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Children's health and RF EMF exposure

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Abstract
The present report documents a dialogue between scientists reviewing the currently available scientific evidence with respect to the effects of RF EMF exposure on children. The focus was directed towards a transparent and comprehensible characterization of the findings and conclusions for the evaluation of the relationship between mobile phone communication and children's health. The now available report, based on the scientific opinions of the experts as well as on a series of workshops, aims to help the public and policy makers to better understand the current state of the scientific evidence as well as implications for the risk evaluation with respect to children.

Keywords
health, exposure, emf, rf, children

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Report

Children's health and RF EMF exposure

Peter Wiedemann, Holger Schütz, Franziska Börner, Gabriele Berg-Beckhoff, Rodney Croft, Alexander Lerchl, Luc Martens, Georg Neubauer, Sabine Regel, and Michael Repacholi

September 2009

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Preface

The present report documents a dialogue between scientists reviewing the currently available scientific evidence with respect to the effects of RF EMF exposure on children.

The focus was directed towards a transparent and comprehensible characterization of the findings and conclusions for the evaluation of the relationship between mobile phone communication and children's health.

The now available report, based on the scientific opinions of the experts as well as on a series of workshops, aims to help the public and policy makers to better understand the current state of the scientific evidence as well as implications for the risk evaluation with respect to children.

We thank T-Mobile Germany, who supported this study financially.

Peter Wiedemann, Holger Schütz, Franziska Börner

Summary

Aim

The report is reviewing and evaluating the current state of the scientific evidence of the effects of EMF exposure from cell phones and base stations on children's health.

Three main areas of children's health were assessed:

- Cancer (brain cancer and leukaemia) and health disturbances,
- Effects on embryonic development, offspring, and blood-brain barrier investigated by animal research,
- Effects on cognition and the central nervous system (CNS).

Additionally, dosimetry issues were considered, i.e. whether children do absorb more power than adults when exposed to RF EMF.

Procedure

The report is based on the scientific opinions of 7 international recognized experts and 4 advisory experts from Australia, Austria, Belgium, Germany, Italy and Switzerland as well as on a series of workshop discussion.

An important criterion for the selection of the experts was that they have a strong record in EMF research, as documented by publications in internationally recognized and peer-reviewed academic journals.

Advisory expert panelists supported the discussions of the expert opinions during the workshops. For their selection, it was not required that the scientific research of the advisory experts focuses specifically on the EMF field. Rather, the selection depended on their theoretical and methodological knowledge for the respective topic area to critically review the expert opinion reports.

Subsequently, for all relevant endpoints evidence maps were constructed, i.e. graphical representations of the main arguments on which the conclusions are based as well as a description of the remaining uncertainties.

The dialogue project was initiated in October 2007 and completed in August 2009.

Results

<u>Dosimetry</u>

For children under 8 years no conclusive evidence exists for the assumption that the SAR level in children's head is higher than for adults. For whole body exposure, there is some evidence that the ICNIRP reference level cannot ensure that basic restrictions are not exceeded under any circumstances. This applies for children younger than 8 years at specific frequency bands, e.g. around 100 MHz and 1.8 GHz. However, even if further research would prove this it has to be taken into account that ICNIRP basic restrictions comprise large safety factors and real-world

whole body exposure levels are usually far below ICNIRP reference levels.

Health specific endpoints

Overall, the review of the existing scientific literature does not support the assumption that children's health is affected by RF EMF exposure from mobile phones or base stations. Especially, animal research provides no substantial argument that children are at risk. However, with respect to some endpoints in human risk assessment, in particular cognitive effects and general health disturbances, the available evidence is rather limited so that no firm conclusions can be drawn. Further research is needed in order to fill these knowledge gaps.

Studies on humans

The balance of evidence does not indicate an evaluated risk of RF EMF exposure for children's health.

Brain cancer: There is no evidence showing that RF EMF exposure might induce brain cancer. Because the available studies investigated the effects of exposure from radio- and television transmitters, the results cannot be extrapolated to exposure from mobile communication base stations without reservations.

Leukaemia: The balance of evidence seems not to support an association with RF EMF. Here, the same reservations have to be taken into account as for the above mentioned brain cancer studies.

Health disturbances: With regard to general health disturbances in children the available evidence is limited but does not indicate an association with RF EMF exposure. However, the studies suffer – with one exception – from poor exposure assessment, which makes it difficult if not impossible to relate RF EMF exposure to health disturbance effects.

Effects on cognition and CNS: On balance, the evidence so far provides no substantive indications for effects of RF EMF exposure on cognitive performance and CNS functions of children. However, the very limited evidence available cannot rule out the possibility that RF EMF exposure might influence cognitive and other CNS functions in children. Even if future evidence would support an influence of RF EMF exposure on cognitive and other CNS functions in children, it would be critical to evaluate whether the effects found can be considered as an indication for a health risk.

Animal experiments

The available data from animal experiments do not indicate that younger animals are at risk, when exposed to RF electromagnetic fields at relevant exposure scenarios. Despite the general problem of extrapolating these results straightforwardly to humans, they provide no indication that children are at higher risk.

Effects on embryonic and fetal development: No adverse effects have been reported at non-thermal exposure levels in the available studies. The extrapolation of these negative results from animal experiments to humans is restricted. Nevertheless, it seems very unlikely that children are at higher risk.

Postnatal development: Nearly all studies concerning offspring do not suggest any significant threat to the development of offspring when exposed to non-thermal RF levels. Whilst the extrapolation of these results from animal experiments to humans is restricted, it provides no substantial argument that children are at risk.

Effects on the blood brain barrier: The weight of evidence solidly refutes the assumption that RF EMF exposure causes effects on the permeability of the blood brain barrier and nerve cell damage in young animals. However, some reservations have to be made when extrapolating these results from animal experiments to humans.

Self assessment of the risk dialogue project

Table 1:Self assessment

Risk dialogue "Children's and RF EMF exposure"		
General information		
1	Source (Link to get the document)	Report available on request
2	Duration	2007-2009
3	Conducted by (name of organization)	MUT
4	Objectives	Assessment of the available evidence for the special vulnerability of children with respect to RF EMF exposure
5	Fields covered in the risk assessment	Dosimetry, cancer epidemiology, impairment of well being, animal research on reproduction and development, effects on CNS & cognition
	EMF spectrum (ELF, RF)	RF EMF
6	Funding	T-Mobile
Mandate		
7	Legal status	No
8	Accountability (to whom)	All project decisions were made by MUT
Membership		
9	Members' selection	Experts selected by MUT
10	Disclosure of members' names	Yes
11	Number of members	7
12	Number of observers / advisors	4
Expertise		
13	Expertise	Demonstrated by expert's own research in the fields relevant for the review
14	Coverage of the needed spectrum of expertise for the goals of the risk assessment	Yes
Impartiality		
15	Firewall	MUT served as firewall, experts did not have contact with the sponsor during the conduct of the risk assessment
Process of Risk Assessment		
16	Endpoint selection (rationale/by whom)	By the experts
17	Literature selection	Description of the data collection procedure, timeframe
18	Explicit description of the study selection criteria	Partially
19	Procedure for weighting evidence with respect to a specific endpoint	Evidence map, constructed by MUT based on expert reports
20	Procedure for combining evidence from different research types (i.e. animal research, epidemiology, e.g., narrative , weight of evidence approach)	Qualitative approach
21	Peer review process (for instance, internal within broader organisations)	Yes, with help of the advisory experts in the interim workshops
22	Overall Judgement and scientific opinion	Consensus reached in the workshops
Consultation		
23	External (Stakeholder)	With other experts at the final workshop
24	Degree of openness to comments and suggestions from external stakeholders and the general public	Open for critique and suggestions
Evaluation & Summary		
25	Differentiation between biological and detrimental effects	Yes
26	Explicit description of both sides of the discussion (two sided argumentation)	Yes
27	Reasonable and transparent derivation of the evaluative conclusions	Yes
28	Description of uncertainties in the evaluation	Yes

Approach to the risk dialogue

Introduction

The use of mobile phones among children and teenagers is growing as documented by surveys in several countries. In Germany about 90% of the children between the age of 12 and 13 owned a mobile phone in 2008 (MPFS 2008); in Hungary nearly 76% of fourth grade school children owned in 2006 a mobile phone (Mezei et al. 2007). Similar data comes from Sweden (Söderqvist 2007); here about 79% of the children aged 7-14 reported mobile phone access in 2006. This development raises questions about potential health risks of the use of mobile phones to children.

It is not surprising that the issue of children's special vulnerability with respect to potential risks from exposure to RF EMF is heavily debated in the scientific community. It has also continued to get rising attention among the public and political decision makers.

The issue started in 2000, when the British Stewart Report underlined its recommendation to implement precautionary principles in RF EMF risk management with the focus on children: Since this time, many papers and conferences have dealt with this issue. The Dutch Health Council summarized in 2002:

> "It is unlikely from a developmental point of view that major changes in brain sensitivity to electromagnetic fields still occur after the second year of life. The committee therefore concludes that there is no reason to recommend that mobile telephone use by children should be limited as far as possible."

The World Health Organization (WHO) conducted in 2004 a workshop[1] on sensitivity of children to EMF exposure in Istanbul and released research recommendations in this respect. In the UK, the National Radiological Protection Board (NRPB) stated in 2005 that the main conclusions of the Stewart report are still valid. Researchers, for example Kheifets et al. (2005) recommend low-cost precautionary measures, particularly for children, regarding the potential long-term health effects of mobile phone use.

In 2006, the Research Association for Radio Application (FGF) and EMF-Net carried out a workshop in order to discuss, whether children represent a special sensitive group for EMF exposure. The workshop concluded that the currently available scientific evidence does not give commonly acknowledged reasons to be concerned about the use of mobile phones by children and teenagers.[2]

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[1] WHO Workshop Sensitivity of Children to EMF Exposure. http://www.who.int/peh-emf/meetings/children_turkey_june2004/en/index1.html

[2] „Die abschießende Diskussion der bisherigen Forschungsergebnisse zur Einwirkung elektromagnetischer Felder ergab, dass es auf wissenschaftlicher Basis derzeit keinen gemeinsam anerkannten Grund gibt, der für Kinder und Jugendliche Anlass zu Besorgnis im Umgang mit der Mobilfunktechnik geben könnte" FGF Newsletter, 1, 2007, p.14

In contrast, the BioInitative Report (2007, section1, p.14) declared:

> “The consequence of prolonged exposures to children, whose nervous systems continue to develop until late adolescence, is unknown at this time. This could have serious implications to adult health and functioning in society if years of exposure of the young to both ELF and RF result in diminished capacity for thinking, judgment, memory, learning, and control over behavior.”

Recently, the European Commission’s Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) has addressed the same topic (2007, 2009). SCENIHR came to the conclusion – from a risk assessment perspective – that information on possible effects caused by RF fields in children is limited.

Procedure

The dialogue project was initiated in October 2007 and completed in August 2009. The project proceeded along the following steps: (1) selection of the experts and advisory expert panelists, (2) preparation of the opinion reports by the experts, (3) discussion of the expert opinion reports with the advisory experts in workshops, (4) possibility for revising the expert opinion reports, and (5) a collective final workshop.

Expert selection

Experts from Australia, Austria, Belgium, Germany, Italy and Switzerland, recognized for conducting their own research programs in the RF EM field, were engaged as experts or advisory expert panelists. The selection of the experts through the program group MUT was to ensure that the spectrum of different expert opinions on each issue was represented.

An important criterion for the selection of the experts was that they have a strong record in EMF research, as documented by publications in internationally recognized and peer-reviewed academic journals. This was to ensure that the experts would have theoretical background as well as the methodological knowledge for preparing an expert opinion report.

The critiques and discussions of the expert opinion reports during the workshops were to be supported by advisory expert panelists. For their selection, it was not required that the scientific research of the advisory experts focuses specifically on the EMF field. Rather, the selection depended on their professional knowledge for the respective topic area to critically review the expert opinion reports and the experts’ line of reasoning in regards to the contextual-theoretical and methodological basis.

Table 2: Participating experts

EEG and effects on cognitive functions in children (memory, attention, learning)	
Experts	*Advisory Expert*
Prof. Dr. Rodney Croft Australian Centre for RF Bioeffects Research, National Health and Medical Research Council,	Prof. Dr. Siegfried Gauggel University Hospital Aachen, Institute for Medical Psychology and Medical Sociology,

Hawthorn, Australia Dr. Sabine Regel University Zurich, Institute for Pharmakology and Toxicology, Zürich, Switzerland	Aachen, Germany

Animal models and development disorder	
Experts	*Advisory Expert*
Prof. Dr. Alexander Lerchl Jacobs University Bremen, School of Engineering and Science, Bremen, Germany Prof. Dr. Michael Repacholi University of Rome "La Sapienza", Department of Electronic Engineering, Rome, Italy	Prof. Dr. Volker Mersch-Sundermann University Hospital Freiburg, Department of Environmental Health Sciences, Freiburg, Germany

Effects on cancer (leukemia/brain tumors) and well being	
Experts	*Advisory Expert*
Prof. Dr. Gabriele Berg-Beckhoff University Bielefeld, Faculty of Health Sciences, Bielefeld, Germany	Prof. Dr. Katja Radon University Hospital Munich, Institute and Outpatient Clinic for Occupational, Social and Environmental Medicine, München, Germany

Dosimetry issues: RF EMF absorption in children's heads	
Experts	*Advisory Expert*
Prof. Dr. Luc Martens Ghent University, Department of Information Technology, Ghent, Belgium Dr. Georg Neubauer ARC Seibersdorf Research GmbH, Smart System Division, Seibersdorf, Austria	Prof. Dr. Norbert Leitgeb Technical University Graz, Institute for Health Care Engineering, Graz, Austria

Expert reports

In order to ensure the greatest amount of uniformity, we suggested a structure for the preparation of the expert reports.[3] Each report should address the following points:

1. Aim of the expert report
   - Characterization of the topic (especially in regard to the relevance of the findings from this topic for the evaluation of potential health risks).
2. Selection of the endpoints
   - Selected endpoints and rationale behind their selection.
3. Selection of the studies to be considered
   - Criteria for the selection of the considered studies (if necessary, also mention of the selected field strengths, frequency range and signal shape).
   - Search strategies for the selection of primary research studies (personal bibliographic lists of references/ databases; Medline, etc.).
   - Information on the quality of method for each study.
4. Presentation of the state of scientific knowledge
   - Discussion of the findings and method of the studies for each individual endpoint.
   - Evaluation of the scientific weight-of-evidence for the individual endpoints.
5. Overall evaluation for the topic
   - Summarizing evaluation of the scientific evidence for the topic
6. List of the considered studies and the references used

The two experts in each group were asked to coordinate the first two work steps among them, so that the reports for each topic would pertain to the same endpoints and be based on the evaluation of the same set of primary studies. All expert reports can be found in annex 1.

Workshops

For each of the four topics a workshop was conducted in order to discuss the preliminary reports with the advisory expert.

All four topic workshops followed the same structure: After introduction of the reports by the two topic experts questions of clarification were answered. Then followed the assessment of the expert reports by the advisory experts, wherein the advisory experts addressed specifically the following points:

- Based on the presented primary studies, are the conclusions drawn in the

[3] The suggestion of MUT for the structured presentation of the expert opinion reports was guided by the Cochrane Review (see http://www.cochrane.dk/cochrane/handbook/3_1_rationale_for_protocols.htm) and (http://www.cochrane.dk/cochrane/handbook/appendix_2a_guide_to_the_format_of_a_cochrane_review.htm), (http://www.cochrane.dk/cochrane/handbook/hbook.htm).

expert opinion reports plausible?

- Did the primary studies use appropriate methodology (study design, exposure measurement, effect measurement, evaluation procedures, etc.)?
- Were alternative explanations for positive as well as negative findings considered?
- How is the consistency or inconsistency of the overall scientific picture to be judged?
- Based on the presented studies, are the conclusions regarding the relevance to children's health plausible?

While only the experts, the advisory experts, and the MUT project team participated in the topic specific workshops, additional experts as well as representatives of the funding organization for the project participated in the final workshop. .

In the final workshop, one expert from each topic area first presented the central results. Then MUT presented the weight-of-evidence for the respective topic area offered in the expert reports in form of several evidence maps. Afterwards the evidence maps as well as cross-linkages between the four topic areas were discussed.

The workshops were conducted from August 2008 until May 2009.

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Dosimetry

Introduction

With respect to radiofrequency fields dosimetry can be defined as the science that investigates the coupling of RF waves from external sources to the human body resulting in power absorption.

Power absorption is measured by the specific absorption rate (SAR). It is defined as the rate at which power is absorbed in body tissues, and measured in watts per kilogram.[4]

A whole-body average SAR of 0.4 W/kg has been chosen by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) as the restriction that provides adequate protection for occupational exposure. An additional safety factor of 5 was introduced for exposure of the public, giving an average whole-body SAR limit of 0.08 W/kg.

The actual amount of power absorption can be influenced by many parameters, e.g., distance to the phone, holding position of the phone, position of the antenna, pinna size, elasticity of the ear, thickness of the skull, type of tissue, tissue type distribution, etc (Christ & Kuster, 2005).

[4] SAR values are to be averaged over any 6-min period as well as over a certain volume.

Body of evidence

Dielectric Properties

The available animal studies clearly indicate that dielectric properties change with age. However, a major restriction is the limited extrapolation of these animal study results to humans. Furthermore, dielectric properties are only one of many factors influencing power absorption under real world conditions. Therefore, the relative impact of dielectric properties on energy absorption compared to all the other factors has to be determined. It seems that an increase of the dielectric properties does not necessarily mean an increase of the SAR level. In general, the impact of dielectric properties on SAR appears to be low.

Table 3: Studies regarding dielectric properties

Author	Assay	Main Findings
Thurai et al., 1984	Mouse and rabbit brain tissue	Systematic changes in the dielectric properties of mouse and rabbit brain tissue as a function of the age of the animal
Thurai et al., 1985	Mouse and rabbit brain tissue	Systematic changes in the dielectric properties of mouse and rabbit brain tissue as a function of he age of the animal
Lu et al. ,1994	Human red blood cells in suspension	Statistically significant age dependence, with a critical age of about 49 years, above this age both permittivity and conductivity decreased significantly
Jaspard et al., 2003	Human blood cells	Above 50 MHz the permittivity decreases with the transition from childhood to adolescence. Conductivity decreases as well.
Peyman et al., 2001; Peyman & Gabriel 2002	Tissue from newborn to fully grown rats	Decrease of dielectric properties with age, the changes are caused by changes in the water content and organic composition of tissues
Peyman 2007	Tissue from pigs	White matter and spinal chord showed significant variation as function of animal age, no age-related variations were recorded for grey matter
Gabriel 2005	Rat tissue	At frequencies above 100 MHz the permittivity and conductivity decrease monotonically with increasing age, at lower frequencies a change in the frequency dependence of the dielectric parameters is observed. Both the conductivity and the permittivity are higher at younger ages.
Schmid & Überbacher, 2005	Bovine brain and ocular tissues	The differences between the dielectric properties of white matter and cortical lense tissue of the two animal groups were significant. In the case of white matter the mean values of conductivity and permittivity of the younger animals' tissue were 15 – 22% and 12-15 % higher compared to the adult tissue in the considered frequency range, respectively. For cortical lens tissue the corresponding values were 25 – 76 and 27 – 39%.
Peyman et al., 2007	Pig cerebrospinal tissues; measured *in vivo* and *in vitro*	In general, both permittivity and conductivity showed a decrease with increasing age and weight.

Head Exposure

The various studies comparing power absorption in adult's and children's head produce heterogeneous results. No consistent picture emerges. Power absorption in the head is influenced by many factors. The models used cannot adequately depict this complexity and different approaches to computations come therefore to different results. Hence, an assessment of the overall uncertainty of the calculations is needed to clarify whether the differences between child and adult models are not due to model and measurement uncertainty.

Table 4: Findings with respect to head exposure

Author	Main Findings	Conclusion
Gandhi et al., 1996	Peak voxel and 1 g SAR values were higher in the children's head models. The peak 1 g SAR value in the brain for the adult, the 10 year 10 old child and the 5 year old child were 1.13, 1.42 and 1.56 W/kg, respectively. A heterogeneous adult head model was used and downscaled to 10 and a 5 year old child head model. The question arises how representative down scaled head models of child's heads can be.	Difference in the peak SAR between adult and child models. However, the question is how representative down scaled head models of child's heads can be.
Schönborn et al., 1998	No significant differences in SAR between children's and adults head were found. These turned out to be true also for downscaled models, therefore these results are in contradiction of these of Gandhi et al. 1996. Head phantoms based on MRI scans of an adult and two children (3 and 7 years old) and distinguished ten different tissue types	No significant difference in the SAR levels of child and adult head models based on MRI scans.
Wang & Fujiwara, 2003	When the authors fixed the output power to 1 W they found, similar as Gandhi et al. an increase of 31.5 % of the 1g peak SAR in the children's phantom compared to the adults peak SAR. For the 10 g averaging procedure they found a 21.6 % increase. In contrary, when they fixed the effective current of the antenna, the differences between children and adults remained below 10 %. The authors suppose that the differences in the results of Gandhi and Schönborn may be caused by differences conditions in their SAR evaluation methods.	Difference in the peak SAR between adult and child head models depend on experimental conditions.
Wang & Fujiwara, 2005	Reproduced both the results from Gandhi's and Kuster's group and associated the differences in their results to different calculation methods. They also did not find relevant age effects of dielectric properties.	Positive and negative results due to different calculation methods.
Anderson, 2003	The analysis showed that the peak SAR of a 4, 8, 12 and 16 years old child compared to the brain peak 10g SAR of an average adult is increased by a factor of 1.31, 1.23, 1.15 and 1.07, respectively. The author points out that these increases do not warrant any special precautionary measures for children using mobile phones because SAR testing protocols as contained in several standards provide an additional safety margin which ensure that allowable local SAR limits are not exceeded. The author states that maximum worst case temperature rise (0.13 to 0.14°C for a 4 year old child model) is well within safe levels and normal physiological parameters and the range of SAR increase in children is less than the expected range of variation of children. Moreover, The rather simple models of the heads consisting of three layered spheres (scalp, cranium and brain) leaves the question on the SAR relation in more detailed head models open. In addition, the investigations are restricted to one frequency. Therefore the results of this study cannot be used to draw final conclusions.	Difference in the peak SAR between adult and child head models. However, the rather simple phantom models restrict the external validity of the results.
Fernández et al., 2005	Considerable higher SAR values for children's exposure. The peak SAR in the 10 year old child's head model was 127 % higher compared to the adults phantom when dielectric properties of children's tissue (based on fitted parameters) were applied. For the 10g peak SAR an increase of 32.5 % was observed.	Higher peak SAR in 10 year old child's head model compared to the adult's head model.
Keshvari et al., 2005	No significant difference in the SAR levels for adult and child heads (3 and 7 years) for a 0.47λ dipole placed operating at 900, 1800, an 2450 MHz close to the ear. They however found that inclusion or exclusion of the 4 mm thick ear affects significantly the SAR levels because inclusion or exclusion affects the distance to the exposure source.	No significant difference in the SAR levels between adult and child head models.
Christ et al., 2005	Results from Schönborn et al. were confirmed, smaller head sizes did not lead to higher SAR values.	Negative with respect to the impact of head size
Hadjem et al., 2005a	The SAR values are slightly higher in the child phantoms compared with the adult phantoms. However, from a dosimetry	Slightly higher peak SAR for child phantoms, however, the

	point-of-view, no great differences appear.	differences seem to be not important.
Hadjem et al., 2005b	Demonstrated that the brains exposure depends on the morphology of the ear and the source.	Brain exposure depends on the morphological features.
Beard et al., 2006	In contradiction to other studies the larger adult head produced statistically higher peak SAR for both the 1 and 10g averages than did the smaller 7 year old child head model for all examined positions and conditions.	Reverse effect: Peak SAR is lower for 7 year old child head model
Fujimoto et al., 2007	Investigated the correlation of the maximum temperature increase and the peak SAR in child and adult head models. They found a linear relationship between maximum temperature increase and peak SAR in the head. No clear differences between adult and child models were found in terms of the slopes of the correlation of temperature and peak SAR. The effect of thermal and electrical properties on these correlations is also small. The maximum temperature increase in the adults head is 0.26°C for a maximum SAR of 1.6 W/kg averaged over 1g, in the brain it is 0.1°C. For the 3 year old child model the respective values are 0.23°C and 0.11°C.	No clear differences between adult and child head models
Lee et al., 2007	The authors conclude that the spatial peak SAR is not higher in a child's head compared to adult's heads for their test positions, but the head averaged SAR might be higher for fixed transmitted power. The authors also investigated the impact of a change of the dielectric properties on the SAR, but little effects were found.	No significant difference in the peak SAR between adult and child head models.
Wiart et al., 2007	The mean 10g averaged SAR for the six child phantoms was 0.28 W/kg, the standard deviation was 0.05 W/kg. For the adults heads the corresponding SAR was 0.38 W/kg, the standard deviation 0.09 W/kg. The study shows that, due to variability, the comparison between two heads is not representative and needs statistical analysis.	No reliable conclusions possible without proper statistical analysis
Hadjem et al., 2008	Checking new usage of cell phones (text messaging) the authors found higher 10 g averaged peak SAR values in the eye in case of the child models with a 1 Watt phone in front of the face but well below the 2 W/kg ICNIRP limit.	SAR induced in the eye of the child model is slightly higher than the one for the adult model but below the 2 W/kg ICNIRP limit
Wiart et al., 2008	The simulations again show that the differences between the maximum SAR over 10 g estimated in the head models of the adults and the ones of the children are small compared to the standard deviations. But they indicate that the maximum SAR in 1 g of peripheral brain tissues of the child models aged between 5 and 8 years is about two times higher than in adult models. This difference is not observed for the child head models of children above 8 years old: the maximum SAR in 1 g of peripheral brain tissues is about the same as the one in adult models. Such differences can be explained by the lower thicknesses of pinna, skin and skull of the younger child models.	Differences in the SAR level for child models aged between 5 and 8 years This difference is not observed for the child head models of children above 8 years old

Furthermore, it seems that newer research does not give reason to revise the opinion of Christ and Kuster (2005) that the variations between child and adult phantoms are not higher in magnitude than those between different adult phantoms.

Whole Body Exposure

The available studies do indicate that for children and other small persons the whole body SAR basic restrictions are exceeded at band ranges from 45 to 170 MHz and around 1,800 MHz, when the reference levels are met – not only with respect to artificial plane wave conditions but apparently also under heterogeneous exposure conditions.

Table 5: Findings with respect to whole body exposure

Authors	Results	Conclusion
Dimbylow,1997 Dimbylow, 2002 Bernardi et al., 2003 Tinniswood et al., 1998 Mason et al., 2000 Dimbylow & Bolch, 2007 Wang et al., 2006	The results clearly demonstrate that whole body SAR limits are exceeded in two frequency ranges when the reference levels are met. One band ranges from 45 to 170 MHz, the other one from 1,400 to 4,000 MHz. Basic levels were only exceeded for child phantoms corresponding to children with an age from 9 months to 11 years. The degree of exceeding is typically below 10 % when comparing the field level at a whole body SAR of 0.08 W/kg with the reference level for general public exposure at the respective frequency.	Whole body SAR limits are exceeded for phantoms modeling children in the age from 9 months to 11 years in two frequency ranges.
Dimbylow, 2007	The highest ratio of 0.83 between the calculated field level and the reference level was found at 1.6 GHz using a phantom of a 9 month old baby.	Whole body SAR limits are exceeded for a phantom of a 9 month old baby in the range of 1.6 GHz.
Hirata et al., 2007	For frontal plane wave exposure at 2 GHz it was shown that the whole body SAR was considerably lower in the phantoms of both a male and female phantom compared to child models of ages 3, 5 and 7 years.	SAR level is higher in phantoms modeling children in the ages of 3, 5, and 7 years in the frequency range of 2 GHz.
Kühn et al., 2009 Hadjem et al., 2007	Both research teams showed that compliance with reference levels cannot ensure that basic restrictions are met when children are exposed to plane waves. Taken together the available data give a consistent picture demonstrating that reference levels might not guarantee that basic restrictions are met in the two above mentioned frequency bands when small persons, e.g. children are exposed to plane waves. In addition it needs to be considered that heterogeneous exposure might lead to somewhat worse conditions.	Compliance with reference levels cannot ensure that basic restrictions are met in two frequency bands for children or small persons.
Conil et al., 2008	The whole-body SAR of the 5-year-old child exceeded the basis restrictions for more than 40% when the reference electric field level was applied.	Whole body SAR exceeded the basic restrictions at the reference level for phantoms modeling a 5-year-old child.
Neubauer et al., 2006 / Neubauer et al., 2009	The relation between the specific absorption rate and the electric field strength was investigated for real life exposure conditions arising next to common RF sources, e.g. mobile communication base stations at 946, 1800 and 2140 MHz. The results show that the whole body specific absorption rate for heterogeneous exposure conditions can be up to 22 % higher compared to plane wave conditions, showing that plane wave exposure does not always represent worst case exposure conditions.	SAR level for heterogeneous exposure conditions at 946, 1800 and 2140 MHz can be higher (up to 22 %) than for plane wave conditions.
Vermeeren et al., 2007	The absorption has been investigated for five different sizes of the spheroid model. It is reported that the highest absorption occurs in the smallest phantom and that the ICNIRP reference levels do not satisfy the absorption limits for a realistic exposure scenario.	Whole body SAR limits are exceeded for heterogeneous exposure conditions.
Hirata et al., 2009	Investigation of plane wave exposure of children in the frequency from 1 to 6 GHz. They calculated the frontal exposure of models of an age of 9 months and 3, 5 and 7 years. Their findings demonstrate that horizontally polarised electric fields lead to higher exposure above 2 GHz compared to vertically aligned fields.	Horizontally polarised electric fields lead to higher exposure above 2 GHz compared to vertically aligned fields.

Whole body exposure of the foetus

So far three studies investigated the exposure of the foetus. The results indicate that the foetus is not exposed in any significant way, i.e. the basic restrictions are not exceeded.

Table 6: Studies investigated the exposure of the foetus

Author	Results	Conclusion
Dimbylow 2007	Results showed that the maternal whole body SAR is lower compared to the non pregnant woman, the difference is increasing with gestation period. Looking at the foetus, the maximum of the absorption was found at 70 MHz for isolated conditions; the whole foetus and the brain absorption is lower compared to the whole body SAR of the mother. The results demonstrate that for plane wave exposure the ICNIRP reference levels are suited to guarantee compliance with the basic restrictions.	Lower SAR levels for the foetus
Nagaoka et al., 2007	The results are in line with those of Dimbylow 2007. Maximum whole body SAR was observed at 80 MHz, during frontal and vertical polarized exposure. Differences between WB SAR of the pregnant and non pregnant woman were small and below 1.1 dB. Compared to the mother, also in this case the WB-SAR was lower in the foetus.	Lower SAR levels for the foetus
Togashi et al., 2008	From their calculated results it was again clear that the SAR values in the foetus were very much dependent on the geometrical relationship between the fetus and the source and on the frequency. The averaged SAR for the foetus is always lower than the RF safety guidelines under the exposure conditions investigated in this study.	Compliance with the RF safety guidelines

Evidence map

Head exposure

With respect to the head exposure, 11 studies exist. The pro-argument for a higher exposure of children consists of 6 studies (Gandhi et al.,1996; Anderson 2003; Wang & Fujiwara 2003; Fernández et al., 2005; Hadjem et al., 2008; Wiart et al., 2008) that report a higher SAR value in children’s head. These studies are well conducted, however due to the high influence of several simulation conditions used in the studies (e.g. position of the mobile phone to the head), the results might be biased. On the other side, the counterargument consists of 5 studies, also in principle well conducted, that show opposite effects. In 4 studies no differences could be demonstrated (Schönborn et al., 1998; Keshvari et al., 2005; Christ et al., 2005; Lee et al., 2007), and in 1 study (Beard et al., 2006) the SAR level was higher in the adult’s head model. However, the same methodological restrictions as for the pro-argument have to be taken into account. In evaluating the results it is important to consider that the results are highly model-specific and are difficult to generalize. This fact constrains the external validity of the results.

Thus, both the pro and the contra argument together lead to the following conclusion: For children under 8 years no conclusive evidence exists for the assumption that the SAR level in children’s head is higher than for adults.

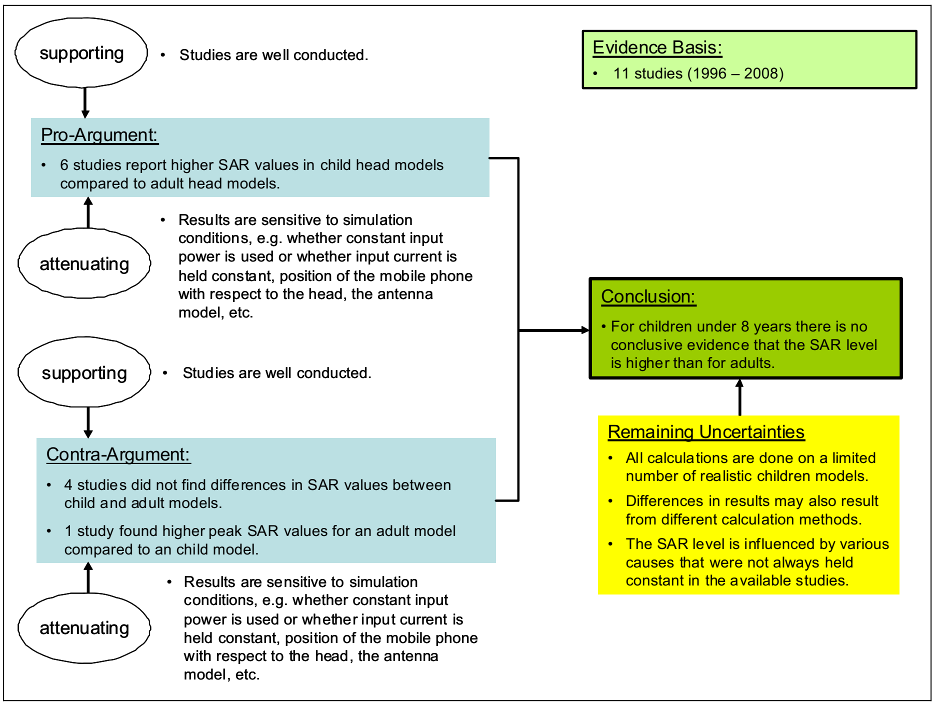

Figure 1: Evidence map head exposure

Whole body exposure

With respect to the whole body exposure 13 studies, conducted between 1997 and 2009, provide the base for evaluation whether the whole body exposure is higher for children than for adults. As depicted in Figure 2 the main pro argument for a higher whole body SAR level in children is the consistency of all available study results. They all show that at two specific frequency ranges an exposure at the reference levels can exceed the basic restrictions under worst case conditions. It means that for children or small persons the reference levels of the ICNIRP recommendations are not conservative estimates. However, two additional sub-arguments should also be taken into account. First, and this weakens the evidence, the studies are usually conducted under circumstances that are untypical for real world exposure with RF EMF. Secondly, and this strengthens the available evidence, newer studies on adult's whole body models show that heterogeneous exposure conditions might worsen the situation.

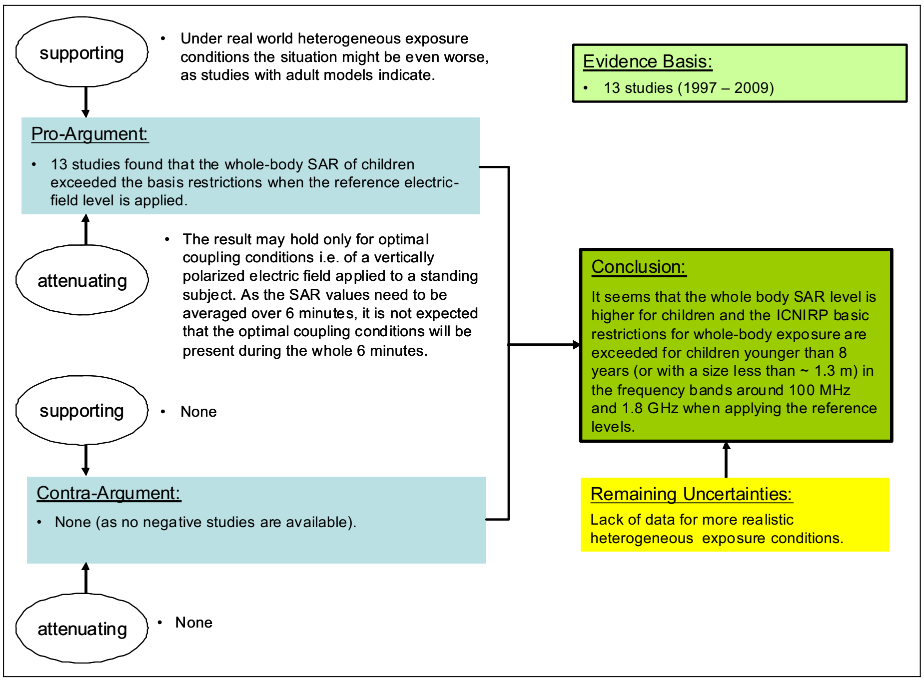

Figure 2: Whole body exposure

The ICNIRP basic restrictions for whole-body exposure are exceeded for children younger than 8 years or small persons for frequencies around 100 MHz and 1.8 GHz, when applying the reference levels (see for instance Bernardi et al., 2003; Conil et al., 2008; Dimbylow, 1997; Dimbylow 2002; Dimbylow & Bolch 2007; Mason et al., 2000; Tinniswood et al., 1998; Wang et al., 2006). In addition, Neubauer et al. (2006, 2009) and Vermeeren et al. (2007) demonstrate with adult models that heterogeneous exposure conditions may be more problematic than the plane wave conditions, which are rated as not representative for real world exposure situations.

The available evidence supports the conclusion that the ICNIRP reference levels are not conservative estimates for basic restrictions for children younger than 8 years and shorter than 1.3 m under worst-case conditions.

Conclusions

The available evidence seems to indicate that the whole body SAR level could be higher for children or small persons, not only for some untypical plain wave exposure conditions but also for more typical heterogeneous exposures.

With respect to the head exposure we encounter a different picture. No conclusive evidence exists with respect to the magnitude of power absorption in children's head. Until new studies with better and representative models are available the issue remains undecided whether the power absorption is higher in children's head or not.

Taking all results together, for children under 8 years no conclusive evidence exists for the assumption that the SAR level in children's head is higher than for adults. For whole body exposure, there is some evidence that the ICNIRP reference levels do not provide a conservative estimate of basic restriction for children younger than 8 years or persons shorter than ~ 1.3 m for frequencies above 1 GHz. However, even if further research would prove this it has to be taken into account that real-world whole body exposure levels are far below ICNIRP reference levels. Furthermore, according to ICNIRP (2009) the exceedance is of negligible importance for health because a large safety factor of 50 is embedded in the basic restrictions.

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Effects on cancer and general health disturbances

Introduction

The question whether exposure to RF EMF could cause cancer is obviously of major importance. With regard to children two types of cancer are at the focus of research. The first is brain tumours, which has been extensively studied with regard to adults (Blettner, Jöckel, & Stang, 2005; see Ahlbom et al., 2009 and Schüz et al., 2009 for a summary). The second is leukaemia, which did not play a main role in previous RF EMF related research, but proved to be an issue of concern with regard to extremely low-frequency magnetic fields. Epidemiological studies consistently found an association between long-term average exposures to magnetic fields above 0.3/0.4 μT and the risk of childhood leukaemia (cf. Schüz & Ahlbom, 2008). However, it has to be taken into account that these results cannot be extrapolated to RF EMF (SSK, 2006).

General health disturbances as a consequence of RF EMF exposure are either investigated using a cross-sectional approach, that is surveys in which the health disturbances and RF EMF exposure (or mobile phone use) are recorded at the same time with the help of questionnaires or as randomized controlled trials in a laboratory. There is no common definition as to what should be considered as general health disturbances. Endpoints considered here include headaches, fatigue/difficulties in sleeping, dizziness/nausea, disturbances in concentrating and memory, pain other than headache, nervousness, depressive mood/or state, skin-related sensation, e.g., itching, tickling, redness, burning or increased temperature of the skin including warm sensation of the ear, tinnitus/ringing of the ear (Seitz, Stinner, Eikmann, Herr, & Röösli, 2005).

Body of evidence

<u>Brain cancer and leukaemia</u>

The evidential basis for evaluating an association between RF EMF exposure and brain cancer in children is much smaller than for adults. There are (until 2008) no studies available for mobile phone use, but there are 9 studies investigating brain cancer or leukaemia with respect to EMF emitted from TV or radio transmitters (see Table 7). Only 7 of these, however, present original data. The other two (Cooper, Hemmings, Saunders, Cherry, & Dolk, 2001; McKenzie, Yin, & Morrell, 1998) are presenting recalculations of the data presented in 2 of these 7 studies.

Table 7: Ecological studies, their recalculations, and case control studies investigating the risk of brain cancer in children from RF EMF exposure

Ecological studies		
Study	**Focus**	**Findings**
Hocking, Gordon, Grain, & Hatfield, 1996	TV towers in the Northern Sydney area, Australia.	Increased risk for total leukaemia, and lymphatic leukaemia. No increased risk for brain cancers.
Dolk, Shaddick et al., 1997	One radio and television transmitter (Sutton Coldfield) in Great Britain.	No statistically significant association found for leukaemia and for brain cancers.
Dolk, Elliott, Shaddick, Walls, & Thakrar, 1997	20 high power radio and television transmitters in Great Britain.	No statistically significant association found for leukaemia and for brain cancers.
Michelozzi et al., 2002	Radio Vatican transmitter station in Rome, Italy.	The risk of leukaemia was higher than expected for the distance up to 6 km from the radio station.
Park, Ha, & Im, 2004	AM radio broadcasting towers in Korea.	Increased leukaemia mortality for children and young adults, increased mortality for all cancers in the population living in the vicinity of AM radio towers. No increased mortality for brain cancer.
Recalculations		
Study	**Focus**	**Findings**
McKenzie et al., 1998	Recalculation of the Hocking (1996) data.	Using a different regional level of analysis yields a weaker association.
Cooper et al., 2001	Recalculation of childhood leukaemia data presented in the Dolk (1997) studies.	No statistically significant association found for leukaemia.
Case control studies		
Study	**Focus**	**Findings**
Maskarinec, Cooper, & Swygert, 1994	AM radio transmitters in Hawaii.	Statistically not significantly increased risk for leukaemia.
Ha et al., 2007	Radio transmitter tower in South Korea.	Statistically significant increased risk for one type of leukaemia for the most extreme (peak) exposure group. No increased risk for brain cancers.
Merzenich et al., 2008[5]	Selected regions in Germany on Radio and TV transmitter towers	No increased risk for leukaemia cases

Five studies are ecological studies. They are not based on individuals but on groups defined by geographical region, which are thought to have different levels of exposure due to their different distances to the transmitter. The problem with this type of study design is that it does not allow drawing firm conclusions from associations found at the group level to the individual level (which is, of course, the level of interest) – let alone conclusions regarding a causal relationship. In doing so one would commit what is called an *ecological fallacy* (cf. Elwood, 1999). The other three studies are case control studies.

[5] This study was not yet published at the time Prof. Berg-Beckhoff wrote her expert opinion report, but she reported the results in her presentation at the final workshop.

Health disturbances

With regard to children five studies are available so far, which address the question whether RF EMF exposure is associated with general health disturbances in children (see Table 8).

Table 8: Studies investigating effects of RF EMF exposure on general health disturbances in children

Study	Focus	Findings
(Koivusilta, Lintonen, & Rimpela, 2007)	Cross-sectional, representative study on the association of mobile phone use with self-reported health status.	Poorest health was reported by mobile phone users.
(Van den Bulck, 2007)	Cohort study using self reported tiredness.	Children using mobile phones after lights out are more likely to be very tired one year later.
(Divan, Kheifets, Obel, & Olsen, 2008)	Cohort study investigating the association between prenatal and postnatal exposure to cell phones and behavioural problems in young children.	Association between prenatal exposure of mobile phone use and behavioural problems.
(Söderqvist, Carlberg, & Hardell, 2008)	Cross-sectional study investigating self-reported health complaints (e.g. tiredness, stress, headache, anxiety, concentration difficulties and sleep disturbances).	Association between mobile phone use and self reported health symptoms.
(Heinrich et al., 2008) (Kühnlein, Heumann, Thomas, Heinrich, & Radon, 2009)	Cross-sectional study on self-reported health complaints due to mobile phone use as well as mobile phone base stations.	No association between measured RF EMF exposure and subjective well-being.

Evidence Map

Brain cancer and leukaemia

No study showed any significant increase of brain cancer in children. Therefore, the following argumentation refers solely to childhood leukaemia.

The pro- and con-arguments for effects of RF EMF exposure on leukaemia in children that can be derived from the expert opinion report are summarized in Figure 3**.**

The argument for a causal influence of RF EMF exposure on leukaemia in children is based on the four studies that found a statistically significant association between RF EMF exposure from radio or TV transmission towers and childhood leukaemia. The argument is strengthened by the fact that one case- control-study (Ha et al., 2007), which used an individual exposure assessment approach and included a sizable number of subjects, found a significant increase for lymphocytic leukaemia, but not for myelocytic leukaemia with respect to peak exposure in the highest exposure category. No significant results were found when exposure was estimated by a different measure (total radio-frequency radiation exposure).[6]

[6] In their original publication, Ha et al. (2007) reported statistically significant associations for two intermediate exposure categories of "*total radio-frequency radiation exposure*", but not for the more

However, the argument for leukaemia is weakened because three of the studies finding a statistically significant association are ecological studies that are not suited for assessing causal relationships. In addition, a recalculation of the Hocking (1996) data showed that the significant result was due to an increased risk for one specific area, which, however, is implausible since no association was not found in other areas with similar exposure (McKenzie et al., 1998).

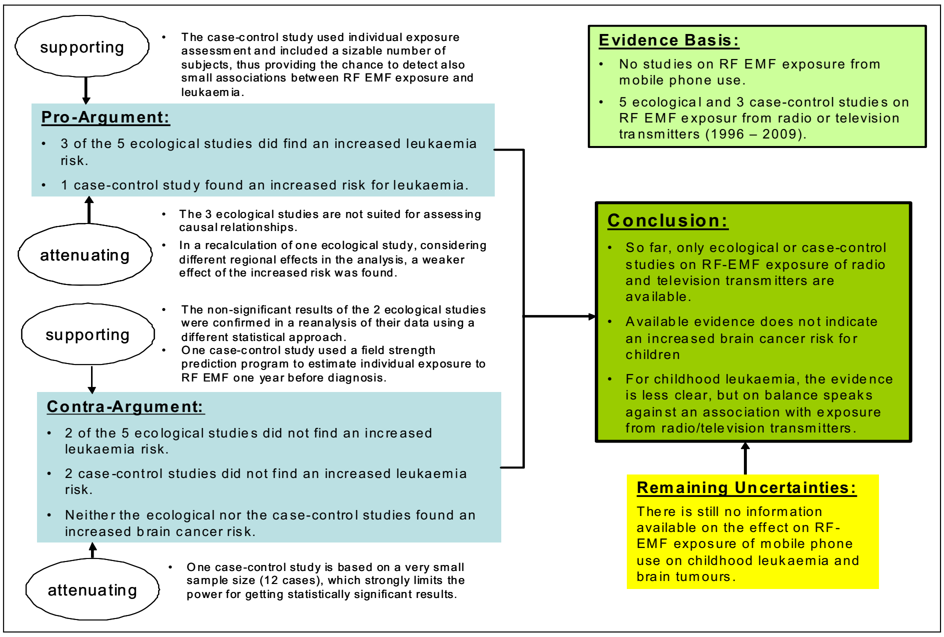

Figure 3: Evidence map for effects of RF EMF exposure on brain cancer or leukaemia in children

The contra-argument is based on the results of two ecological studies and two case-control studies that all did not find an increased leukaemia risk for children. The findings of the two ecological studies (Dolk, Elliott et al., 1997; Dolk, Shaddick et al., 1997) were confirmed in a reanalysis of their data using a different statistical approach (Cooper et al., 2001). The contra-argument is further strengthened by the negative results of one of the two case-control studies that used a novel approach for estimating individual exposure. The negative result of the other case-control study, however, does not really provide support for the contra-argument, as it was based on a very small sample size (12 cases), which strongly limits the power for getting statistically significant results even if an association had been real.

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extreme exposure category. That is, they did not find a linear trend with regard to strength of exposure and association. This was criticized by Prof. Berg-Beckhoff in her expert report as implausible. Meanwhile, however, Ha and colleagues have published a correction of these data in which these significant results have been eliminated (Ha et al., 2008), thus making this criticism obsolete. At the same time, however, the revised data, Ha and colleagues present, exhibit a statistically significant association for the most extreme exposure category of “*peak radio-frequency radiation exposure*”, but not for three lower exposure categories. It is this result that is used in the present evaluation, although it is too recent to be included in Prof. Berg-Beckhoff’s report.

In sum, there is no evidence for an elevated brain cancer risk in children. The available evidence with respect to childhood leukaemia does not show a consistent picture. However, taken into account the power of study design as well as the study quality it appears that the contra-argument is somewhat stronger, i.e. the weighted evidence does not support an association between exposure from radio/television-transmitters and cancer in children.

<u>Health disturbances</u>

The pro- and con-arguments for effects of RF EMF exposure on general health disturbances in children that can be derived from the expert opinion report are summarized in Figure 4.

The pro-argument is based on 4 studies. These studies found statistically significant associations between mobile phone use and health symptoms or health related behaviours, thereby supporting the notion that RF EMF exposure might cause general health disturbances in children. In a cross-sectional study Koivusilta and colleagues (2007) examined in a representative sample of 12–18-year-olds the association of mobile phone use with self reported health status. The poorest health was reported by mobile phone users. Van den Bulck and colleagues (2007) conducted a cohort study to assess the association between phone use by adolescents after lights out and levels of tiredness after one year. Participants were adolescents with an average age of 14 in the youngest group and 17 in the oldest group. The authors found that those who used the mobile phone for calling and sending text messages after lights out were more likely to be very tired one year later. A cross-sectional study by Söderquist and colleagues (2008) investigated adolescents (aged 15-19) and found an association between their mobile phone use and self-reported health complaints, such as tiredness, stress, headache, anxiety, concentration difficulties and sleep disturbances. Another cross-sectional study examined the association between prenatal and postnatal exposure to mobile phones and behavioural problems in children at the age of 7 (Divan et al., 2008). In this study mothers were asked to report behavioural problems of their children by using a standardized questionnaire (*Strength and Difficulties Questionnaire*). To assess prenatal and postnatal exposure to mobile phones, mothers were asked about their use of mobile phones during pregnancy, use of hands-free equipment during pregnancy, and location of the phone when not in use. In addition they were also asked about their children's current use of mobile and other wireless phones. The authors report a statistically significant association between prenatal or postnatal exposure to cell phone use and behavioural problems.

Unfortunately, the quality of these studies is hampered by restrictions, potential biases and confounders. First, the results based on a cross sectional study design do not allow conclusions about causal relationships. Second, and this is the major drawback of all studies, they use self-reported mobile phone use as a proxy for RF EMF exposure assessment. Not only is this a rather indirect and probably unreliable way of measuring exposure – it also leaves the possibility open that the associations found are actually not due to RF EMF exposure *per se* but to the behaviour of using mobile phones. Thus it seems quite plausible, for instance, that using the mobile for sending text messages after lights out leads to tiredness. Another explanation could be that intensive mobile phone use is part of the same health-related lifestyle as specific health compromising behaviours – an explanation suggested by Koivusilta and colleagues (2005). This line of argumentation does also hold for the study by Divan and colleagues (2008), which focused mainly on the mother's (and not the children's) use of mobile phones. As the authors themselves discuss, it may well be a lack of attention given to a child by mothers who are frequent users of cell phones might be a cause of the children's behavioural problems.

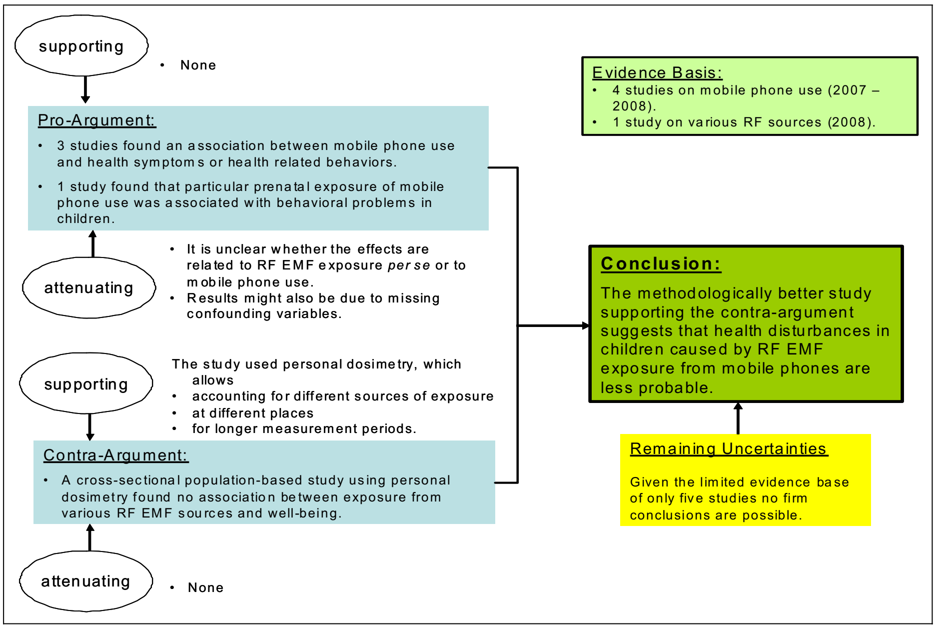

Figure 4: Evidence map for effects of RF EMF exposure on general health disturbances in children

The contra-argument is based on one study. Heinrich and colleagues (2008; see also Kühnlein et al., 2009) conducted a cross-sectional population-based study to investigate possible health effects of mobile communication networks on children (8-12 years) and adolescents (13-17 years) using personal dosimetry.[7] Individual exposure was assessed with dosimeters for a period of 24 hours and subjective health complaints (e.g. headaches, dizziness, tiredness) concerning the preceding 6 months as well as potential confounders were recorded in personal interviews. No association between measured exposure and subjective well-being was found. Interestingly, however, those adolescents who were concerned about RF-EMF were more likely to report health complaints.

The result of this study as an argument against a causal impact of RF EMF on general health disturbances is strengthened by the method used for exposure assessment. Different from the other studies reviewed in this section, which used self-reports of mobile phone use as an indicator for RF EMF exposure, Heinrich and colleagues (2008) utilized personal dosimetry. This provides a direct and much more

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[7] As this study was not yet published at the time Prof. Berg-Beckhoff wrote her expert opinion report, she only described the study design but could not present the results. However, the results were reported in her presentation at the final workshop.

reliable measurement of the actual extent to which the children were exposed and thus a better estimation of the association between RF EMF exposure and health complaints.

Comparing the pro- and con-arguments, the contra-argument has a higher weight because in the underlying study a more reliable exposure assessment was used. This fact supports the conclusion that health disturbances in children caused by RF EMF exposure from mobile phones are less probable. However, given that only five studies are available that investigated a potential association between RF EMF exposure of children and their well-being, no firm conclusions are possible.

Conclusions

The available evidence does not provide an indication for an association between RF EMF exposure and brain cancer in children. Although the results are less clear for the association between RF EMF exposure and childhood leukaemia, the balance of evidence does not support an association with RF EMF.

With regard to the relationship between RF EMF exposure and general health disturbances in children the available evidence is even more limited. In particular it suffers – with one exception – from poor exposure assessment, which makes it difficult if not impossible to relate RF EMF exposure to health disturbance effects. The one study with good exposure assessment did not find an effect of RF EMF exposure on general health disturbances. But again this is surely a too small basis for drawing firm conclusions.

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Cognitive effects and CNS effects

Introduction

At least since the publication of the so-called 'Stewart-Report' (IEGMP, 2000) in the year 2000, potential effects of RF EMF exposure on cognitive function have played a prominent role not only in the scientific debate but also in public and media discussions on potential adverse effects of RF EMF exposure.

Body of evidence

There are four original papers addressing the effect of RF EMF on cognitive function and CNS in children. The age of the children investigated in these studies was in the range of 10 to 17 years. Table 9 gives an overview of the measured variables and the findings.

Table 9: Studies selected for the expert opinion reports on cognitive and CNS effects

Study	Focus	Findings
Lee et al., 2001	Three measures of attention	Increased performance speed for the Trail Making Test, but not for Symbol Digit Modality Test and Stroop Color Word Test.
Haarala et al., 2005	Several measures of memory, reaction time and vigilance	No statistically significant effects found
Preece et al., 2005	Several measures of memory, reaction time and vigilance	No statistically significant effects found
Krause et al., 2006	Event-related potentials (ERP)	Statistically significant increased ERS and ERD response (4-8 Hz)

Evidence Maps

Both experts follow a similar line of argumentation in their evaluation of the four studies, which is displayed in Figure 5, and they also come to similar conclusions.

The argument supporting causal influence of RF EMF exposure on cognitive function in children is based on the two studies by Lee at al. (2001) and Krause et al. (2006). Lee and colleagues administered three different tests that measure attention of 72 adolescents, who reported to either use a mobile phone or not. They found a statistically significant effect for one, the Trail Making Test. For the other two tests administered in the study, no statistically significant effects were found. Krause and colleagues measured the effect of RF EMF exposure on event-related potentials (ERP) in 15 children while performing an auditory memory task. They found statistically significant event related desynchronisation (ERD) and synchronisation (ERS) responses in the 4-8 Hz range under the exposure condition, compared to non-exposure.

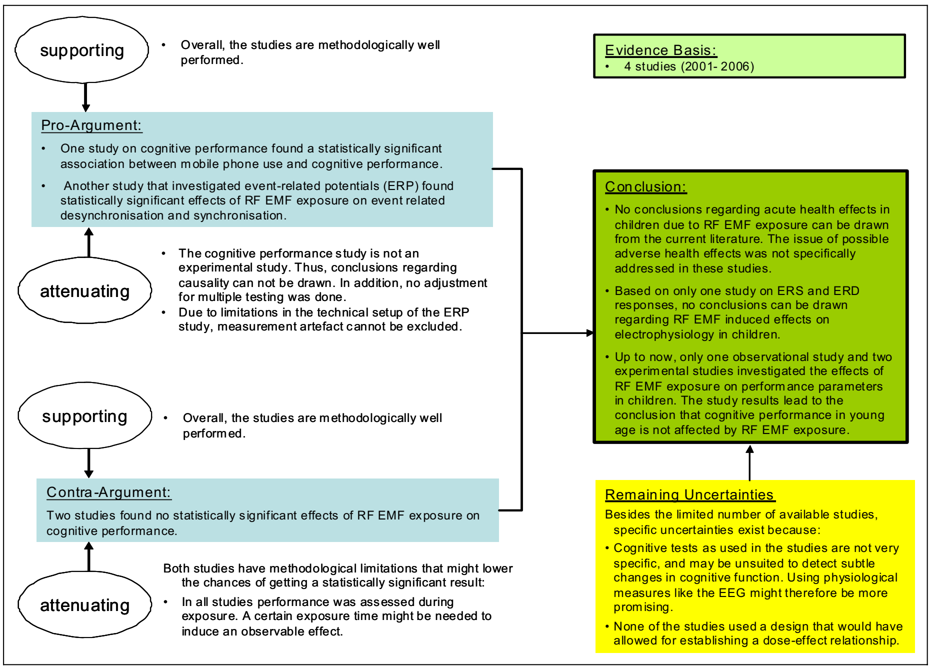

Figure 5: Evidence map for cognitive and CNS effects

Both studies, however, have limitations that reduce their cogency for establishing a causal influence between RF EMF exposure and cognitive function in children. The study by Lee and colleagues is an observational study only. It means that RF EMF exposure was not experimentally controlled nor even really measured, but only indirectly assessed by self reported frequency of mobile phone use. This design is not suited for drawing causal conclusions regarding the influence of RF EMF exposure on cognitive function. A further critical point is that the authors did not adjust for multiple testing in their statistical analysis, which increases the chance of getting statistically significant results that are actually purely due to chance. The study by Krause and colleagues is potentially limited because it is not clear from their paper whether a proper shielding of the electrophysiological measurement system against and the RF EMF exposure system was used. Should this not have been the case, the observed effects may – at least in part – only be measurement artefacts.

The argument against a causal influence of RF EMF exposure on cognitive function in children is also based on two studies. In their experimental study, Haarala et al. (2005) used several cognitive tests to measure the effect of RF EMF exposure on memory, reaction time, and vigilance. No statistically significant differences between the exposure and non-exposure condition were found. The study by Preece et al. (2005) addressed similar cognitive parameters (memory, reaction time, vigilance), but used different tests. They, too, did not find statistically significant cognitive differences between the exposure and non-exposure condition.

Both studies are methodologically well conducted. However, in all studies cognitive performance was measured during the exposure time. Possible effects of RF EMF exposure may be immediate but also delayed in time. It cannot be excluded that some of the negative results that emerged may have resulted from the fact that a task was actually applied before or after a measurable effect had developed. As certain length of exposure time might be needed to induce an observable effect, finding the right timing for measuring cognitive performance might be critical, and indeed difficult to attain. Thus, it cannot be excluded that the non-significant results may be due to such timing problems.

Altogether, no conclusions regarding acute health effects in children due to RF EMF exposure can be drawn from the available studies because the issue of possible adverse health effects was not addressed. Furthermore, based on only one study on EEG responses, no conclusions can be drawn regarding RF EMF induced effects on electrophysiology in children. It remains to state that the available evidence on cognitive performance in young age does not indicate any effect of RF EMF exposure.

Conclusions

On balance, the evidence so far does not provide substantial arguments for effects of RF EMF exposure on cognitive performance of children. Some caveats should be acknowledged: the very limited available evidence cannot rule out that RF EMF exposure might influence cognitive and other CNS functions in children.

But even if future evidence would support an influence of RF EMF exposure on cognitive and other CNS functions in children, it will be critical to evaluate whether the effects found can be considered as an indication for an impairment of cognitive function.

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Animal studies

Introduction

Due to ethical constraints with respect to humans and sometimes also limited human exposure data, animal experiments are an indispensible part of human risk assessment. The main argument for relying upon animal studies is that human biology is very much like that of many animals, i.e. most laboratory animals have the same set of organs which work in the same way as they do in humans. However, some researchers have questioned the predictive value of animal data in human cancer risk assessment of animal data for humans (Knight et al. 2006; Shank et al. 2009).

The animal species chosen as models for investigating effects of RF EMF exposure on the development of embryos and fetuses have a shorter period to sexual maturity, a shorter gestational period, and larger litter size than humans. This provides remarkable advantages: First, animal models may be more sensitive to the developmental effects of exogenous influences because of the rapid rate at which cell proliferation, migration, and differentiation occur. Second, studies can take place over a much shorter period of time.

Body of evidence

Studies on development: Embryo and fetus

Table 10: Studies on embryos and fetuses

Study	Results	Conclusion
Klug et al., 1997	Rat embryos were exposed *in vitro* for up to 36 h using 900 MHz fields modulated at 217 Hz, at SAR levels of 0.2, 1 and 5 W/kg. No significant effects were observed on the growth and differentiation of the embryos	No significant effects on embryonic development
Juutilainen, 2005	The review assessed postnatal behavioural effects reported in early studies and concluded that exposure to RF fields does not cause any consistent effects on behavioural endpoints in the absence of hyperthermia.	No consistent effects at non-thermal RF fields levels
Kaplan et al.,1982	33 squirrel monkeys were exposed during the second trimester of pregnancy for 3 h/day to 2.45 GHz fields at whole body SARs of 0.034, 0.34, or 3.4 W/kg. Parts of the offspring were additionally exposed for 18 months after birth. No significant differences were seen in EEG or the behavioural endpoints tested (righting, orienting, climbing down, climbing up, directed locomotion).	No significant effects in EEG and on behavioural endpoints, however, study has very limited statistical power.
Jensh, 1997	In post-natal studies following prenatal exposure no effects were seen in the offspring of rats exposed to 2.45 GHz or 915 MHz at whole body SARs estimated	No consistent, significant increase in reproductive risk

	to be about 2-4 W/kg	at non-thermal RF fields levels
Bornhausen and Scheingraber, 2000	Exposed rats continuously during pregnancy to 900 MHz GSM mobile phone-type fields (pulse- modulated at 217 Hz) and a power density 1 W/m^2, corresponding to the maximum level of mobile phone base stations (estimated SAR 17.5-75 mW/kg). While 9 operant-behaviour performance tests were performed on offspring (3 months of age) no performance deficits were observed in the exposed animals.	No measurable effects of RF exposure
Cobb et al., 2000	When pregnant rats were exposed to ultra-wideband (UWB) pulses (55 kV/m peak, 1.8 ns pulse width, 300 ps rise time, 1000 pulses/s, 0.1-1 GHz, SAR 0.45 mW/kg, exposure 2 min/day during gestation days 3-18, and continued during 10 postnatal days for part of the animals) no changes were found in 39 of 42 endpoints. The authors concluded that there was no unifying physiological or behavioural relationship among the differences observed (more stress vocalizations, longer medial-to-lateral length of the hippocampus, less frequent mating in exposed males but no difference in fertility).	Significant effects in 3 out of 42 endpoints, however possibly due to multiple testing

<u>Offspring</u>

For many chemicals, prenatal and postnatal exposure is a critical risk factor for the development of offspring (Pryor et al., 2000).

Table 11: Studies on offspring

Study	**Results**	**Conclusion**
Cobb et al., 2000	In the behavioural study RF exposure started during pregnancy and was continued for 10 days after birth.	No significant effects
Paulraj & Behari, 2006	5-week-old male Wistar rats were exposed for 2 h per day for 35 days to 2.45 GHz fields at 3.44 W/m^2 (~ 0.1 W/kg). A significant decrease in PKC activity in the hippocampus compared to whole brain PKC activity and an increase in the glial cell population in the exposed group as compared to the sham-exposed group was reported Unfortunately the small study size (6 or 8 animals per group) precludes any firm conclusions on whether RF has any affect on brain development.	Inconclusive because of methodological flaws
Kumlin et al., 2007	The study investigated whether prolonged exposure to 900 MHz mobile phone RF fields has any effect on the developing central nervous system, 3 week old rats were exposed or sham-exposed to RF fields at average whole-body SARs of 0.3 or 3.0 W/kg for 2 hrs/ day, 5 days/week for 5 weeks.	No significant changes in brain tissue or effects on the performance

Sommer et al., 2009	This multi-generation study in mice investigated effects of continuous exposure at power density levels of 1.35, 6.8, and 22 W / m², corresponding to SARs of 0.08, 0.4, and 1.3 W/kg in adult animals.	No adverse effects

Blood-brain barrier

The blood-brain barrier (BBB) restricts the diffusion of particles from the blood into the CNS, hereby protecting the brain against unwanted substances with possible pathological consequences.

Table 12: Studies on blood-brain barrier

Study	**Result**	**Conclusion**
Salford et al., 2003	Reported that single, brief exposure of young rats to pulsed 896 MHz fields for 2 h at SARs between 0.002, and 0.2 W/kg caused increased blood-brain barrier permeability to albumin and neuronal damage throughout the brain.	Increased blood-brain barrier permeability to albumin and neuronal damage throughout the brain. Concerns with this study include using only 8 animals per group, a wide age range of 12-26 weeks, highly subjective assessment of neuronal damage, and serious uncertainties about the dosimetry.
Kuribayashi et al., 2005	Using pulsed 1.439 GHz TDMA fields on BBB function in 4 week and 10-week-old rats, the study assessed permeability to dextran and the expression of genes involved in the regulation of barrier function. Repeated exposure of the head at 2 or 6 W/kg over a one or two week period had no effect on BBB permeability or on gene expression. Further, no histopathalogical lesions were seen.	No significant effect on BBB permeability
Cosquer et al., 2005	Used the radial arm maze test, the study investigated whether exposure to RF would increase BBB permeability to a drug known to affect radial arm maze performance. Rats were exposed to pulsed 2.45 GHz at a whole- body SAR of 2 W/kg and 3 W/kg in the brain for 45 min. No effect was seen on behaviour or on leakage of Evans blue, known to bind to albumin.	No significant effects on BBB permeability
Finnie et al., 2006a	Used endogenous albumin as a vascular tracer identified by monoclonal antibody staining, conducted *in utero* daily exposure of embryonic and fetal mice from day 1 to day 19 of gestation to 900 MHz GSM RF fields and reported no	No significant effects on BBB permeability

	increase in BBB permeability.	
Finnie et al., 2006b	The study investigated the effect of a similar exposure for the first seven days following birth, during which time neurogenesis continues. Again no effects were seen on BBB permeability.	No significant effects on BBB permeability
Eberhardt et al., 2008; Nittby et al., 2009	Effects on the BBB in adult rats at low SAR levels of up to 0.12 W/kg	Significant effects on BBB permeability
Masuda et al., 2009[8]	No significant effects on albumin immunoreactivity in the exposed groups. No statistically significant difference between exposed and sham-exposed animals with respect to dark neurons	No significant effects on BBB permeability
McQuade et al., 2009[9]	The study investigated whether radiofrequency electromagnetic field at SAR levels between 0.002 W/kg and 20 W/kg exposure affects blood-brain barrier permeability.The analysis revealed no significant increase in albumin extravasation in any of the exposed animals compared to the sham-exposed or home cage control animals.	No significant effects on BBB permeability

Evidence Maps

Effects on embryo and fetus

Six studies published between 1982 and 2005 provide the empirical base for this evidence map on embryonic and fetal effects of RF EMF exposure. Because none of the available studies did demonstrate adverse effects no pro-argument is presented. The contra-argument against an influence of low level RF EMF exposure consists of all six studies available (Klug et al.,1997; Juutilainen 2005; Kaplan et al., 1982; Jensh 1997; Bornhausen & Scheingraber 2000; Cobb et al., 2000).The studies did not show any adverse effects on embryos and fetuses at non-thermal exposure levels. The power of the contra-argument is reinforced by the fact that one of the studies (Kaplan et al., 1982) was conducted with primates that are highly similar to humans with respect to physiology.

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[8] This study was published after the completion of the Lerchl-Repacholi expert report on animal studies and is therefore not considered in the expert report.

[9] This study was published after the completion of the Lerchl-Repacholi expert report on animal studies and is therefore not considered in the expert report.

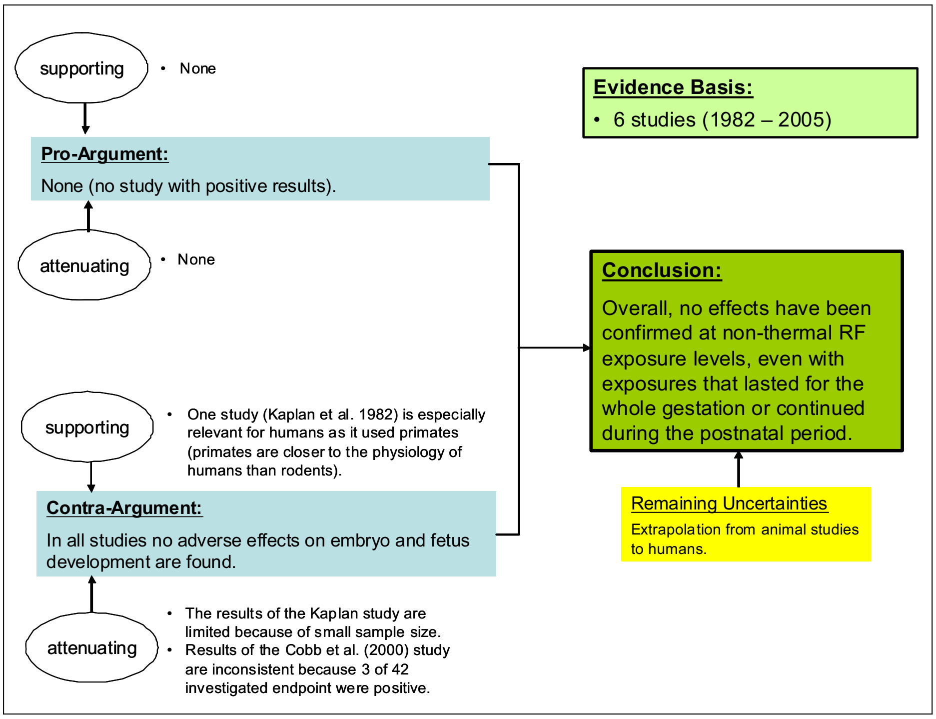

Figure 6: Evidence map on embryonic and fetal effects

However, some reservations have to be mentioned. First, the sample size of the Kaplan study was rather small resulting in low statistical power. Second, in 3 out of the 42 endpoints studied in the Cobb study significant effects were found. However, the minor three positive results (out of 42 measures) in the study by Cobb et al. (2000) might be explained by multiple testing biases.

Overall, the weight of pro- and con-arguments lead to the conclusion that effects from RF EMF exposure at non-thermal levels on embryonic and fetal development of humans are improbable. The remaining uncertainties refer to the extrapolation problems from the animal model based data to humans.

Offspring

The empirical base contains four key studies published between 2000 and 2009 (Cobb et al., 2000; Paulraj & Behari, 2006; Kumlin et al., 2007; Sommer et al., 2009). Only Paulraj and Behari (2006) provide an effect that can be used as pro-argument supporting the assumption of a causal influence of RF EMF exposure at low levels on adverse health effects in offspring. They found a significant decrease of PKC[10]

[10] PKC stands for Protein Kinase C. It is a Ca2+-dependent enzyme mediating the phosphorylation of certain cellular proteins, thereby regulating important physiological functions, such as cell growth, ion channel activity, secretion, and synaptic transmission.

activity in the hippocampus as compared to the control group. However, the small sample size of the study precludes any firm conclusion.

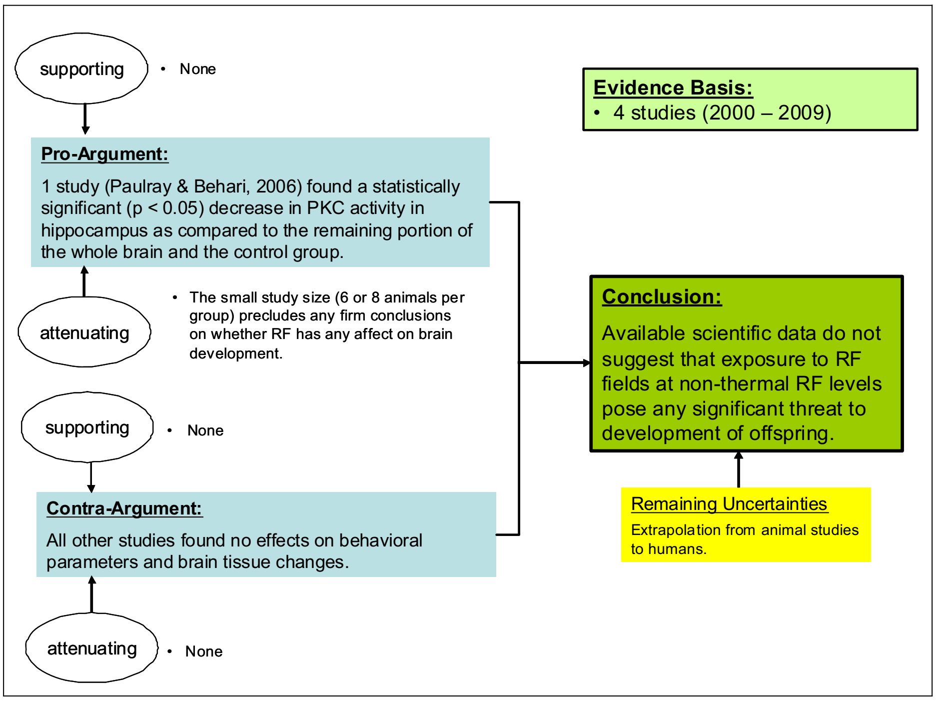

Figure 7: Evidence map on offspring effects

Taken this condition into account, the power of the pro-argument is weakened. All the other studies substantiate the contra-argument against a causal influence of RF EMF exposure at low levels: No effects on the brain as well as on behavioral activities were found. Even a multi-generation study points in this direction (Sommer et al., 2009).

This leads to the conclusion that the available studies do not suggest any significant threat to the development of offspring when exposed to non-thermal RF levels.

However, uncertainties remain due to the unclear extrapolation from the animal model based data to humans.

Blood-brain barrier

The evidence consists of seven studies (Salford et al., 2003; Kuribayashi et al., 2005; Cosquer et al.,2005; Finnie et al., 2006a; Finnie et al., 2006b; Eberhardt et al., 2008; Nittby et al., 2009) that investigated effects on the blood-brain barrier in young rats and mice. In addition, two recent studies (Masuda et al., 2009; McQuade et al., 2009), which were published after the completion of the expert reports, have been taken into account.

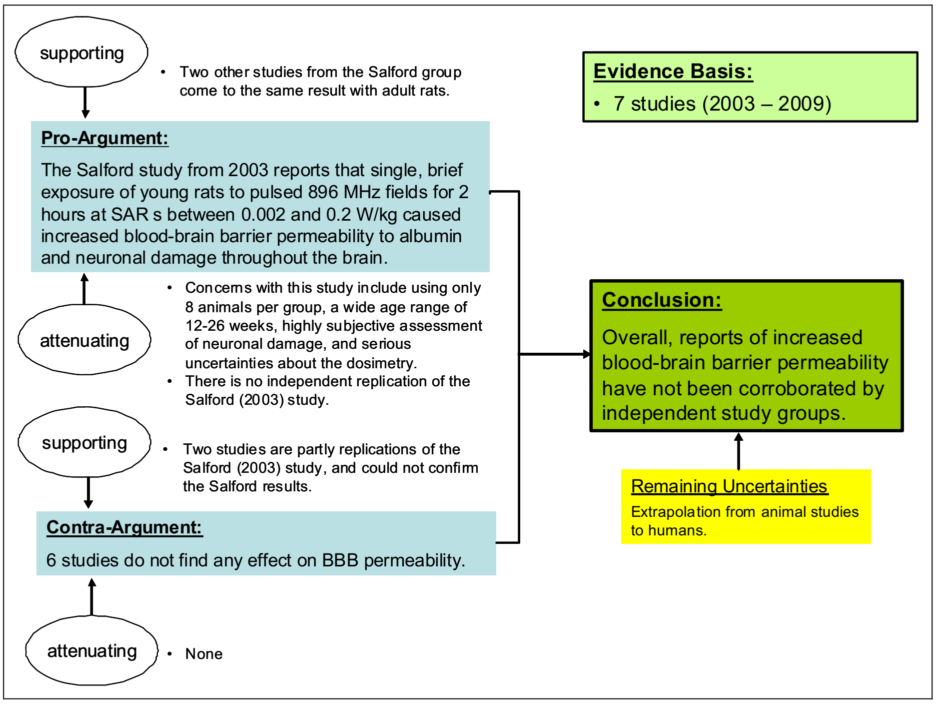

Figure 8: Evidence map on blood-brain barrier

The pro-argument supporting a causal influence of RF EMF exposure at low levels on the blood-brain barrier is based on the studies conducted by the Salford group. Salford et al. (2003) found evidence for neuronal damage in the cortex, hippocampus, and basal ganglia in the brains of exposed rats due to increased permeability of the blood-brain barrier. On the one side, the power of this pro-argument is strengthened by further studies of this research group (Eberhardt et al. 2008; Nittby et al. 2009) which show increased blood brain permeability and nerve cell damages in adult rats. However, on the other side, the Salford et al. (2003) study suffers from severe methodological weaknesses, above all poor dosimetry and the highly subjective assessment of neuronal damage. This weakens the power of the pro-argument.

The contra-argument against an influence of low level RF EMF exposure on the blood-brain barrier is based on six studies (Kuribayashi et al., 2005; Cosquer et al., 2005; Finnie et al., 2006a; Finnie et al., 2006b) that do not show any effect of RF EMF exposure on the permeability of the blood-brain barrier in pups. The recent studies by Masuda et al. (2009) and McQuade et al. (2009), which were partly replications of the earlier Salford et al. (2003) study, also found no effect of low level RF EMF exposure on the blood-brain barrier.

Therefore, one might conclude that the evidence for increased permeability of the blood-brain barrier in juvenile animals is at least conflicting. However, taking into account the methodological shortcomings of the Salford et al. (2003) study and the negative results from the six other studies, this rather suggests that there is no effect of RF EMF exposure on the blood-brain barrier in young animal models.

The remaining uncertainties refer to the unclear extrapolation from the animal model based data to humans.

Conclusions

From our point of view the available evidence from animal studies on development does not point to adverse effects when animals are exposed to non-thermal SAR levels.

For effects on embryonic and fetal development the picture is clear: No adverse effects have been detected at non-thermal exposure levels by the available studies.

Nearly all studies concerning offspring do not suggest any significant threat to the development of offspring when exposed to non-thermal RF levels.

Effects on the permeability of the blood-brain barrier and nerve cell damage could not been detected in young animals except in the research conducted by Salford et al. (2003). Again, this study does not provide firm evidence because of its poor methodology that does not stand up to scientific scrutiny. Therefore, the weight of evidence solidly refutes the assumption that adverse effects will be caused by RF EMF exposure.

The last point to mention is the inherent uncertainty of animal study findings when they are used for human risk assessment. Results from animal experiments cannot be extrapolated to human beings without reservations. Therefore, the animal data should not be evaluated in isolation, but together with epidemiological data and data from experiments with human volunteers.

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List of abbreviations

AGNIR	Advisory Group on Non-ionising Radiation
BBB	Blood-brain barrier
CNS	Central Nervous System
COST	European Corporation in Science and Technology
COST 281	Cost Action: Potential Health Implications from Mobile Communication Systems
EEG	Electroencephalography
ELF	Extremely Low Frequency
ERD	Event-related desynchronisation
ERP	Event-related potentials
ERS	Event-related synchronisation
FGF	Research Association for Radio Applications (Forschungsgemeinschaft Funk e.V.)
IARC	International Agency for Research on Cancer
ICNIRP	Commission on Non-Ionizing Radiation Protection
IEGMP	Independent Expert Group on Mobile Phones
NRPB	National Radiological Protection Board
RF EMF	Radio-Frequency Electromagnetic Fields
RF	Radio-Frequency
SAR	Specific Absorption Rate
SCENIR	Scientific Committee on Emerging and Newly Identified Health Risks of the European Commission
SSI	Swedish Radiation Protection Agency
SSK	German Radiation Protection Commission (Strahlenschutzkommission)
WHO	World Health Organization

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