Review

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A novel database of bio-effects from non-ionizing radiation

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Abstract: A significant amount of electromagnetic field/electromagnetic radiation (EMF/EMR) research is available that examines biological and disease associated endpoints. The quantity, variety and changing parameters in the available research can be challenging when undertaking a literature review, meta-analysis, preparing a study design, building reference lists or comparing findings between relevant scientific papers. The Oceania Radiofrequency Scientific Advisory Association (ORSAA) has created a comprehensive, non-biased, multi-categorized, searchable database of papers on non-ionizing EMF/EMR to help address these challenges. It is regularly added to, freely accessible online and designed to allow data to be easily retrieved, sorted and analyzed. This paper demonstrates the content and search flexibility of the ORSAA database. Demonstration searches are presented by Effect/No Effect; frequency-band/s; *in vitro*; *in vivo*; biological effects; study type; and funding source. As of the 15th September 2017, the clear majority of 2653 papers captured in the database examine outcomes in the 300 MHz–3 GHz range. There are 3 times more biological "Effect" than "No Effect" papers; nearly a third of papers provide no funding statement; industry-funded studies more often than not find "No Effect", while institutional funding commonly reveal "Effects". Country of origin where the study is conducted/funded also appears to have a dramatic influence on the likely result outcome.

Keywords: bio-effects; electromagnetic radiation; ELF; EME; EMR; microwaves; mobile phones; RF; Wi-Fi.

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Introduction

The environmental profile of man-made electromagnetic field (EMF) and associated radiation [electromagnetic radiation (EMR)] over the last several decades has grown by 12 orders of magnitude (10^{12}) [1] and is now considered one of the major sources of environmental pollution.

During more recent years, the use of mobile phones in close proximity to the brain has become a major focus of much research. Successful marketing and subsequent uptake have necessitated an on-going increase in the number of mobile phone base stations being deployed, contributing to increasing levels of background, environmental non-ionizing radiation. With these increased levels of man-made EMF exposure, also referred to as EMR, it raises the question of whether the short- or long-term health and well-being of the public is being compromised.

EMR within the scope of this paper encompasses the broad frequency bands of extremely low frequency (ELF), very low frequency (VLF) and radiofrequency (RF) – the higher portion of which is also commonly referred to as microwave (MW) radiation.

Research on the effects of exposure to EMR has been ongoing for many decades. The number of papers now published in the peer-reviewed literature is very extensive. It covers the full range of frequency bands; represents all applicable study approaches; examines an extensive array of biological and health associated endpoints; and considers many different types of exposure and modulation patterns.

The number, variety and changing parameters of research papers can provide a challenge when searching for material relevant for a literature review, or necessary for further study design, or for comparing findings of others with those being undertaken.

Some freely accessible databases on EMR exist today, such as the EMF-Portal; however, the types of data captured and the range of ways in which data can be searched for are limited, and this particular database stopped having new publications added in November 2017. Furthermore, the facility for rapidly tabulating multiple results is non-existent. The Oceania

Radiofrequency Scientific Advisory Association (ORSAA) (www.orsaa.org) has addressed these deficits by creating a multi-categorized, searchable database of papers on EMR. This database, based on FileMaker® Pro (FMP), is freely accessible online. It is designed to allow data to be easily retrieved, sorted and analyzed. Retrieved data can be readily tabulated and exported to a comma-separated values (CSV) file.

The main purpose of this paper is to bring awareness to the scientific community of a publicly available research tool. The paper showcases the ORSAA database and demonstrates the richness of the captured research data as well as the flexible search capabilities on offer. It is envisaged that the ORSAA database will provide invaluable assistance to researchers who need to perform a literature review in support of their own research initiatives and findings.

Description (design aspects)

Accessing papers for inclusion in the ORSAA database

Two main sources are, on an ongoing basis, used by ORSAA for accessing candidate studies relating to non-ionizing radiation (specifically ELF to RF frequencies). These are the US National Library of Medicine PubMed database and the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) technical series documentation along with their EMR monthly literature surveys with reviews. The EMF-Portal of Rheinisch-Westfälische Technische Hochschule (RWTH) Aachen University was also a main source until November 2017.

ARPANSA was also kind enough to share their database content (abstracts) in a text format based on specific categories (*in-vivo*, *in-vitro*, epidemiology, human provocation and review studies) for the period of 2000–2013, which helped ORSAA establish a balanced non-biased database. Each study was individually imported into the ORSAA database. Data were extracted from full papers, where available, and from the aforementioned sources to populate endpoints, experimental data, effect categories, study details and statistics.

The following selection criteria for establishing the ORSAA database and keeping it current have been applied:

- All ARPANSA database papers for the period 01/01/2000 to 31/01/2013
- All papers included in ARPANSA monthly survey of literature with reviews after January 2008
- Scientific studies in the following categories that have been published in a peer-reviewed journal:
  a. *in-vivo* experiments
  b. *in-vitro* experiments
  c. dosimetry experiments
  d. epidemiological studies
  e. human provocation experiments
- Non-English-language papers with a published abstract in English in peer-reviewed national journals in the country of origin.
- Literature reviews, meta-analyses, government EMF summary reports, guideline materials, measurement surveys, government disease statistical reports and brochures. Such documents are classified in the ORSAA database as a Non-Experimental Supporting Study (NESS).
- Systematic search for papers using pre-selected search terms on PubMed, e.g. RF therapy, immune response, adaptive response, oxidative stress, etc.
- Scientific papers taken from references of published papers, typically those papers that have performed a meta-analysis for specific topics of interest.

Papers reporting MW ablation procedures used in medical applications have been explicitly excluded. This decision was taken due to thermal effects being well documented and known for their application in medical procedures. This is not a medical procedure database but a tool for researchers who are investigating whether man-made transmitting/electrical devices and power sources have unintended biological consequences with potential health implications.

Database search categories and statistical information

Many categories have been itemized and a synopsis/abstract for each paper is provided.

Authors generally provide a detailed study methodology and result information as free-flowing text or data in tables with a large number of unsearchable fields buried within. PubMed does not attempt to categorize this information for the instances where it simply reproduces the study abstract, while the EMF-portal often extracts the most important information and summarizes it for the reader but not all studies captured are reviewed. ARPANSA, on the other hand, gives their opinion on the research they review by way of commentary.

ORSAA has taken a different approach by splitting important information into separate purpose-built pages

that are accessible by clicking on the page tab of interest. The database landing page has five tabs on the top bar: Article, Exposure, Study Categories, Effects Categories and Study Statistics. Each one is explained below.

Article tab: Article is the main landing page when first connecting to the database and provides an overview of the currently selected scientific paper.

Exposure tab: A detailed exposure screen in which the experimental data have been entered. Searches can capture information on a number of separate experiments from any one paper on animals or cells at different exposure frequencies; the recorded specific absorption rate (SAR) or power densities; and any statistically significant findings or lack thereof. Furthermore, different periods and durations of EMR exposures that were used may be examined. The exposure screen also contains details on the type of signal used in the experiment (see Supplementary File 1) as well as the wave type (i.e. Pulsed, Continuous, Sinusoidal, Triangular, Square, Amplitude Modulation). There can be a number of exposures used by the researcher in any given experiment. The researcher is often looking for bio-effects for various signal types and pulsed vs. continuous waves at different power levels and frequencies. In order to control the signal characteristics and power levels, signal generators are often used to simulate various real-world transmitters. The exposure screen supports a tiered layout, which allows for a number of exposures to be entered against a particular paper. The tiered approach implements a one-to-many relationship in the FMP relational database.

Study Categories tab: This tab contains the following study categories: *in-vivo*, *in-vitro*, dosimetry, epidemiological, human provocation, as well as whether this publication was one of those supplied by ARPANSA database. The funding categories and details of the specific funding sources are reported, where available.

Effects Categories tab: For all the papers that are classified as having a statistically significant "Effect", the bio-effects are indicated from a set of pre-defined categories. Some "endpoints" or outcomes of the research are not well represented by the existing categories. In such circumstances, a free-formatted text field is available to capture this data. A number of effects papers are about the possibility of therapy using weak EMF exposure and these have been noted as therapeutic papers.

Study Statistics tab: This screen is used predominately for representing epidemiological study data and contains statistical summaries of the results of the study.

On the Article page, there are 14 other informative "screens", including the abstract, reference data and more, and 13 actionable "screens", each accessible by individual tabs. A detailed description of every field presented on each screen (a screen is represented by individual tabs) can be found in the ORSAA online Data Dictionary [2].

Types of searches

Searches using FMP terminology "find request" can be performed using any one element or a combination of elements across multiple categories and screens.

Complex searches can be made across multiple fields simultaneously and in varying combinations. This categorization allows for searching individual effects or combinations thereof. The search engine allows for Boolean searches such as "AND" and "OR" searches as well as mathematical operators such as ">" or "<" search operations.

The ORSAA website contains instructional videos and manuals on how to utilize the data for producing a sub-set of data and examples of how to produce CSV downloads and how to manipulate data in excel spreadsheets.

The ORSAA database categorizes the electromagnetic spectrum by frequency bands according to the ranges utilized in various studies as shown in Table 1. This categorization is well defined with specific definitions used to describe them, e.g. ELF, covering frequencies between 3 Hz and 30 Hz for International Telecommunications Union (ITU) designation and 3 Hz–3 kHz (atmospheric science). Many studies contained in the ORSAA database tend to focus on a specific frequency band. However, some papers include more than one discrete frequency category in their experiments. For these specific cases, composite frequency categories are available and can be used for search purposes, e.g. ELF-SHF.

Each study that is represented in the ORSAA database is classified as one or more of the following research categories:

- *In-vivo*
- *In-vitro*
- Animal studies
- Plant studies
- Dosimetry
- Human provocation
- Epidemiology
- Meta-analysis

An extra field has been added to indicate those epidemiological studies that have been prospectively designed. A

Table 1: Discrete frequency bands as classified in the ORSAA database.

Frequency range	Wavelength range	Description	Detailed abbrev	General abbrev
3 Hz–30 Hz[a]	100,000 km–10,000 km	Extremely low frequency	ELF	ELF
30 Hz–300 Hz	10,000 km–1000 km	Super low frequency	SLF	
300 Hz–3 kHz	1000 km–100 km	Ultra low frequency	ULF	
3 kHz–30 kHz	100 km–10 km	Very low frequency	VLF	VLF
30 kHz–300 kHz	10 km–1 km	Low frequency	LF	
300 kHz–3 MHz	1 km–100 m	Medium frequency	MF	
3 MHz–30 MHz	100 m–10 m	High frequency	HF	RF[b]
30 MHz–300 MHz	10 m–1 m	Very high frequency	VHF	
300 MHz–3 GHz	1 m–10 cm	Ultra high frequency	UHF	RF or MW[c]
3 GHz–30 GHz	10 cm–1 cm	Super high frequency	SHF	
30 GHz–20 THz	1 cm–15 μm	Radar		

[a]WHO definition of ELF is 3–30 Hz, [b]Radio frequency, [c]Microwave.

searchable field to indicate if the study was a meta-analysis study has also been included. A field is provided to indicate whether a selected paper has been referenced by ARPANSA in their technical reports or monthly EMR literature research surveys.

Funding sources

The ORSAA database collects the funding sources and maps them to seven pre-defined categories as follows:

- Government;
- Private;
- Public (not-for profit) organizations;
- Industry;
- Institutional;
- United Nations [World Health Organization (WHO) funding];
- Not known.

Paper classification system

An over-arching outcome classification system is used as shown in Table 2. A further criterion was considered for weighing the quality of studies included in the ORSAA database (methodology and result analysis) by panel deliberation. However, this could introduce bias and so a decision was made to accept the fact that the papers having been peer reviewed was sufficient.

Application (illustration and use)

The ORSAA database is a living resource; relevant papers are being added on a continual basis as they are published. Results reported here were applicable on the 15th September 2017.

Many papers show multiple statistically significant biological effects. Each of these effect categories for the

Table 2: Simple classification of peer-reviewed paper outcomes.

Result	Selection criteria	Comment
Effect	An observed change of status occurred in one or more parameters examined	Bio-effects are categorized as shown in Figure 1
No Effect	No examined endpoints had a statistically significant change	
Uncertain Effect	Defined outcomes are not clearly reported or are unsure and conclusions are qualified	ORSAA had these papers assessed by a number of independent reviewers to ensure correct classification
Non-Experimental Supporting Study (NESS)	These articles, although of general interest, have no original scientific data (e.g. reviews, meta-analyses, standards documents or measurement studies or supporting information of national disease statistics)	Literature reviews and meta-analyses were published in peer-reviewed journals. Other materials were not peer reviewed, e.g. reports

This table itemizes how ORSAA records results based on reported effect outcomes.

1485 effect papers identified out of 2653 total records are included in Figure 1. This summary of bio-effects aligns with the number of papers that are classified as "Effect" papers in Table 4.

The majority of observed biological effects are found in the following areas:

- Oxidative Stress/ROS/Super Oxides/Free Radicals/ Lipid Peroxidation;
- Altered Enzyme Activity/Protein Damage/Altered Protein Levels;
- Biochemical Changes;
- Neurobehavioral/Cognitive Effects;
- Cell Irregularities/Cell Damage/Morphological Changes;
- DNA Damage/Mutagenic/Genotoxic.

The remaining papers in the database either did not investigate these endpoints specifically or found no effect. "No Effect" papers can be searched separately.

The selected biological effect categories that are included on the summary effect page were based on those

Find Search Summary Totals

Peer Reviewed Studies Showing Biological Effects Number of records used : 1485 of 2653

Auditory Dysfunction / Hearing loss / Tinnitus	32	Apoptosis (Programmed Cell Death)	96	Brain Tumours	44
Blood Brain Barrier Permeability Changes	15	Breast Cancer	13	Cellular Stress	61
Brain Development / Neuro Degeneration	39	Biochemical Changes	331	EEG changes / Brain Waves	93
Neuro Behavioural Effect / Cognitive Effects	171	Cell Irregularities/ Damage/ Morphological Changes	187	Effects on Mitochondria	35
Calcium Influx / Efflux	24	Fatigue	41	Altered Enzyme Activity / Protein Levels / Protein Damage	418
Circadian Rhythm Disruption	11	Altered Gene Expression	144	Headaches/Migraines	57
DNA Damage / Mutagenic / Genotoxic	154	Altered Glucose Level / Glucose Metabolism	21	Inflammation	23
Endocrine / Hormone Effects	66	Cardiovascular/Vascular Effects	70	Hepatic Effects (Liver)	25
Miscarriage / Spontaneous Abortion / Foetus Resorption	7	Immune System Effects	70	Impaired / Reduced Healing/ Bone Density Changes	3
Memory Impairment	65	Oxidative Stress / ROS/ Free Radicals	346	Speech Impairment	4
Sperm /Testicular Effects	83	Sleep Effects	58	Haematological Effects	54
Tumour Promotion	35	Neurotransmitter Effects	30	Synergistic/Combinative Effects	62
Thyroid Effects	14	Visual Disturbances/ Ocular Effects	40	Autism	8
Leukemia	14	Parotid Gland Malignancy	4	Neoplasis/ Hyperplasia (Abnormal Tissue Growth)	3
Depression	23	Induced Adaptive Response	55	Dizziness / Vertigo / Vestibular Effects	23

Continue

Figure 1: Number of papers showing biological effects by Effect Category.
Total number of papers in the ORSAA database showing biological effects in each effect category. Many papers have multiple statistically significant biological effects, each of which is included in the summary totals.

Table 3: Number of bio-effect mobile phone studies with signal type and waveform.

Research categories	Real mobile phone used in experiments			Simulated mobile phone signals used in experiments					
Waveform	Pulsed			Pulsed			Continuous		
Outcome	#Effect	#No Effect	#Uncertain Effect	#Effect	#No Effect	#Uncertain Effect	#Effect	#No Effect	#Uncertain Effect
In vivo	120	18	11	69	49	8	6	4	0
In vitro	28	8	1	60	63	7	10	17	2

Table 4: Number of scientific papers that are in each category.

	Effect		No Effect		Uncertain Effect		NESS	Totals
	Animal studies	Non-animal	Animal studies	Non-animal	Animal studies	Non-animal		
Number (%)	718 (27%)	767 (29%)	144 (5%)	372 (14%)	26 (1%)	157 (6%)	467	2651[a]
Totals		1485 (56%)		516 (19%)		183 (7%)	18%	100%

A majority of papers found at least one effect, approximately evenly split between animal and non-animal studies. [a]Minus 2 papers retraction pending.

most commonly reported. Those less frequently researched are generally included in the "Others" category as free text.

Examples of ORSAA database usage

Simulated signals versus real mobile phone signals used in bio-effect studies

It has been noted by other researchers that real commercially available mobile phone signals are more bio-active than simulated signals [3]. Table 3 demonstrates that more "Effect" studies than "No Effect" studies are found when real mobile phones are used in experiments. For *in-vivo* studies there are almost 7 times more "Effect" than "No Effect" studies, while for studies using simulated signals via signal generators, the numbers are more evenly split. Studies that use non-pulsed (continuous) waveforms again show results that are inconsistent.

Number of papers, by effect

We examined the total collection of 2653 papers in the ORSAA database as of the 15th September 2017. The first of these considered Effect/No Effect/Uncertain Effect as shown in Table 4.

There are approximately 3 times more "Effect" papers than "No Effect" papers in the scientific literature as shown in Table 4. Although approximately 18% of all the literature collected do not contain any original experimental data, these are reviews or meta-analyses of existing scientific information. Other NESS material includes standards documents, measurement/dosimetry studies and other supporting information, e.g. national disease statistics.

In-vivo studies in the mobile Wi-Fi communications ultra high frequency (UHF) band

Table 5 was constructed from the ORSAA database as an example of the types of data reporting that can be extracted. The researcher can export a list of associated papers that underpin these results to a CSV file for examination in more detail.

Table 5 illustrates that for both animal and non-animal *in-vivo* studies the finding of statistically significant biological effect studies far outweighs those studies finding no effect and the ratios (effect vs. no effect) are comparable.

Human studies examine many endpoints including: salivary concentrations of protein and flow rate, sperm motility and quality, cognitive and neurobehavioral function, hormonal analysis, *in-vivo* capillary blood micronuclei tests, chromosomal aberrations, thyroid hormone levels, hematologic parameters, reactive oxygen species (ROS)-mediated oxidative damage and activities of antioxidant enzymes.

Research funding – a potential source of bias

The ORSAA database provides funding source(s) information when this has been explicitly stated in the

Table 5: Number of scientific papers that are in each exposure category for *in-vivo* studies in the UHF (300 MHz–3 GHz) studies.

Study type	Effect	No Effect	Uncertain Effect
Animal *in-vivo* studies in UHF band	432	114	22
Human *in-vivo* studies in UHF band	45	10	7

An example of how data can be extracted according to chosen criteria, in this example: study type, frequency band and reported effects.

disclosure section of a given research paper. Unless the paper specifically refers to the funding source it cannot be assumed that the institution or department where the research is conducted has provided the funds and so such papers are designated as funding source "Not Known".

Funding sources are classified in the ORSAA database into the following major categories:

1. Government;
2. Private;
3. Public not-for profit;
4. Industry;
5. Institutional;
6. United Nations (WHO);
7. Not known.

The ORSAA database captures the specific funder(s) in a free text field. It should be noted that funding could be disbursed from multiple sources. Figure 2 shows a summary of funding for all experimental type studies (i.e. non-NESS) in the ORSAA database. Almost a third of the papers do not state the funding sources, while governments are funding over a third of all RF research.

The data can be broken down further, such as by outcome per funding source (Supplementary File 2). Such analyses can be undertaken for specific types of study, such as experimental, or particular effects, such as increased ROS, when doing a review.

Country of origin – issues of potential bias and potential industry and government influence on study outcomes?

The ORSAA database can also be used to collate research by country, based on the origin of the primary author or the principal funding source. Table 6 summarizes some of the key findings.

When country of origin is searched according to study outcome, the countries that have large ratios of "Effect" to "No Effect" are Russia, China, Turkey, Iran, Egypt, India, Israel, Sweden, Brazil, Ukraine and Hungary (Table 6).

We note that a number of these countries have adopted more stringent EMF exposure standards than the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines. For instance, China, India and Russia have power density public reference levels 90–100 times lower than the ICNIRP limit [4].

Discussion and conclusion

ORSAA's new database provides a highly flexible way of searching a wide, and increasing, range of the EMF literature. It can be used to search for papers according to frequency range, power, SAR, tested endpoints, reported outcomes and study type, amongst others. Furthermore, the data can be exported to create graphs to identify trends in research as well as biological effect outcomes based on frequency and/or exposure duration.

Our method of selecting papers for inclusion is intended to minimize bias and we anticipate that the resulting library is representative of the spread of peer-reviewed papers being published.

Nearly a third of the studies do not declare research funding in the papers so they are marked as funding source unknown in the ORSAA database. Maisch discusses this problem [5]. It may be that these are generally funded by the institution or department where the work was performed, but without a declaration the reader cannot know. Although we have not included NESS studies in the funding

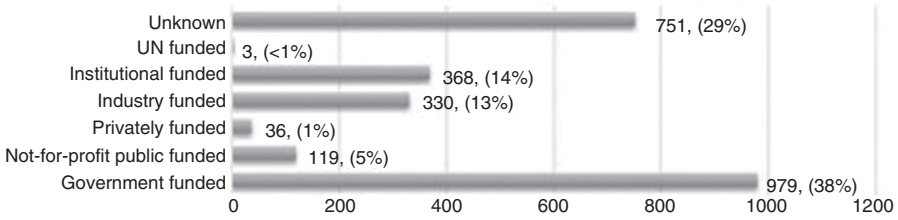

Figure 2: Funding sources for all experimental studies in the ORSAA database.
Reported source of funding can be explored with this example examining experimental studies.

Table 6: Review of research by country of origin.

Leading EMF "Effect" countries			Leading EMF "No Effect" countries		
Country	**Effect papers**	**No Effect papers**	**Country**	**Effect papers**	**No Effect papers**
China (CHN)	176	14	USA	129	61
Turkey (TUR)	170	25	Germany (DEU)	44	52
USA	129	61	Japan (JPN)	38	47
India (IND)	90	5	Great Britain (GBR)	25	36
Sweden (SWE)	67	13	South Korea (KOR)	37	31
Iran (IRN)	65	4	Australia (AUS)	38	23
Russia (RUS)	53	2			

Data can be analyzed in several ways. This example uses the country of origin of the lead author and reported results. Country of funder, frequency band and effect (or specific effect) are other possibilities.

chart (Figure 2), it should be borne in mind that the choice of papers selected for reviews and meta-analyses may be related to the funding source and may ultimately affect the paper conclusions. ORSAA considers funding declarations are of critical importance to ensure transparency and to help identify potential biases. ORSAA also encourages all journals to insist on providing this, even when there is no specific funder to declare. Requiring full disclosure of income affiliations is vital, especially in the latter circumstance.

Although animal studies cannot provide direct evidence of human biological effects, animal models can provide a strong indication of likely risks to humans. The ORSAA database can be used to enumerate and compare the many instances where both animal and human studies have found the same biological effect outcomes.

Our demonstration tables also indicate that although there are studies that report no effect on the tested parameters, there are in many cases significantly more that do find an effect. Closer examination suggests that this inconsistency can be explained in large part by the lack of replication between studies.

The evolving database cannot be used as a sole source of reference for a systematic review on any particular endpoint, and can only reflect the status quo with reference to the included papers. However, it provides many benefits to the general public and researchers alike.

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