** e0177651.

SUZUKI, S., OKUTSU, M., SUGANUMA, R., KOMIYA, H., NAKATANI-ENOMOTO, S., KOBAYASHI, S., UGAWA, Y., TATENO, H. & FUJIMORI, K. 2017. Influence of radiofrequency-electromagnetic waves from 3rd-generation cellular phones on fertilization and embryo development in mice. *Bioelectromagnetics,* 38**,** 466-473.

TAN, S., WANG, H., XU, X., ZHAO, L., ZHANG, J., DONG, J., YAO, B., WANG, H., ZHOU, H., GAO, Y. & PENG, R. 2017. Study on dose-dependent, frequency-dependent, and accumulative effects of 1.5 GHz and 2.856 GHz microwave on cognitive functions in Wistar rats. *Sci Rep,* 7**,** 10781.

TURNER, M. C., BENKE, G., BOWMAN, J. D., FIGUEROLA, J., FLEMING, S., HOURS, M., KINCL, L., KREWSKI, D., MCLEAN, D., PARENT, M. E., RICHARDSON, L., SADETZKI, S., SCHLAEFER, K., SCHLEHOFER, B., SCHUZ, J., SIEMIATYCKI, J., TONGEREN, M. V. & CARDIS, E. 2017. Interactions between occupational exposure to

extremely low frequency magnetic fields and chemicals for brain tumour risk in the INTEROCC study. *Occup Environ Med,* 74**,** 802-809.

TURNER, M. C., BENKE, G., BOWMAN, J. D., FIGUEROLA, J., FLEMING, S., HOURS, M., KINCL, L., KREWSKI, D., MCLEAN, D., PARENT, M. E., RICHARDSON, L., SADETZKI, S., SCHLAEFER, K., SCHLEHOFER, B., SCHUZ, J., SIEMIATYCKI, J., VAN TONGEREN, M. & CARDIS, E. 2014. Occupational exposure to extremely low-frequency magnetic fields and brain tumor risks in the INTEROCC study. *Cancer Epidemiol Biomarkers Prev,* 23**,** 1863-72.

VALADEZ-LIRA, J. A., MEDINA-CHAVEZ, N. O., OROZCO-FLORES, A. A., HEREDIA-ROJAS, J. A., RODRIGUEZ-DE LA FUENTE, A. O., GOMEZ-FLORES, R., ALCOCER-GONZALEZ, J. M. & TAMEZ-GUERRA, P. 2017. Alterations of Immune Parameters on Trichoplusia ni (Lepidoptera: Noctuidae) Larvae Exposed to Extremely Low-Frequency Electromagnetic Fields. *Environ Entomol,* 46**,** 376-382.

VAN EEGHEM, V., EL ARFANI, A., ANTHOULA, A., WALRAVE, L., POURKAZEMI, A., BENTEA, E., DEMUYSER, T., SMOLDERS, I. & STIENS, J. 2017. Selective changes in locomotor activity in mice due to low-intensity microwaves amplitude modulated in the EEG spectral domain. *Neuroscience,* 359**,** 40-48.

WANG, H., TAN, S., XU, X., ZHAO, L., ZHANG, J., YAO, B., GAO, Y., ZHOU, H. & PENG, R. 2017a. Long term impairment of cognitive functions and alterations of NMDAR subunits after continuous microwave exposure. *Physiol Behav,* 181**,** 1-9.

WANG, J., SU, H., XIE, W. & YU, S. 2017b. Mobile Phone Use and The Risk of Headache: A Systematic Review and Meta-analysis of Cross-sectional Studies. *Sci Rep,* 7**,** 12595.

WANG, Y. & GUO, X. 2016. Meta-analysis of association between mobile phone use and glioma risk. *J Cancer Res Ther,* 12**,** C298-C300.

VERDOM, B.H., ABDOLMALEKI, P., BEHMANESH, M. 2018. The static magnetic field remotely boosts the efficiency of doxorubicin through modulating ROS behaviors. *Scientific reports, 8:990*

VERRENDER, A., LOUGHRAN, S. P., ANDERSON, V., HILLERT, L., RUBIN, G. J., OFTEDAL, G. & CROFT, R. J. 2018. IEI-EMF provocation case studies: A novel approach to testing sensitive individuals. *Bioelectromagnetics,* 39**,** 132-143.

VINCETI, M., MALAGOLI, C., FABBI, S., KHEIFETS, L., VIOLI, F., POLI, M., CALDARA, S., SESTI, D., VIOLANTI, S., ZANICHELLI, P., NOTARI, B., FAVA, R., ARENA, A., CALZOLARI, R., FILIPPINI, T., IACUZIO, L., ARCOLIN, E., MANDRIOLI, J., FINI, N., ODONE, A., SIGNORELLI, C., PATTI, F., ZAPPIA, M., PIETRINI, V., OLEARI, P., TEGGI, S., GHERMANDI, G., DIMARTINO, A., LEDDA, C., MAUCERI, C., SCIACCA, S., FIORE, M. & FERRANTE, M. 2017. Magnetic fields exposure from high-voltage power lines and risk of amyotrophic lateral sclerosis in two Italian populations. *Amyotroph Lateral Scler Frontotemporal Degener,* 18**,** 583-589.

VISNJIC, A., VELICKOVIC, V., SOKOLOVIC, D., STANKOVIC, M., MIJATOVIC, K., STOJANOVIC, M., MILOSEVIC, Z. & RADULOVIC, O. 2018. Relationship between the Manner of Mobile Phone Use and Depression, Anxiety, and Stress in University Students. *Int J Environ Res Public Health,* 15.

WOJCIK-PIOTROWICZ, K., KASZUBA-ZWOINSKA, J., ROKITA, E., NOWAK, B. & THOR, P. 2017. Changes in U937 cell viability induced by stress factors - possible role of calmodulin. *J Physiol Pharmacol,* 68**,** 629-636.

WU, S., DI, G. & LI, Z. 2017. Does static electric field from ultra-high voltage direct-current transmission lines affect male reproductive capacity? Evidence from a laboratory study on male mice. *Environ Sci Pollut Res Int,* 24**,** 18025-18034.

WYDE, M. E., HORN, T. L., CAPSTICK, M. H., LADBURY, J. M., KOEPKE, G., WILSON, P. F., KISSLING, G. E., STOUT, M. D., KUSTER, N., MELNICK, R. L., GAUGER, J., BUCHER, J. R. & MCCORMICK, D. L. 2018. Effect of cell phone radiofrequency radiation on body temperature in rodents: Pilot studies of the National Toxicology Program's reverberation chamber exposure system. *Bioelectromagnetics,* 39**,** 190-199.

YANG, M., GUO, W., YANG, C., TANG, J., HUANG, Q., FENG, S., JIANG, A., XU, X. & JIANG, G. 2017. Mobile phone use and glioma risk: A systematic review and meta-analysis. *PLoS One,* 12**,** e0175136.

YANG, X., HE, H., GAO, Q. & HE, C. 2018. Pulsed electromagnetic field improves subchondral bone microstructure in knee osteoarthritis rats through a Wnt/beta-catenin signaling-associated mechanism. *Bioelectromagnetics,* 39**,** 89-97.

ZHANG, H., DAI, Y., CHENG, Y., HE, Y., MANYAKARA, Z., DUAN, Y., SUN, G. & SUN, X. 2017a. Influence of extremely low frequency magnetic fields on Ca(2+) signaling and double messenger system in mice hippocampus and reversal function of procyanidins extracted from lotus seedpod. *Bioelectromagnetics,* 38**,** 436-446.

ZHANG, H., GAN, L., ZHU, X., WANG, J., HAN, L., CHENG, P., JING, D., ZHANG, X. & SHAN, Q. 2018. Moderate-intensity 4mT static magnetic fields prevent bone architectural deterioration and strength reduction by stimulating bone formation in streptozotocin-treated diabetic rats. *Bone,* 107**,** 36-44.

ZHANG, J., SUMICH, A. & WANG, G. Y. 2017b. Acute effects of radiofrequency electromagnetic field emitted by mobile phone on brain function. *Bioelectromagnetics,* 38**,** 329-338.

ZHANG, J. P., ZHANG, K. Y., GUO, L., CHEN, Q. L., GAO, P., WANG, T., LI, J., GUO, G. Z. & DING, G. R. 2017c. Effects of 1.8 GHz Radiofrequency Fields on the Emotional Behavior and Spatial Memory of Adolescent Mice. *Int J Environ Res Public Health,* 14.

ZHANG, K. Y., XU, H., DU, L., XING, J. L., ZHANG, B., BAI, Q. S., XU, Y. Q., ZHOU, Y. C., ZHANG, J. P., ZHOU, Y. & DING, G. R. 2017d. Enhancement of X-ray Induced Apoptosis by Mobile Phone-Like Radio-Frequency Electromagnetic Fields in Mouse Spermatocyte-Derived Cells. *Int J Environ Res Public Health,* 14.

ZHANG, L., HOU, Y., LI, Z., JI, X., WANG, Z., WANG, H., TIAN, X., YU, F., YANG, Z., PI, L., MITCHISON, T. J., LU, Q. & ZHANG, X. 2017e. 27 T ultra-high static magnetic field changes orientation and morphology of mitotic spindles in human cells. *Elife,* 6.

ZOTHANSIAMA, ZOSANGZUALI, M., LALRAMDINPUII, M. & JAGETIA, G. C. 2017. Impact of radiofrequency radiation on DNA damage and antioxidants in peripheral blood lymphocytes of humans residing in the vicinity of mobile phone base stations. *Electromagn Biol Med,* 36**,** 295-305.

Appendix: Studies excluded from analysis

Articles were identified in relevant scientific literature data bases such as PubMed as well as in the specialized database EMF Portal. Reference lists of articles were screened for relevant papers. Several studies had to be excluded from further analysis as they did not fulfil quality criteria. In this Appendix, the excluded studies[6] are listed and the reasons for exclusion are indicated. The list is divided into epidemiological studies, human studies, animal studies and cell studies.

Epidemiological studies

In a first step, all articles that were not relevant for this report were discarded, i.e.

A)   Papers that did not study non-ionizing electromagnetic fields (i.e. static, extremely low frequency, intermediate frequency or radiofrequency EMF), or

B)   did not study any health outcome (including letters, commentaries etc.), or

C)   did not in any way study the association between radiofrequency fields and a health outcome (e.g. use of text messages for self-management of diabetes).

D)   Studies on using EMF as therapeutic interventions (e.g. diathermy),

E)   Case-reports were also excluded.

F)   Further, studies that did not include humans were excluded, as well as studies of humans with an experimental design (these studies are included under "human studies").

G)   Not a peer-reviewed publication, or published in another language than English,

H)   Studies published outside of the time frame of this report (online publication date).

Further, the following exclusion criteria were applied after screening the abstracts:

I)   Study base not identified (e.g. self-selection of subjects in cross-sectional or case-control studies, the population intended for inclusion not described)

J)   No comparison group or no exposure considered (either no unexposed group or lacking denominator for prevalence/incidence calculation in descriptive or incidence study), with the exception of incidence trend studies from registries applying a systematic data collection.

K)   Narrative reviews

L)   Duplicate reports, unless new additional analyses are presented (including the first original publication, and information from duplicate reports if new additional results were presented)

M)   Addressing exclusively exposure assessment methods which have been proven to be invalid such as self-estimated distance to mobile phone base stations.

---

[6] The articles are primarily identified through searches in relevant scientific literature data bases. However, the searches will never give a complete list of published articles. Neither will the list of articles that do not fulfil quality criteria be complete.

Bilgrami et al. (2017)	A
Brascher et al. (2017)	A
Demoury et al. (2017)	A
Huang et al. (2018)	A
Lu et al. (2017)	A
Ostrom et al. (2018)	A
Sagar et al. (2018a)	A
Sagiv et al. (2018)	A
Satta et al. (2018)	A
Straker et al. (2018)	A
Wiedemann et al. (2017)	A
Xu et al. (2017b)	A
Beghi (2017)	B
Bhatt et al. (2017)	B
Brzozek et al. (2018)	B
Burgi et al. (2017)	B
Chiaramello et al. (2017)	B
Choi et al. (2018b)	B
Choi et al. (2018a)	B
Fernandez-Garcia and Gil (2017)	B
Fischer et al. (2017)	B
Gkonis et al. (2017)	B
Hardell (2018)	B
Heuser and Heuser (2017)	B
Jung et al. (2018)	B
Korpinen and Paakkonen (2018)	B
Mireku et al. (2018)	B

Mortazavi and Mortazavi (2018)	B
Redmayne (2018)	B
Reedijk et al. (2018)	B
Roozbeh et al. (2018)	B
Sagar et al. (2018b)	B
Sage and Hardell (2018)	B
Sato et al. (2018)	B
Schmiedchen et al. (2018)	B
Toledano et al. (2018)	B
Turner et al. (2016)	B
Vermeulen et al. (2017)	B
Altuntas et al. (2018)	F
Bhargav et al. (2017)	F
Dalecki et al. (2018)	F
Davarpanah Jazi et al. (2017)	F
Henz et al. (2018)	F
Misek et al. (2018)	F
Modolo et al. (2017)	F
Nayback-Beebe et al. (2017)	F
Garzillo et al. (2016)	H
Gunnarsson and Bodin (2017)	H
Sato et al. (2017)	H
Gulati et al. (2018)	I
Taheri et al. (2017)	I
Claeson et al. (2018)	J
Jarusevicius et al. (2018)	J
Podolska (2018)	J

Vuokko et al. (2018)	J
Callahan et al. (2018)	K
Carlberg and Hardell (2017)	K
Curcio (2018)	K
Di Ciaula (2018)	K
Frankel et al. (2018)	K
Hardell (2017)	K
Kocaman et al. (2018)	K
Mattsson et al. (2018)	K
Miah and Kamat (2017)	K
Pall (2018)	K
Russell (2018)	K
Sage and Burgio (2018)	K
Schuz and Erdmann (2016)	K
Sienkiewicz et al. (2017)	K
Wang and Zhang (2017)	K
Yan (2018)	K
Brignardello-Petersen (2017)	L
Das et al. (2017)	M
Kalafatakis et al. (2017)	F

Human studies

Static fields (SF) and Radiofrequency (RF) fields

Reference	Reason for exclusion
Bhargav et al. (2017)	Parallel group design, differences between groups at baseline for many of the "significant" differences assessed post-exposure are larger than the changes between pre and post in the real exposure condition. This reflects the general criticism to the method, i.e. that measurement results are due to chance and not reproducible. The method is not validated.

Derkacz et al. (2018)	No sham exposure condition
Gawit et al. (2017)	Parallel group design, lack of information on exposure, no sham intervention
Kalafatakis et al. (2017)	Parallel group design

Animal studies

Static fields (SF) and extremely low frequency (ELF) fields

Reference	Reason for exclusion
Adamkova et al. (2017)	GMF & directional preference in dogs
Akbarnejad et al. (2017b)	No sham exposed AD control, Improper description of exposure, experimental timing and animal housing
Aslankoc et al. (2018)	No sham-control, 1 EF level (10 kV/m) only, "resveratrol can ameliorate the damage caused by EF"
de Sousa et al. (2017)	No control, descriptive study using n=5 rats subjected to anorectal electro stimulation aiming to improve incontinence
Dogan et al. (2017)	Improper description of exposure (8h, 2,48 µT, 80.3 V/m) and rats' housing during exposure, no. per group missing
Djordjevic et al. (2017)	No sham control, 2 x n=5/gr, 1 MF (10mT) + 1 control
Xiaolin et al. (2017)	Treatment related: EF stimulation (0 ± 0.5mV) of injured spinal cord of rats
Kantarcioglu et al. (2018)	MR imaging (1.5 and 3 T) affects neural tube closure and growth in chicken embryos
Jasmi et al. (2017)	No sham control, improper description of SMF ovaries'and mice'(?) exposure. Treatment-related: Vitrification process & 1mT SMF
Kazemein Jasemi et al. (2017)	No sham control, improper description of SMF and mice' exposure. Major study parts are identical to the previous citation (…2017a)
Kilfoyle et al. (2018)	SMF and ELF-MF effects of undersea electric cables on coral reef fish
Klimley et al. (2017)	GMF & local MF produced by DC cable and bridges and influence on seasonal movement patterns of salmonid smolts & adult green surgeon
Kouzani et al. (2017)	Development and testing of a low power deep brain stimulation device in rats
Landler et al. (2017)	Ecotoxicological influence of Hg on spontaneous magnetic alignment of snapping turtle hatchlings
Laszlo et al. (2018)	Improper description of p ELF-MF exposure (50Hz, 10µT) of turkeys. Number of controls (N04x1) questionable.
Lei et al. (2018)	Treatment-related (osteoporosis, OVX mice), no sham-exposure group, pEMF
Li et al. (2017a)	Treatment-related (disuse osteoporosis, rat model), no sham-exposure group, pEMF
Li et al. (2017c)	Treatment-related: Neuropathic pain and spinal cord stimulation (SCS) in a rat model at 50Hz to 10 kHz and 40 or 200µs pulse width
Li et al. (2017b)	Treatment-related (promotion of bone formation in diabetic db/db mice), no sham-exposure group, pEMF
Li et al. (2018)	Treatment-related: Enhanced drug delivery to glioma in rats via

	EMP-induced BBB-disruption
Luyck et al. (2017)	Treatment-related: Deep brain stimulation (DBS) at 100Hz, 40μs and 300μA or at 130Hz, 220μs
Madularu et al. (2017)	Treatment-related: Intracerebral stimulation during MRI in rats using a special in situ coil system
Myklatun et al. (2018)	GMF, magnetoreception and orientation in zebrafish & medaka
Newton and Kajiura (2017)	GMF, magnetic field discrimination, memory in yellow stingray
Naisbett-Jones et al. (2017)	GMF, Magneto-orientation of juvenile European eels
Opitz et al. (2017)	Transcranial electric stimulation (TES) in a NHP (Cebus monkey) pre- and postmortem
Osanai et al. (2018)	Treatment-related: Micro-coil-induced activation of the mouse auditory cortex; i.e., new highly focal neuro-stimulation technique
Pinzon-Rodriguez and Muheim (2017)	Magnetoreception: Light-dependent magnetic compass of zebra finches
Putman et al. (2018)	GMF and orientation (upward movement) of young Chinook salmon emerging from nest
Samaddar et al. (2017)	Treatment-related: Transspinal direct current stimulation (tsDCS) affects adult-born spinal (stem) cells in mice
Seo et al. (2018)	Treatment-related: Technical paper of a microwave signal generation system for brain stimulation using a mouse.
Shakhparonov and Ogurtsov (2017)	GMF and orientation (determination of migratory direction) in marsh frogs
Soliman et al. (2017)	Treatment-related: EF (30 mV/mm) for 10 min enhanced homing of mesenchymal stem cells in damaged myocardium of rats. EF exposure not described.
Vaena et al. (2017)	No (sham) control pigs for transcutaneous magnetic fixation (SMF). Treatment-related: SMFs for treatment of injury and disease.
Voroslakos et al. (2018)	Treatment-related: Transcranial electric stimulation on brain circuits in rats and humans
Vuka et al. (2018)	Treatment-related: El. stimulation of DRG in the context of pain: a systematic review; in vitro & in vivo studies
Xu et al. (2017a)	GMF & orientation: Magnetic sense for flight orientation in armyworm moths.
Yamaguchi et al. (2018)	Treatment-related: E2 incorporation by nsPEMF into fertilized medaka embryos → assessment of mechanistic teratology
Zhao et al. (2017a)	Treatment-related: SMF and wound healing in diabetic rats. SMF applied by gluing a magnetic disk (230mT)
Zhou et al. (2017)	Treatment-related: Effect of PEMF therapy-timing on OVX-induced deterioration in rat bone
Zhu et al. (2018)	Treatment-related: Determination of an optimal duration (1.5h!) of 50Hz, 1.8mT ELF-MF-exposure per day regarding increase of peak bone mass in newborn and weaning rats. (In vitro and in vivo paper.)

Radiofrequency (RF) fields

Reference	Reason for exclusion
Bahreyni Toossi et al. (2018)	Incomplete dosimetry

Cetkin et al. (2017)	No dosimetry
Gevrek (2018)	Cell phone in talk mode as source, no dosimetry
Ghatei et al. (2017)	No dosimetry
Gohari et al. (2017)	No dosimetry
Hao et al. (2018)	No frequency provided
Hassanshahi et al. (2017)	No dosimetry
Hiscock et al. (2017)	Theoretical study
Hu et al. (2017)	No RF frequency provided, incomplete dosimetry
Ibitayo et al. (2017)	No dosimetry
Kim et al. (2017a)	Incomplete dosimetry
Othman et al. (2017a)	No dosimetry
Othman et al. (2017c)	No dosimetry
Othman et al. (2017b)	No dosimetry
Oyewopo et al. (2017)	No dosimetry
Pandey and Giri (2018)	No sham exposed group
Shahin et al. (2018)	SAR calculation refers to Shahin et al. (2017) where SAR is incorrectly calculated (for uterus!) assuming mobile phone transmission at full power
Shahin et al. (2017)	SAR incorrectly calculated assuming mobile phone transmission at full power

Cell studies

Static fields

Reference	Reason for exclusion
Chen et al. (2018)	No sham-control
Kamalipooya et al. (2017)	No sham-control
Kim et al. (2017d)	No sham-control
Mousavidoust et al. (2017)	No sham-control
Prasad et al. (2017)	No sham-control

Extremely low frequency (ELF) fields

Reference	Reason for exclusion
Aldahoun et al. (2017)	No sham-control
Akbarnejad et al. (2017a)	No sham-control
Ehnert et al. (2017)	No sham-control
Ehnert et al. (2018)	No sham-control
Kim et al. (2017c)	No sham-control
Kim et al. (2017d)	No sham-control
Lucia et al. (2017)	No sham-control
Errico Provenzano et al. (2018)	No sham-control
Rezaie-Tavirani et al. (2017)	No sham-control
Villarini et al. (2017)	No sham-control

Radiofrequency (RF) fields

Reference	Reason for exclusion
Alcantara et al. (2017)	No sham-control
Asano et al. (2017)	No sham control. Inadequate description of the RF exposure system and dosimetry.
Danese et al. (2017)	No dosimetry performed. Mobile phone in 'on' mode
D'Silva et al. (2017)	No dosimetry performed. Mobile phone in 'on' mode
Eghlidospour et al. (2017)	No dosimetry performed. Mobile phone in 'on' mode
Kayhan et al. (2016)	Inadequate description of the RF exposure system and dosimetry. No monitoring of sample temperature.
Kim et al. (2017b)	Only Western blot images provided, no protein data reported. No statistical analysis of protein data. No monitoring of sample temperature.
Kuzniar et al. (2017)	Inadequate description of the RF exposure system and dosimetry. No monitoring of sample temperature.
Park et al. (2018)	No sham control.
Ulasov et al. (2017)	No sham control. Inadequate description of the RF exposure system and dosimetry.
Zhao et al. (2017b)	Inadequate description of the RF exposure system and dosimetry. No monitoring of sample temperature.
Zilov et al. (2017)	No sham control. Inadequate description of the RF exposure system and dosimetry.

References excluded studies

ADAMKOVA, J., SVOBODA, J., BENEDIKTOVA, K., MARTINI, S., NOVAKOVA, P., TUMA, D., KUCEROVA, M., DIVISOVA, M., BEGALL, S., HART, V. & BURDA, H. 2017. Directional preference in dogs: Laterality and "pull of the north". *PLoS One,* 12**,** e0185243.

AKBARNEJAD, Z., ESKANDARY, H., DINI, L., VERGALLO, C., NEMATOLLAHI-MAHANI, S. N., FARSINEJAD, A., ABADI, M. F. S. & AHMADI, M. 2017a. Cytotoxicity of temozolomide on human glioblastoma cells is enhanced by the concomitant exposure to an extremely low-frequency electromagnetic field (100Hz, 100G). *Biomed Pharmacother,* 92**,** 254-264.

AKBARNEJAD, Z., ESMAEILPOUR, K., SHABANI, M., ASADI-SHEKAARI, M., SAEEDI GORAGHANI, M. & AHMADI-ZEIDABADI, M. 2017b. Spatial memory recovery in Alzheimer's rat model by electromagnetic field exposure. *Int J Neurosci***,** 1-6.

ALCANTARA, D. Z., SOLIMAN, I. J. S., POBRE, R. F. & NAGUIB, R. N. G. 2017. Effects of Pulsed Electromagnetic Fields on Breast Cancer Cell Line MCF 7 Using Absorption Spectroscopy. *Anticancer Res,* 37**,** 3453-3459.

ALDAHOUN, M. A., JAAFAR, M. S., AL-AKHRAS, M. H. & BOUOUDINA, M. 2017. Enhanced nanocurcumin toxicity against (PC3) tumor and microbial by using magnetic field in vitro. *Artif Cells Nanomed Biotechnol,* 45**,** 843-853.

ALTUNTAS, G., SADOGLU, D., ARDIC, S., YILMAZ, H., IMAMOGLU, M. & TUREDI, S. 2018. Acute effects of the electromagnetic waves emitted by mobile phones on attention in emergency physicians. *Am J Emerg Med,* 36**,** 455-460.

ASANO, M., TANAKA, S., SAKAGUCHI, M., MATSUMURA, H., YAMAGUCHI, T., FUJITA, Y. & TABUSE, K. 2017. Normothermic Microwave Irradiation Induces Death of HL-60 Cells through Heat-Independent Apoptosis. *Sci Rep,* 7**,** 11406.

ASLANKOC, R., GUMRAL, N., SAYGIN, M., SENOL, N., ASCI, H., CANKARA, F. N. & COMLEKCI, S. 2018. The impact of electric fields on testis physiopathology, sperm parameters and DNA integrity-The role of resveratrol. *Andrologia.*

BAHREYNI TOOSSI, M. H., SADEGHNIA, H. R., MOHAMMAD MAHDIZADEH FEYZABADI, M., HOSSEINI, M., HEDAYATI, M., MOSALLANEJAD, R., BEHESHTI, F. & ALIZADEH RAHVAR, Z. 2018. Exposure to mobile phone (900-1800 MHz) during pregnancy: tissue oxidative stress after childbirth. *J Matern Fetal Neonatal Med,* 31**,** 1298-1303.

BEGHI, E. 2017. Use of cell phones and brain tumors: a true association? *Neurol Sci,* 38**,** 713-714.

BHARGAV, H., SRINIVASAN, T. M., BISTA, S., MOOVENTHAN, A., SURESH, V., HANKEY, A. & NAGENDRA, H. R. 2017. Acute effects of mobile phone radiations on subtle energy levels of teenagers using electrophotonic imaging technique: A randomized controlled study. *Int J Yoga,* 10**,** 16-23.

BHATT, C. R., ABRAMSON, M. J. & BENKE, G. 2017. Wi-Fi radiation exposures to children in kindergartens and schools - results should lessen parental concerns. *Aust N Z J Public Health,* 41**,** 647-648.

BILGRAMI, Z., MC, L. L., MILANAIK, R. & ADESMAN, A. 2017. Health implications of new-age technologies: a systematic review. *Minerva Pediatr,* 69**,** 348-367.

BRASCHER, A. K., RAYMAEKERS, K., VAN DEN BERGH, O. & WITTHOFT, M. 2017. Are media reports able to cause somatic symptoms attributed to WiFi radiation? An experimental test of the negative expectation hypothesis. *Environ Res,* 156**,** 265-271.

BRIGNARDELLO-PETERSEN, R. 2017. Cell phone use may increase the risk of developing parotid gland tumors. *J Am Dent Assoc,* 148**,** e61.

BRZOZEK, C., BENKE, K. K., ZELEKE, B. M., ABRAMSON, M. J. & BENKE, G. 2018. Radiofrequency Electromagnetic Radiation and Memory Performance: Sources of Uncertainty in Epidemiological Cohort Studies. *Int J Environ Res Public Health,* 15.

BURGI, A., SAGAR, S., STRUCHEN, B., JOSS, S. & ROOSLI, M. 2017. Exposure Modelling of Extremely Low-Frequency Magnetic Fields from Overhead Power Lines and Its Validation by Measurements. *Int J Environ Res Public Health,* 14.

CALLAHAN, M. J., MACDOUGALL, R. D., BIXBY, S. D., VOSS, S. D., ROBERTSON, R. L. & CRAVERO, J. P. 2018. Ionizing radiation from computed tomography versus anesthesia for magnetic resonance imaging in infants and children: patient safety considerations. *Pediatr Radiol,* 48**,** 21-30.

CARLBERG, M. & HARDELL, L. 2017. Evaluation of Mobile Phone and Cordless Phone Use and Glioma Risk Using the Bradford Hill Viewpoints from 1965 on Association or Causation. *Biomed Res Int,* 2017**,** 9218486.

CETKIN, M., KIZILKAN, N., DEMIREL, C., BOZDAG, Z., ERKILIC, S. & ERBAGCI, H. 2017. Quantitative changes in testicular structure and function in rat exposed to mobile phone radiation. *Andrologia,* 49.

CHEN, W. T., LIN, G. B., LIN, S. H., LU, C. H., HSIEH, C. H., MA, B. L. & CHAO, C. Y. 2018. Static magnetic field enhances the anticancer efficacy of capsaicin on HepG2 cells via capsaicin receptor TRPV1. *PLoS One,* 13**,** e0191078.

CHIARAMELLO, E., PARAZZINI, M., FIOCCHI, S., RAVAZZINI, P., WIART, J. 2017 Assessment of fetal exposure to 4G LTE tablet in realistic scenarios: Effect of position, gestational age and frequency. *IEEE Journal of Electromagnetics, RF and Microwaves in Medicine and Biology, Vol. 1, No. 1*

CHOI, S., CHA, W., PARK, J., KIM, S., KIM, W., YOON, C., PARK, J. H., HA, K. & PARK, D. 2018a. Extremely Low Frequency-Magnetic Field (ELF-MF) Exposure Characteristics among Semiconductor Workers. *Int J Environ Res Public Health,* 15.

CHOI, J., HWANG, J.H., LIM, H., JOO, H., YANG, H.S., LEE, Y.H., EEFTENS, M., STRUCHEN, B., RÖÖSLI, M., LEE, A.K., CHOI, H.D., KWON, J.H., HA, M. 2018b Assessment of radiofrequency electromagnetic field exposure from personal measurements considering the body shadowing effect in Korean children and parents. *Sci Total Environ. 2018 June 15;627:1544-1551*

CLAESON, A. S., PALMQUIST, E. & NORDIN, S. 2018. Physical and chemical trigger factors in environmental intolerance. *Int J Hyg Environ Health,* 221**,** 586-592.

CURCIO, G. 2018. Exposure to Mobile Phone-Emitted Electromagnetic Fields and Human Attention: No Evidence of a Causal Relationship. *Front Public Health,* 6**,** 42.

D'SILVA, M. H., SWER, R. T., ANBALAGAN, J. & RAJESH, B. 2017. Effect of Radiofrequency Radiation Emitted from 2G and 3G Cell Phone on Developing Liver of Chick Embryo - A Comparative Study. *J Clin Diagn Res,* 11**,** AC05-AC09.

DALECKI, A., LOUGHRAN, S. P., VERRENDER, A., BURDON, C. A., TAYLOR, N. A. S. & CROFT, R. J. 2018. Does acute radio-frequency electromagnetic field exposure affect visual event-related potentials in healthy adults? *Clin Neurophysiol,* 129**,** 901-908.

DANESE, E., LIPPI, G., BUONOCORE, R., BENATI, M., BOVO, C., BONAGURI, C., SALVAGNO, G. L., BROCCO, G., ROGGENBUCK, D. & MONTAGNANA, M. 2017. Mobile phone radiofrequency exposure has no effect on DNA double strand breaks (DSB) in human lymphocytes. *Ann Transl Med,* 5**,** 272.

DAS, S., CHAKRABORTY, S. & MAHANTA, B. 2017. A study on the effect of prolonged mobile phone use on pure tone audiometry thresholds of medical students of Sikkim. *J Postgrad Med,* 63**,** 221-225.

DAVARPANAH JAZI, S., MODOLO, J., BAKER, C., VILLARD, S. & LEGROS, A. 2017. Effects of A 60 Hz Magnetic Field of Up to 50 milliTesla on Human Tremor and EEG: A Pilot Study. *Int J Environ Res Public Health,* 14.

DE SOUSA, H. A., SILVA, M., BARBOSA, K. P., VIANNA, L. M. S., PACHECO, Y. G., DE GODOY, J. R. P. & KUCKELHAUS, S. A. S. 2017. Electrical stimulation structurally affects the tissues of the rectum and anus of nulliparous rats. *J Anat,* 231**,** 398-404.

DEMOURY, C., MARQUANT, F., IELSCH, G., GOUJON, S., DEBAYLE, C., FAURE, L., COSTE, A., LAURENT, O., GUILLEVIC, J., LAURIER, D., HEMON, D. & CLAVEL, J. 2017. Residential Exposure to Natural Background Radiation and Risk of Childhood Acute Leukemia in France, 1990-2009. *Environ Health Perspect,* 125**,** 714-720.

DERKACZ, A., GAWRYS, J., GAWRYS, K., PODGORSKI, M., MAGOTT-DERKACZ, A., POREBA, R. & DOROSZKO, A. 2018. Effect of electromagnetic field accompanying the magnetic resonance imaging on human heart rate variability - a pilot study. *Int J Inj Contr Saf Promot,* 25**,** 229-231.

DI CIAULA, A. 2018. Towards 5G communication systems: Are there health implications? *Int J Hyg Environ Health,* 221**,** 367-375.

DJORDJEVIC, N. Z., PAUNOVIC, M. G. & PEULIC, A. S. 2017. Anxiety-like behavioural effects of extremely low-frequency electromagnetic field in rats. *Environ Sci Pollut Res Int,* 24**,** 21693-21699.

DOGAN, M. S., YAVAS, M. C., YAVUZ, Y., ERDOGAN, S., YENER, I., SIMSEK, I., AKKUS, Z., ERATILLA, V., TANIK, A. & AKDAG, M. Z. 2017. Effect of electromagnetic fields and antioxidants on the trace element content of rat teeth. *Drug Des Devel Ther,* 11**,** 1393-1398.

EGHLIDOSPOUR, M., GHANBARI, A., MORTAZAVI, S. M. J. & AZARI, H. 2017. Effects of radiofrequency exposure emitted from a GSM mobile phone on proliferation, differentiation, and apoptosis of neural stem cells. *Anat Cell Biol,* 50**,** 115-123.

EHNERT, S., FENTZ, A. K., SCHREINER, A., BIRK, J., WILBRAND, B., ZIEGLER, P., REUMANN, M. K., WANG, H., FALLDORF, K. & NUSSLER, A. K. 2017. Extremely low frequency pulsed electromagnetic fields cause antioxidative defense mechanisms in human osteoblasts via induction of *O2(-) and H2O2. *Sci Rep,* 7**,** 14544.

EHNERT, S., VAN GRIENSVEN, M., UNGER, M., SCHEFFLER, H., FALLDORF, K., FENTZ, A. K., SEELIGER, C., SCHROTER, S., NUSSLER, A. K. & BALMAYOR, E. R. 2018. Co-Culture with Human Osteoblasts and Exposure to Extremely Low Frequency Pulsed Electromagnetic Fields Improve Osteogenic Differentiation of Human Adipose-Derived Mesenchymal Stem Cells. *Int J Mol Sci,* 19.

ERRICO PROVENZANO, A., AMATORI, S., NASONI, M. G., PERSICO, G., RUSSO, S., MASTROGIACOMO, A. R., GAMBARARA, A. & FANELLI, M. 2018. Effects of Fifty-Hertz Electromagnetic Fields on Granulocytic Differentiation of ATRA-Treated Acute Promyelocytic Leukemia NB4 Cells. *Cell Physiol Biochem,* 46**,** 389-400.

FERNANDEZ-GARCIA, R. & GIL, I. 2017. Measurement of the environmental broadband electromagnetic waves in a mid-size European city. *Environ Res,* 158**,** 768-772.

FISCHER, H. J., VERGARA, X. P., YOST, M., SILVA, M., LOMBARDI, D. A. & KHEIFETS, L. 2017. Developing a job-exposure matrix with exposure uncertainty from expert elicitation and data modeling. *J Expo Sci Environ Epidemiol,* 27**,** 7-15.

FRANKEL, J., WILEN, J. & HANSSON MILD, K. 2018. Assessing Exposures to Magnetic Resonance Imaging's Complex Mixture of Magnetic Fields for In Vivo, In Vitro, and Epidemiologic Studies of Health Effects for Staff and Patients. *Front Public Health,* 6**,** 66.

GARZILLO, E. M., MIRAGLIA, N., PEDATA, P., FEOLA, D. & LAMBERTI, M. 2016. Risk agents related to work and amyotrophic lateral sclerosis: An occupational medicine focus. *Int J Occup Med Environ Health,* 29**,** 355-67.

GAWIT, K. G., TIWARI, S. A., KASABE, G. H., DESHPANDE, P. K. & GHONGANE, B. B. 2017. Effect of Cellular Mobile Phone Use and Cetrizine on Hand-Eye Coordination and Visual Acuity. *J Clin Diagn Res,* 11**,** FC09-FC12.

GEVREK, F. 2018. Histopathological, immunohistochemical, and stereological analysis of the effect of Ginkgo biloba (Egb761) on the hippocampus of rats exposed to long-term cellphone radiation. *Histol Histopathol,* 33**,** 463-473.

GHATEI, N., NABAVI, A. S., TOOSI, M. H. B., AZIMIAN, H., HOMAYOUN, M., TARGHI, R. G. & HAGHIR, H. 2017. Evaluation of bax, bcl-2, p21 and p53 genes expression variations on cerebellum of BALB/c mice before and after birth under mobile phone radiation exposure. *Iran J Basic Med Sci,* 20**,** 1037-1043.

GKONIS, F., BOURSIANIS, A. & SAMARAS, T. 2017. Electromagnetic Field Exposure Changes Due to the Digital Television Switchover in Thessaloniki, Greece. *Health Phys,* 113**,** 382-386.

GOHARI, F. A., SARANJAM, B., ASGARI, M., OMIDI, L., EKRAMI, H. & MOUSSAVI-NAJARKOLA, S. A. 2017. An Experimental Study of the Effects of Combined Exposure to Microwave and Heat on Gene Expression and Sperm Parameters in Mice. *J Hum Reprod Sci,* 10**,** 128-134.

GULATI, S., YADAV, A., KUMAR, N., PRIYA, K., AGGARWAL, N. K. & GUPTA, R. 2018. Phenotypic and genotypic characterization of antioxidant enzyme system in human population exposed to radiation from mobile towers. *Mol Cell Biochem,* 440**,** 1-9.

GUNNARSSON, L. G. & BODIN, L. 2017. Parkinson's disease and occupational exposures: a systematic literature review and meta-analyses. *Scand J Work Environ Health,* 43**,** 197-209.

HAO, Y., LI, W., WANG, H., ZHANG, J., YU, C., TAN, S., WANG, H., XU, X., DONG, J., YAO, B., ZHOU, H., ZHAO, L. & PENG, R. 2018. Autophagy mediates the degradation of synaptic vesicles: A potential mechanism of synaptic plasticity injury induced by microwave exposure in rats. *Physiol Behav,* 188**,** 119-127.

HARDELL, L. 2017. World Health Organization, radiofrequency radiation and health - a hard nut to crack (Review). *Int J Oncol,* 51**,** 405-413.

HARDELL, L. 2018. Effects of Mobile Phones on Children's and Adolescents' Health: A Commentary. *Child Dev,* 89**,** 137-140.

HASSANSHAHI, A., SHAFEIE, S. A., FATEMI, I., HASSANSHAHI, E., ALLAHTAVAKOLI, M., SHABANI, M., ROOHBAKHSH, A. & SHAMSIZADEH, A. 2017. The effect of Wi-Fi electromagnetic waves in unimodal and multimodal object recognition tasks in male rats. *Neurol Sci,* 38**,** 1069-1076.

HENZ, D., SCHOLLHORN, W. I. & POEGGELER, B. 2018. Mobile Phone Chips Reduce Increases in EEG Brain Activity Induced by Mobile Phone-Emitted Electromagnetic Fields. *Front Neurosci,* 12**,** 190.

HEUSER, G. & HEUSER, S. A. 2017. Corrigendum to: Functional brain MRI in patients complaining of electrohypersensitivity after long term exposure to electromagnetic fields. *Rev Environ Health,* 32**,** 379-380.

HISCOCK, H. G., MOURITSEN, H., MANOLOPOULOS, D. E. & HORE, P. J. 2017. Disruption of Magnetic Compass Orientation in Migratory Birds by Radiofrequency Electromagnetic Fields. *Biophys J,* 113**,** 1475-1484.

HU, H. X., SUN, J., GAO, Y. J., FANG, H., XU, S. Q., DONG, J., WEI, L. Z., LUO, S. B., SHEN, C. Y., ZHANG, Q. L. & XIE, Y. L. 2017. Effect of modified Wuzi Yanzong Pill () on Tip60-mediated apoptosis in testis of male rats after microwave radiation. *Chin J Integr Med*.

HUANG, P. C., LI, K. H. & GUO, H. R. 2018. Association between media coverage and prevalence of idiopathic environmental intolerance attributed to electromagnetic field in Taiwan. *Environ Res,* 161**,** 329-335.

IBITAYO, A. O., AFOLABI, O. B., AKINYEMI, A. J., OJIEZEH, T. I., ADEKOYA, K. O. & OJEWUNMI, O. O. 2017. RAPD Profiling, DNA Fragmentation, and Histomorphometric Examination in Brains of Wistar Rats Exposed to Indoor 2.5 Ghz Wi-Fi Devices Radiation. *Biomed Res Int,* 2017**,** 8653286.

JARUSEVICIUS, G., RUGELIS, T., MCCRATY, R., LANDAUSKAS, M., BERSKIENE, K. & VAINORAS, A. 2018. Correlation between Changes in Local Earth's Magnetic Field and Cases of Acute Myocardial Infarction. *Int J Environ Res Public Health,* 15.

JASMI, V. K., SAMADI, F., EIMANI, H., HASANI, S., FATHI, R. & SHAHVERDI, A. 2017. Follicle Development in Grafted Mouse Ovaries after Vitrification Processes Under Static Magnetic Field. *Cryo Letters,* 38**,** 166-177.

JUNG, J. S., LEE, J. W., RAJITHA KAWSHALYA, M. A. D., PARK, D. S. & HONG, S. C. 2018. Characteristics and Potential Human Health Hazards of Charged Aerosols Generated by High-voltage Power Lines. *Int J Occup Saf Ergon***,** 1-19.

KALAFATAKIS, F., BEKIARIDIS-MOSCHOU, D., GKIOKA, E. & TSOLAKI, M. 2017. Mobile phone use for 5 minutes can cause significant memory impairment in humans. *Hell J Nucl Med,* 20 Suppl**,** 146-154.

KAMALIPOOYA, S., ABDOLMALEKI, P., SALEMI, Z., JAVANI JOUNI, F., ZAFARI, J. & SOLEIMANI, H. 2017. Simultaneous application of cisplatin and static magnetic field enhances oxidative stress in HeLa cell line. *In Vitro Cell Dev Biol Anim,* 53**,** 783-790.

KANTARCIOGLU, E., KAHILOGULLARI, G., ZAIMOGLU, M., ATMIS, E. O., PEKER, E., YIGMAN, Z., BILLUR, D., AYDIN, S., ERDEN, I. M. & UNLU, A. 2018. The effect of magnetic resonance imaging on neural tube development in an early chicken embryo model. *Childs Nerv Syst,* 34**,** 933-938.

KAYHAN, H., ESMEKAYA, M. A., SAGLAM, A. S., TUYSUZ, M. Z., CANSEVEN, A. G., YAGCI, A. M. & SEYHAN, N. 2016. Does MW Radiation Affect Gene Expression, Apoptotic Level, and Cell Cycle Progression of Human SH-SY5Y Neuroblastoma Cells? *Cell Biochem Biophys,* 74**,** 99-107.

KAZEMEIN JASEMI, V. S., SAMADI, F., EIMANI, H., HASANI, S., FATHI, R. & SHAHVERDI, A. 2017. Comparison of Allotransplantation of Fresh and Vitrified Mouse Ovaries to The Testicular Tissue under Influence of The Static Magnetic Field. *Cell J,* 19**,** 492-505.

KILFOYLE, A. K., JERMAIN, R. F., DHANAK, M. R., HUSTON, J. P. & SPIELER, R. E. 2018. Effects of EMF emissions from undersea electric cables on coral reef fish. *Bioelectromagnetics,* 39**,** 35-52.

KIM, J. H., YU, D. H. & KIM, H. R. 2017a. Activation of autophagy at cerebral cortex and apoptosis at brainstem are differential responses to 835 MHz RF-EMF exposure. *Korean J Physiol Pharmacol,* 21**,** 179-188.

KIM, J. Y., KIM, H. J., KIM, N., KWON, J. H. & PARK, M. J. 2017b. Effects of radiofrequency field exposure on glutamate-induced oxidative stress in mouse hippocampal HT22 cells. *Int J Radiat Biol,* 93**,** 249-256.

KIM, S. J., JANG, Y. W., HYUNG, K. E., LEE, D. K., HYUN, K. H., JEONG, S. H., MIN, K. H., KANG, W., JEONG, J. H., PARK, S. Y. & HWANG, K. W. 2017c. Extremely low-frequency electromagnetic field exposure enhances inflammatory response and inhibits effect of antioxidant in RAW 264.7 cells. *Bioelectromagnetics,* 38**,** 374-385.

KIM, Y. M., CHO, S. E., KIM, S. C., JANG, H. J. & SEO, Y. K. 2017d. Effects of Extremely Low Frequency Electromagnetic Fields on Melanogenesis through p-ERK and p-SAPK/JNK Pathways in Human Melanocytes. *Int J Mol Sci,* 18.

KLIMLEY, A. P., WYMAN, M. T. & KAVET, R. 2017. Chinook salmon and green sturgeon migrate through San Francisco Estuary despite large distortions in the local magnetic field produced by bridges. *PLoS One,* 12**,** e0169031.

KOCAMAN, A., ALTUN, G., KAPLAN, A. A., DENIZ, O. G., YURT, K. K. & KAPLAN, S. 2018. Genotoxic and carcinogenic effects of non-ionizing electromagnetic fields. *Environ Res,* 163**,** 71-79.

KORPINEN, L. & PAAKKONEN, R. 2018. Workers' exposure to electric fields during the task 'maintenance of an operating device of circuit breaker from a service platform' at 110-kV substations. *Int J Occup Saf Ergon***,** 1-4.

KOUZANI, A. Z., KALE, R. P., ZARATE-GARZA, P. P., BERK, M., WALDER, K. & TYE, S. J. 2017. Validation of a Portable Low-Power Deep Brain Stimulation Device Through Anxiolytic Effects in a Laboratory Rat Model. *IEEE Trans Neural Syst Rehabil Eng,* 25**,** 1365-1374.

KUZNIAR, A., LAFFEBER, C., EPPINK, B., BEZSTAROSTI, K., DEKKERS, D., WOELDERS, H., ZWAMBORN, A. P., DEMMERS, J., LEBBINK, J. H. & KANAAR, R. 2017. Semi-quantitative proteomics of mammalian cells upon short-term exposure to non-ionizing electromagnetic fields. *PLoS One,* 12**,** e0170762.

LANDLER, L., PAINTER, M. S., COE, B. H., YOUMANS, P. W., HOPKINS, W. A. & PHILLIPS, J. B. 2017. High levels of maternally transferred mercury disrupt magnetic responses of snapping turtle hatchlings (Chelydra serpentina). *Environ Pollut,* 228**,** 19-25.

LASZLO, A. M., LADANYI, M., BODA, K., CSICSMAN, J., BARI, F., SERESTER, A., MOLNAR, Z., SEPP, K., GALFI, M. & RADACS, M. 2018. Effects of extremely low frequency electromagnetic fields on turkeys. *Poult Sci,* 97**,** 634-642.

LEI, T., LIANG, Z., LI, F., TANG, C., XIE, K., WANG, P., DONG, X., SHAN, S., JIANG, M., XU, Q., LUO, E. & SHEN, G. 2018. Pulsed electromagnetic fields (PEMF) attenuate changes in vertebral bone mass, architecture and strength in ovariectomized mice. *Bone,* 108**,** 10-19.

LI, B., BI, J., LI, W., HUANG, S., ZHANG, S., ZHAO, J., MENG, Q. & FEI, J. 2017a. Effects of pulsed electromagnetic fields on histomorphometry and osteocalcin in disuse osteoporosis rats. *Technol Health Care,* 25**,** 13-20.

LI, J., ZENG, Z., ZHAO, Y., JING, D., TANG, C., DING, Y. & FENG, X. 2017b. Effects of low-intensity pulsed electromagnetic fields on bone microarchitecture, mechanical strength and bone turnover in type 2 diabetic db/db mice. *Sci Rep,* 7**,** 10834.

LI, K., ZHANG, K., XU, S., WANG, X., ZHOU, Y., ZHOU, Y., GAO, P., LIN, J., DING, G. & GUO, G. 2018. EMP-induced BBB-disruption enhances drug delivery to glioma and increases treatment efficacy in rats. *Bioelectromagnetics,* 39**,** 60-67.

LI, S., FARBER, J. P., LINDEROTH, B., CHEN, J. & FOREMAN, R. D. 2017c. Spinal Cord Stimulation With "Conventional Clinical" and Higher Frequencies on Activity and Responses of Spinal Neurons to Noxious Stimuli: An Animal Study. *Neuromodulation.*

LU, X., ODA, M., OHBA, T., MITSUBUCHI, H., MASUDA, S. & KATOH, T. 2017. Association of excessive mobile phone use during pregnancy with birth weight: an adjunct study in Kumamoto of Japan Environment and Children's Study. *Environ Health Prev Med,* 22**,** 52.

LUCIA, U., GRISOLIA, G., PONZETTO, A. & SILVAGNO, F. 2017. An engineering thermodynamic approach to select the electromagnetic wave effective on cell growth. *J Theor Biol,* 429**,** 181-189.

LUYCK, K., TAMBUYZER, T., DEPREZ, M., RANGARAJAN, J., NUTTIN, B. & LUYTEN, L. 2017. Electrical stimulation of the bed nucleus of the stria terminalis reduces anxiety in a rat model. *Transl Psychiatry,* 7**,** e1033.

MADULARU, D., KUMARAGAMAGE, C., MATHIEU, A. P., KULKARNI, P., RAJAH, M. N., GRATTON, A. P. & NEAR, J. 2017. A chronic in situ coil system adapted for intracerebral stimulation during MRI in rats. *J Neurosci Methods,* 284**,** 85-95.

MATTSSON, M.O., ZENI, O., SIMKÓ, M. 2018 Is there a biological basis for therapeutic applications of milli-metre waves and THz waves? *J Infrared Milli Terahz Waves. doi.org/10.1007/s10762-018-0483-5.*

MIAH, T. & KAMAT, D. 2017. Current Understanding of the Health Effects of Electromagnetic Fields. *Pediatr Ann,* 46**,** e172-e174.

MIREKU, M. O., MUELLER, W., FLEMING, C., CHANG, I., DUMONTHEIL, I., THOMAS, M. S. C., EEFTENS, M., ELLIOTT, P., ROOSLI, M. & TOLEDANO, M. B. 2018. Total recall in the SCAMP cohort: Validation of self-reported mobile phone use in the smartphone era. *Environ Res,* 161**,** 1-8.

MISEK, J., BELYAEV, I., JAKUSOVA, V., TONHAJZEROVA, I., BARABAS, J. & JAKUS, J. 2018. Heart rate variability affected by radiofrequency electromagnetic field in adolescent students. *Bioelectromagnetics,* 39**,** 277-288.

MODOLO, J., THOMAS, A. W. & LEGROS, A. 2017. Human exposure to power frequency magnetic fields up to 7.6 mT: An integrated EEG/fMRI study. *Bioelectromagnetics,* 38**,** 425-435.

MORTAZAVI, S. A. R. & MORTAZAVI, S. M. J. 2018. Women with hereditary breast cancer predispositions should avoid using their smartphones, tablets, and laptops at night. *Iran J Basic Med Sci,* 21**,** 112-115.

MOUSAVIDOUST, S., MOBASHERI, H. & RIAZI, G. H. 2017. Effects of static magnetic fields on the structure, polymerization, and bioelectric of tubulin assemblies. *J Biomol Struct Dyn,* 35**,** 3370-3383.

MYKLATUN, A., LAURI, A., EDER, S. H. K., CAPPETTA, M., SHCHERBAKOV, D., WURST, W., WINKLHOFER, M. & WESTMEYER, G. G. 2018. Zebrafish and medaka offer insights into the neurobehavioral correlates of vertebrate magnetoreception. *Nat Commun,* 9**,** 802.

N, A. S., ABD-ALLAH, S. H., HUSSEIN, S. & ALAA ELDEEN, M. 2017. Factors enhancing the migration and the homing of mesenchymal stem cells in experimentally induced cardiotoxicity in rats. *IUBMB Life,* 69**,** 162-169.

NAISBETT-JONES, L. C., PUTMAN, N. F., STEPHENSON, J. F., LADAK, S. & YOUNG, K. A. 2017. A Magnetic Map Leads Juvenile European Eels to the Gulf Stream. *Curr Biol,* 27**,** 1236-1240.

NAYBACK-BEEBE, A. M., YODER, L. H., GOFF, B. J., ARZOLA, S. & WEIDLICH, C. 2017. The effect of pulsed electromagnetic frequency therapy on health-related quality of life in military service members with chronic low back pain. *Nurs Outlook,* 65**,** S26-S33.

NEWTON, K. C. & KAJIURA, S. M. 2017. Magnetic field discrimination, learning, and memory in the yellow stingray (Urobatis jamaicensis). *Anim Cogn,* 20**,** 603-614.

OPITZ, A., FALCHIER, A., LINN, G. S., MILHAM, M. P. & SCHROEDER, C. E. 2017. Limitations of ex vivo measurements for in vivo neuroscience. *Proc Natl Acad Sci U S A,* 114**,** 5243-5246.

OSANAI, H., MINUSA, S. & TATENO, T. 2018. Micro-coil-induced Inhomogeneous Electric Field Produces sound-driven-like Neural Responses in Microcircuits of the Mouse Auditory Cortex In Vivo. *Neuroscience,* 371**,** 346-370.

OSTROM, Q. T., GITTLEMAN, H., STETSON, L., VIRK, S. & BARNHOLTZ-SLOAN, J. S. 2018. Epidemiology of Intracranial Gliomas. *Prog Neurol Surg,* 30**,** 1-11.

OTHMAN, H., AMMARI, M., RTIBI, K., BENSAID, N., SAKLY, M. & ABDELMELEK, H. 2017a. Postnatal development and behavior effects of in-utero exposure of rats to radiofrequency waves emitted from conventional WiFi devices. *Environ Toxicol Pharmacol,* 52**,** 239-247.

OTHMAN, H., AMMARI, M., SAKLY, M. & ABDELMELEK, H. 2017b. Effects of prenatal exposure to WIFI signal (2.45GHz) on postnatal development and behavior in rat: Influence of maternal restraint. *Behav Brain Res,* 326**,** 291-302.

OTHMAN, H., AMMARI, M., SAKLY, M. & ABDELMELEK, H. 2017c. Effects of repeated restraint stress and WiFi signal exposure on behavior and oxidative stress in rats. *Metab Brain Dis,* 32**,** 1459-1469.

OYEWOPO, A. O., OLANIYI, S. K., OYEWOPO, C. I. & JIMOH, A. T. 2017. Radiofrequency electromagnetic radiation from cell phone causes defective testicular function in male Wistar rats. *Andrologia,* 49.

PALL, M. L. 2018. Wi-Fi is an important threat to human health. *Environ Res,* 164**,** 405-416.

PANDEY, N. & GIRI, S. 2018. Melatonin attenuates radiofrequency radiation (900 MHz)-induced oxidative stress, DNA damage and cell cycle arrest in germ cells of male Swiss albino mice. *Toxicol Ind Health,* 34**,** 315-327.

PARK, J., KWON, J. H., KIM, N. & SONG, K. 2018. Effects of 1950 MHz radiofrequency electromagnetic fields on Abeta processing in human neuroblastoma and mouse hippocampal neuronal cells. *J Radiat Res,* 59**,** 18-26.

PINZON-RODRIGUEZ, A. & MUHEIM, R. 2017. Zebra finches have a light-dependent magnetic compass similar to migratory birds. *J Exp Biol,* 220**,** 1202-1209.

PODOLSKA, K. 2018. The Impact of Ionospheric and Geomagnetic Changes on Mortality from Diseases of the Circulatory System. *J Stroke Cerebrovasc Dis,* 27**,** 404-417.

PRASAD, A., TEH, D. B. L., BLASIAK, A., CHAI, C., WU, Y., GHARIBANI, P. M., YANG, I. H., PHAN, T. T., LIM, K. L., YANG, H., LIU, X. & ALL, A. H. 2017. Static Magnetic Field Stimulation Enhances Oligodendrocyte Differentiation and Secretion of Neurotrophic Factors. *Sci Rep,* 7**,** 6743.

PUTMAN, N. F., SCANLAN, M. M., POLLOCK, A. M., O'NEIL, J. P., COUTURE, R. B., STONER, J. S., QUINN, T. P., LOHMANN, K. J. & NOAKES, D. L. G. 2018. Geomagnetic field influences upward movement of young Chinook salmon emerging from nests. *Biol Lett,* 14.

REDMAYNE, M. 2018. An explanation for under-estimation of high mobile phone use. *Int J Hyg Environ Health,* 221**,** 990-992.

REEDIJK, M., LENTERS, V., SLOTTJE, P., PIJPE, A., PEETERS, P. H., KOREVAAR, J. C., BUENO-DE-MESQUITA, B., VERSCHUREN, W. M. M., VERHEIJ, R. A., PIETERSON, I., VAN LEEUWEN, F. E., ROOKUS, M. A., KROMHOUT, H. & VERMEULEN, R. C. H. 2018. Cohort profile: LIFEWORK, a prospective cohort study on occupational and environmental risk factors and health in the Netherlands. *BMJ Open,* 8**,** e018504.

REZAIE-TAVIRANI, M., HASANZADEH, H., SEYYEDI, S. & ZALI, H. 2017. Proteomic Analysis of the Effect of Extremely Low-Frequency Electromagnetic Fields (ELF-EMF) With Different Intensities in SH-SY5Y Neuroblastoma Cell Line. *J Lasers Med Sci,* 8**,** 79-83.

ROOZBEH, N., ABDI, F., AMRAEE, A., ATARODI KASHANI, Z. & DARVISH, L. 2018. Influence of Radiofrequency Electromagnetic Fields on the Fertility System: Protocol for a Systematic Review and Meta-Analysis. *JMIR Res Protoc,* 7**,** e33.

RUSSELL, C. L. 2018. 5 G wireless telecommunications expansion: Public health and environmental implications. *Environ Res,* 165**,** 484-495.

SAGAR, S., ADEM, S. M., STRUCHEN, B., LOUGHRAN, S. P., BRUNJES, M. E., ARANGUA, L., DALVIE, M. A., CROFT, R. J., JERRETT, M., MOSKOWITZ, J. M., KUO, T. & ROOSLI, M. 2018a. Comparison of radiofrequency electromagnetic field exposure levels in different everyday microenvironments in an international context. *Environ Int,* 114**,** 297-306.

SAGAR, S., DONGUS, S., SCHOENI, A., ROSER, K., EEFTENS, M., STRUCHEN, B., FOERSTER, M., MEIER, N., ADEM, S. & ROOSLI, M. 2018b. Radiofrequency electromagnetic field exposure in everyday microenvironments in Europe: A systematic literature review. *J Expo Sci Environ Epidemiol,* 28**,** 147-160.

SAGE, C. & BURGIO, E. 2018. Electromagnetic Fields, Pulsed Radiofrequency Radiation, and Epigenetics: How Wireless Technologies May Affect Childhood Development. *Child Dev,* 89**,** 129-136.

SAGE, C. & HARDELL, L. 2018. Fatal collision? Are wireless headsets a risk in treating patients? *Electromagn Biol Med,* 37**,** 95-99.

SAGIV, D., MIGIROV, L., MADGAR, O., NAKACHE, G., WOLF, M. & SHAPIRA, Y. 2018. Mobile phone usage does not affect sudden sensorineural hearing loss. *J Laryngol Otol,* 132**,** 29-32.

SAMADDAR, S., VAZQUEZ, K., PONKIA, D., TORUNO, P., SAHBANI, K., BEGUM, S., ABOUELELA, A., MEKHAEL, W. & AHMED, Z. 2017. Transspinal direct current stimulation modulates migration and proliferation of adult newly born spinal cells in mice. *J Appl Physiol (1985),* 122**,** 339-353.

SATO, Y., KOJIMAHARA, N., TAKI, M. & YAMAGUCHI, N. 2018. Analysis of ear side of mobile phone use in the general population of Japan. *Bioelectromagnetics,* 39**,** 53-59.

SATO, Y., KOJIMAHARA, N. & YAMAGUCHI, N. 2017. Analysis of mobile phone use among young patients with brain tumors in Japan. *Bioelectromagnetics,* 38**,** 349-355.

SATTA, G., MASCIA, N., SERRA, T., SALIS, A., SABA, L., SANNA, S., ZUCCA, M. G., ANGELUCCI, E., GABBAS, A., CULURGIONI, F., PILI, P., MURA, E., CAPPAI, M., ENNAS, M. G. & COCCO, P. 2018. Estimates of Environmental Exposure to Radiofrequency Electromagnetic Fields and Risk of Lymphoma Subtypes. *Radiat Res,* 189**,** 541-547.

SCHMIEDCHEN, K., PETRI, A. K., DRIESSEN, S. & BAILEY, W. H. 2018. Systematic review of biological effects of exposure to static electric fields. Part II: Invertebrates and plants. *Environ Res,* 160**,** 60-76.

SCHUZ, J. & ERDMANN, F. 2016. Environmental Exposure and Risk of Childhood Leukemia: An Overview. *Arch Med Res,* 47**,** 607-614.

SEO, T., OH, S., JUNG, D., HUH, Y., CHO, J., KWON, Y. 2018. Noninvasive brain stimulation using a modulated microwave signal. *JEES* 18: 70-72

SHAHIN, S., SINGH, S. P. & CHATURVEDI, C. M. 2017. Mobile phone (1800MHz) radiation impairs female reproduction in mice, Mus musculus, through stress induced inhibition of ovarian and uterine activity. *Reprod Toxicol,* 73**,** 41-60.

SHAHIN, S., SINGH, S. P. & CHATURVEDI, C. M. 2018. 1800 MHz mobile phone irradiation induced oxidative and nitrosative stress leads to p53 dependent Bax mediated testicular apoptosis in mice, Mus musculus. *J Cell Physiol,* 233**,** 7253-7267.

SHAKHPARONOV, V. V. & OGURTSOV, S. V. 2017. Marsh frogs, Pelophylax ridibundus, determine migratory direction by magnetic field. *J Comp Physiol A Neuroethol Sens Neural Behav Physiol,* 203**,** 35-43.

SIENKIEWICZ, Z., CALDERON, C., BROOM, K. A., ADDISON, D., GAVARD, A., LUNDBERG, L. & MASLANYJ, M. 2017. Are Exposures to Multiple Frequencies the Key to Future Radiofrequency Research? *Front Public Health,* 5**,** 328.

SOLIMAN, N.A., ABD-ALLAH, S.H., HUSSEIN, S., ALAA ELDEEN, M. 2017. Factors enhancing the migration and the homing of mesenchymal stem cells in experimentally induced cardiotoxicity in rats. *IUBMB Life* 69: 162-169

STRAKER, L., HARRIS, C., JOOSTEN, J. & HOWIE, E. K. 2018. Mobile technology dominates school children's IT use in an advantaged school community and is associated with musculoskeletal and visual symptoms. *Ergonomics,* 61**,** 658-669.

TAHERI, M., ROSHANAEI, G., GHAFFARI, J., RAHIMNEJAD, S., KHOSROSHAHI, B. N., ALIABADI, M. & EFTEKHARIAN, M. M. 2017. The effect of Base Transceiver Station waves on some immunological and hematological factors in exposed persons. *Hum Antibodies,* 25**,** 31-37.

TOLEDANO, M. B., AUVINEN, A., TETTAMANTI, G., CAO, Y., FEYCHTING, M., AHLBOM, A., FREMLING, K., HEINAVAARA, S., KOJO, K., KNOWLES, G., SMITH, R. B., SCHUZ, J., JOHANSEN, C., POULSEN, A. H., DELTOUR, I., VERMEULEN, R., KROMHOUT, H., ELLIOTT, P. & HILLERT, L. 2018. An international prospective cohort study of mobile phone users and health (COSMOS): Factors affecting validity of self-reported mobile phone use. *Int J Hyg Environ Health,* 221**,** 1-8.

TURNER, M. C., SADETZKI, S., LANGER, C. E., VILLEGAS PH, D. R., FIGUEROLA, J., ARMSTRONG, B. K., CHETRIT, A., GILES, G. G., KREWSKI, D., HOURS, M., MCBRIDE, M. L., PARENT, M. E., RICHARDSON, L., SIEMIATYCKI, J., WOODWARD, A. & CARDIS, E. 2016. Investigation of bias related to differences between case and control interview dates in five INTERPHONE countries. *Ann Epidemiol,* 26**,** 827-832 e2.

ULASOV, I. V., FOSTER, H., BUTTERS, M., YOON, J. G., OZAWA, T., NICOLAIDES, T., FIGUEROA, X., HOTHI, P., PRADOS, M., BUTTERS, J. & COBBS, C. 2017. Precision knockdown of EGFR gene expression using radio frequency electromagnetic energy. *J Neurooncol,* 133**,** 257-264.

VAENA, M., SINNECKER, J. P., VARGAS, T. J. S., SERRA-GUIMARAES, F. & MARQUES, R. G. 2017. Magnetic transcutaneous fixation: an experimental study in pigs. *J Surg Res,* 220**,** 139-146.

WANG, H. & ZHANG, X. 2017. Magnetic Fields and Reactive Oxygen Species. *Int J Mol Sci,* 18.

VERMEULEN, R., KOEMAN, T. & KROMHOUT, H. 2017. Response to: 'Does 'job' predict exposure to magnetic fields?' by Sorahan and Swanson. *Occup Environ Med,* 74**,** 925-926.

WIEDEMANN, P. M., FREUDENSTEIN, F., BOHMERT, C., WIART, J. & CROFT, R. J. 2017. RF EMF Risk Perception Revisited: Is the Focus on Concern Sufficient for Risk Perception Studies? *Int J Environ Res Public Health,* 14.

VILLARINI, M., GAMBELUNGHE, A., GIUSTARINI, D., AMBROSINI, M. V., FATIGONI, C., ROSSI, R., DOMINICI, L., LEVORATO, S., MUZI, G., PIOBBICO, D. & MARIUCCI, G. 2017. No evidence of DNA damage by co-exposure to extremely low frequency magnetic fields and aluminum on neuroblastoma cell lines. *Mutat Res,* 823**,** 11-21.

VOROSLAKOS, M., TAKEUCHI, Y., BRINYICZKI, K., ZOMBORI, T., OLIVA, A., FERNANDEZ-RUIZ, A., KOZAK, G., KINCSES, Z. T., IVANYI, B., BUZSAKI, G. & BERENYI, A. 2018. Direct effects of transcranial electric stimulation on brain circuits in rats and humans. *Nat Commun,* 9**,** 483.

VUKA, I., VUCIC, K., REPIC, T., FERHATOVIC HAMZIC, L., SAPUNAR, D. & PULJAK, L. 2018. Electrical Stimulation of Dorsal Root Ganglion in the Context of Pain: A Systematic Review of In Vitro and In Vivo Animal Model Studies. *Neuromodulation,* 21**,** 213-224.

VUOKKO, A., KARVALA, K., LAMPI, J., KESKI-NISULA, L., PASANEN, M., VOUTILAINEN, R., PEKKANEN, J. & SAINIO, M. 2018. Environmental Intolerance, Symptoms and Disability Among Fertile-Aged Women. *Int J Environ Res Public Health,* 15.

XIAOLIN, H., GUANGHAO, Z., CHANGZHE, W. & CHENG, Z. 2017. Electric field stimulation protects injured spinal cord from secondary inflammatory response in rats. *Conf Proc IEEE Eng Med Biol Soc,* 2017**,** 1958-1961.

XU, J., PAN, W., ZHANG, Y., LI, Y., WAN, G., CHEN, F., SWORD, G. A. & PAN, W. 2017a. Behavioral evidence for a magnetic sense in the oriental armyworm, Mythimna separata. *Biol Open,* 6**,** 340-347.

XU, X., LIU, Y., LIU, D., LI, X., RAO, Y., SHARMA, M. & ZHAO, Y. 2017b. Prevalence and Determinants of Gestational Diabetes Mellitus: A Cross-Sectional Study in China. *Int J Environ Res Public Health,* 14.

YAMAGUCHI, A., ISHIBASHI, H., KONO, S., IIDA, M., UCHIDA, M., ARIZONO, K. & TOMINAGA, N. 2018. Nanosecond pulsed electric field incorporation technique to predict molecular mechanisms of teratogenicity and developmental toxicity of estradiol-17beta on medaka embryos. *J Appl Toxicol,* 38**,** 714-723.

YAN, Z. 2018. Child and Adolescent Use of Mobile Phones: An Unparalleled Complex Developmental Phenomenon. *Child Dev,* 89**,** 5-16.

ZHAO, J., LI, Y. G., DENG, K. Q., YUN, P. & GONG, T. 2017a. Therapeutic Effects of Static Magnetic Field on Wound Healing in Diabetic Rats. *J Diabetes Res,* 2017**,** 6305370.

ZHAO, L., LI, J., HAO, Y. H., GAO, Y. B., WANG, S. M., ZHANG, J., DONG, J., ZHOU, H. M., LIU, S. C. & PENG, R. Y. 2017b. Microwave-induced Apoptosis and Cytotoxicity of NK Cells through ERK1/2 Signaling. *Biomed Environ Sci,* 30**,** 323-332.

ZHOU, J., LIAO, Y., ZENG, Y., XIE, H., FU, C. & LI, N. 2017. Effect of intervention initiation timing of pulsed electromagnetic field on ovariectomy-induced osteoporosis in rats. *Bioelectromagnetics,* 38**,** 456-465.

ZHU, B. Y., YANG, Z. D., CHEN, X. R., ZHOU, J., GAO, Y. H., XIAN, C. J. & CHEN, K. M. 2018. Exposure Duration Is a Determinant of the Effect of Sinusoidal Electromagnetic Fields on Peak Bone Mass of Young Rats. *Calcif Tissue Int*.

ZILOV, V. G., KHADARTSEV, A. A., TEREKHOV, I. V. & BONDAR, S. S. 2017. Relationship between the Contents of Cyclins, Cyclin-Dependent Kinases, and Their Inhibitors in Whole Blood Mononuclear Leukocytes during the Postclinical Stage of Community-Acquired Pneumonia under the Influence of 1-GHz Microwaves. *Bull Exp Biol Med,* 163**,** 623-626.

2019:08

The Swedish Radiation Safety Authority has a comprehensive responsibility to ensure that society is safe from the effects of radiation. The Authority works to achieve radiation safety in a number of areas: nuclear power, medical care as well as commercial products and services. The Authority also works to achieve protection from natural radiation and to increase the level of radiation safety internationally.

The Swedish Radiation Safety Authority works proactively and preventively to protect people and the environment from the harmful effects of radiation, now and in the future. The Authority issues regulations and supervises compliance, while also supporting research, providing training and information, and issuing advice. Often, activities involving radiation require licences issued by the Authority. The Swedish Radiation Safety Authority maintains emergency preparedness around the clock with the aim of limiting the aftermath of radiation accidents and the unintentional spreading of radioactive substances. The Authority participates in international co-operation in order to promote radiation safety and finances projects aiming to raise the level of radiation safety in certain Eastern European countries.

The Authority reports to the Ministry of the Environment and has around 300 employees with competencies in the fields of engineering, natural and behavioural sciences, law, economics and communications. We have received quality, environmental and working environment certification.