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ARTICLE

Knowledge, risk perception and information needs of general practitioners regarding potential health effects of electromagnetic fields: A scoping review of the scientific literature

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Abstract – We aimed to summarise the evidence regarding the knowledge, risk perception and information needs of general practitioners (GPs) regarding electromagnetic fields (EMF). To achieve this aim, we searched for relevant articles in PubMed and additional sources, screened them based on the inclusion criteria and extracted relevant information from the eligible articles. Included manuscripts were summarised *via* narrative synthesis. Out of 274 records, nine articles from five different studies (all from Europe) were included. All studies reported considerable concern about the possible negative health-effects caused by EMF among GPs. In most of the studies GPs, indicated insufficiently covered information needs concerning EMF. Four studies reported that GPs were consulted by patients regarding potential health effects of EMF. The level of concern regarding health effects of EMF among GPs is high, while their information needs are insufficiently satisfied. It remains unclear what factors determine this concern. Likewise, there is little data on GPs' actual level of knowledge on EMF and health. Future studies may take new perspectives such as concepts from communication science and use additional methods like qualitative techniques. Moreover, the communication of scientific evidence about EMF towards GPs needs to be improved in order to enable them to provide evidence-based counselling.

Keywords: Risk communication / education / health effect / public information / patient protection

1 Introduction

High- and low-frequency electromagnetic fields (EMF) are ubiquitous in the everyday life of the general population around the world. This is due, on the one hand, to the widespread use of communication technologies, such as mobile phones and electrical household devices and on the other hand, to the omnipresence of high-voltage power lines and mobile phone base stations (Jalilian *et al.*, 2019, Regrain *et al.*, 2020). Consequently, possible health-damaging effects of EMF are of very high relevance and interest for public health.

Health-related endpoints discussed in connection with EMF include neoplasms (regarding phone use especially brain tumours (Interphone Study Group, 2010, Castaño-Vinyals *et al.*, 2021)), childhood leukaemia (Amoon *et al.*, 2022), neurological and neurodegenerative diseases (Frei *et al.*, 2013, Funk and Fähnle, 2021), sleep disorders (Tettamanti *et al.*, 2020, Cabré-Riera *et al.*, 2022), non-specific symptoms (Durusoy *et al.*, 2017, Röösli *et al.*, 2021), cognitive impairment (Cabré-Riera *et al.*, 2021) and behavioural deficits in children (Birks *et al.*, 2017). Thus far, the numerous studies so far provide little evidence for adverse health effects of EMF, even though there are isolated indications, for example, of a possible association between exposure to low-frequency EMF and childhood leukaemia (Grellier *et al.*, 2014) and Alzheimer's disease (Huss *et al.*, 2009) as well as pre- and postnatal exposure to high-frequency EMF and behavioural problems in primary school children (Birks *et al.*, 2017). However, these potential associations cannot yet be explained in a biologically plausible way and it remains unclear if they are causal.

Despite the lack of clear evidence for adverse health effects of EMF exposure, some surveys point towards considerable concern in the general population about such effects. For instance, regular surveys in the German general population reported that about one-fifth of the interviewees indicated concern about the potential detrimental effects of EMF exposure (Götte und Ludewig, 2019). Relatively high estimates regarding the concern in the general population

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were also observed in Austria and Switzerland (Schreier *et al.*, 2006, Schröttner and Leitgeb, 2008). Additionally, there is a noteworthy number of individuals reporting electromagnetic hypersensitivity syndrome (EHS), which is defined by the attribution of a wide range of non-specific symptoms to EMF exposure (Röösli, 2008, Dieudonné, 2020).

General practitioners (GPs) and—in the case of children and adolescents—paediatricians, as the central pillars of primary care, are the first point of contact in the healthcare system for most parts of the population, including individuals concerned about EMF and patients with EHS. Hence, GPs play a crucial role in imparting medical knowledge and explaining scientific evidence to the public. This role applies particularly to the communication and explanation of results from complex studies on the possible health effects from EMF exposure (Huss und Röösli, 2006), especially as questions around EMF are not only an area of controversial discussions but also a topic that is often connected to non-science-based theories and conspiracy beliefs (Meese *et al.*, 2020, Elzanaty *et al.*, 2021).

Consequently, to communicate and transfer scientific knowledge and risk assessment regarding the potential health effects of EMF to the general population and to ensure that patients are counselled on the basis of scientific evidence, it is vital to understand the state of knowledge, risk perception and information needs of GPs as well as the relevance of this topic in their everyday practice. For instance, these aspects were examined by a survey among Dutch physicians who reported to being consulted frequently with respect to EMF while at the same time feeling not very well informed about the current state of evidence (Slottje *et al.*, 2017).

To the best of our knowledge, the scope and extent of the literature covering these aspects have not been determined yet. Nonetheless, it would be helpful to summarise the existing scientific evidence concerning GPs attitudes and level of information concerning the potential health risks related to EMF exposure as a basis for health-policy makers to potentially derive needs for educational efforts among GPs. On top of this, such as scoping exercise may also be useful to identify research gaps and core questions that have not been answered yet.

Consequently, our primary aim was to summarise the current state of evidence regarding the state of knowledge, risk perception and information needs of GPS as well as the relevance of questions around EMF in their occupational practice *via* a scoping review. Our secondary aim was to identify research gaps and derive practical implications and recommendations for future research.

2 Methods

This work was performed following the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (Tricco *et al.*, 2018). We searched for relevant articles in PubMed and additional scientific/medical sources, screened the identified manuscripts based on *a priori* defined inclusion criteria and extracted relevant data and information from the eligible articles.

2.1 Search strategy

For the search in PubMed, we developed a search string based on the PICO framework (Schardt *et al.*, 2007), considering GPs and paediatricians as participants (P), EMF and sources of EMF like mobile phones or power lines as exposure (I/E) and items like the attitudes, risk perception, knowledge and information needs of participants as outcome (O). The C (comparator) from the PICO framework was regarded as not applicable. The full search string is provided in Appendix A.

Applying this string, we searched for original articles published in English or German until October 11, 2022 with no further restrictions regarding other aspects, like article type or study design. In addition, we examined the reference lists of the included manuscripts and the respective list of similar articles provided by PubMed for potentially eligible publications. We also screened the websites of relevant organisations such as the World Health Organization, the International Commission on Non-Ionizing Radiation Protection (ICNIRP), the World Medical Association or the Federal Office for Radiation Protection for any relevant reports.

2.2. Selection process

All identified publications were screened for eligibility based on the PICO criteria described above. As the first step, titles and abstracts of the retrieved articles were evaluated by two researchers. Any disagreement has been reconciled by consultation of a third referee and subsequent discussion until consensus was reached. Next, the full texts of the remaining publications were again judged for eligibility by two researchers and a third referee if necessary.

2.3. Data extraction

While reviewing the included articles, all data were charted independently in separate tables by two researchers and compared afterwards. Again, any discrepancies were reconciled by consensus.

2.4. Data items

Five items were relevant outcomes for our review. One of them was the GPs' level of information concerning EMF, for example, the knowledge about the legal exposure limits within the general population. Another item was GPs' risk perception such as the subjective perception on how hazardous EMF exposure is to health. The item 'relevance in practice and EMF-related consultations' dealt with the frequency of counselling related to EMF, while 'information needs' asked for the participation of GPs in training courses on EMF and the type of sources they use when seeking information on EMF. The last relevant data items were potential determinants of the attitudes and beliefs of GPs towards possible health effects of EMF.

2.5. Synthesis of results

Based on the definition of the data items, comparable results of different articles were summarised by narrative synthesis. Items that were only assessed by one study are reported based on the results of the respective individual study.

3 Results

3.1. Selection of sources of evidence

Altogether, 274 articles were identified. After removing one duplicate, 273 studies remained for title screening. 261 records were classified as non-eligible as they were identified as not relevant for our research question. Out of the twelve articles left, two did not address the population of interest, three did not focus on the required exposure and one did not include the outcomes of interest. Consequently, six studies were included in the full-text screening. The examination of the reference lists of these six studies led to three more records of interest. All nine sources met our inclusion criteria (Fig. 1).

3.2 Characteristics of sources of evidence

All studies were conducted in Central/Western Europe. Five out of the nine records refer to a German study that was first published in 2009 with four more articles from the same study being published until 2015 (Berg-Beckhoff *et al.*, 2009, Berg-Beckhoff *et al.*, 2009, Kowall *et al.*, 2010, Berg-Beckhoff *et al.*, 2014, Kowall *et al.*, 2015). The remaining studies were from Austria (Leitgeb *et al.*, 2005), France (Lambrozo *et al.*, 2013), the Netherlands (Slottje *et al.*, 2017) and Switzerland (Huss und Röösli, 2006). All studies had a cross-sectional design, included GPs and evaluated different outcomes in relation to our data items of interest. All studies used phone interviews or self-administered questionnaires. Additionally, the German study provided a long version and a short version of its questionnaire (Tab. 1).

3.3. Results of individual sources of evidence

3.3.1. Level of information/knowledge

In the German study, GPs were asked about their EMF-related knowledge regarding several EMF-related questions. Between those items, the percentage of physicians giving the correct answer varied between 26.4% and 58.6% of the participants. For every question, almost one third picked the option ‘I don’t know’. An additional latent class analysis revealed four kinds of answer types: GPs who answered correctly most of the time; GPs who mainly chose ‘I don’t know’; GPs who were primarily able to answer questions on low-frequency EMF and GPs who answered health-related questions (correct or incorrect) and picked ‘I don’t know’ for the remaining questions (Berg-Beckhoff *et al.*, 2009, Berg-Beckhoff *et al.*, 2014).

A large part of the French GPs knew that mobile phone base stations, mobile phones, power lines and WiFi are the primary sources of EMF exposure in the general population. However, the authors concluded the GPs’ knowledge concerning health risks in relation to EMF is limited (Lambrozo *et al.*, 2013). The other three studies did not ask about GP’s knowledge levels.

3.3.2. Attitude/perception of risk

In the Austrian study, a large part of GPs declared that in their opinion EMF can cause diseases. On a six-point Likert scale, 77% chose a value on the ‘agreement-half’ and 33% picked the highest value of agreement. The sources most mentioned as relevant for health-related effects of EMF were power lines, mobile phones, mobile phone base stations and wireless phones (Leitgeb *et al.*, 2005). In the Swiss study, a smaller proportion, but still more than half of the GPs, estimated a relation between EMF and health-related symptoms to be plausible, while 29% of them said it is not. Tinnitus, difficulties concentrating and neoplasms were the most stated possible health effects. Most relevant sources of EMF exposure mentioned by the GPs were mobile phones, wireless phones and other electric devices that are used close to the body (Huss und Röösli, 2006).

Between 31.7% (short questionnaire) and 57.5% (long questionnaire) of the German GPs stated that in their view EMF exposure within legal exposure limits can cause health issues. The long questionnaire had an additional question on whether GPs believe that EMF can cause health issues. The difference to other questions was the phrasing ‘do you think...’ instead of ‘are there...’ and the missing of the additive ‘within legal limits’. Altogether, 54.3% affirmed this statement. About half of the GPs (54.5%) considered health issues related to EMF as psychosomatic. Most frequently stated symptoms were headache and sleep disorders. Most relevant EMF sources listed were mobile phones and mobile phone base stations (Berg-Beckhoff *et al.*, 2009, Berg-Beckhoff *et al.*, 2014).

The study from the Netherlands used a six-point Likert scale from fully disagree to fully agree for five different items. Almost two-thirds of the GPs disagreed that EMF exposure can cause health issues by choosing an answer on the ‘disagree-ment-half’. Furthermore, 73% agreed to the statement that EMF-related health issues are psychosomatic most of the time. Regarding their last consultation, 18% of GPs saw a plausible link between reported symptoms and EMF (Slottje *et al.*, 2017).

3.3.3. Relevance in practice and EMF-related consultations

Among Austrian GPs, 68% reported that at least one of their patients has asked them about harmful effects of EMF. Moreover, 59% indicated that they have had consultations with patients who even associated their health issues with EMF at least rarely or from time to time (Leitgeb *et al.*, 2005). Similarly, in the Swiss study, 69% of the GPs reported at least one consultation relating to EMF. In 77% of these consultations, the suspicion of a link to EMF was stated by the patient. If advice was given, the GPs mainly recommended reducing exposure (Huss und Röösli, 2006).

Those numbers were relatively similar to the German study, where 61.4% of the GPs stated that health-related effects of EMF came up for discussion at least once. In almost three quarters of the consultations, patients themselves mentioned

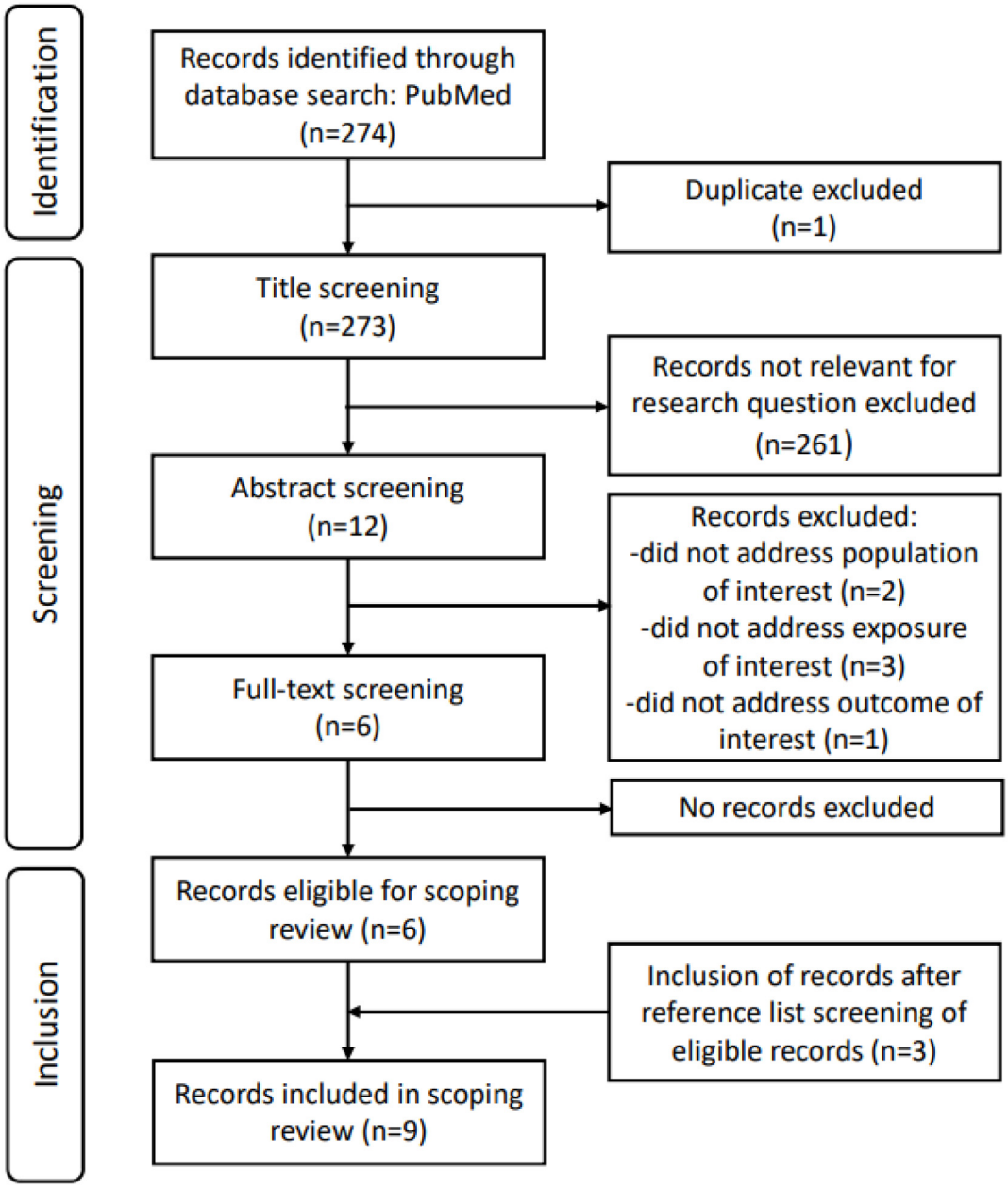

Fig. 1. Flowchart for the selection of articles.

the relation between their health issues and EMF. Furthermore, also the German physicians stated that their most frequent recommendation given to their patients was exposure reduction (Berg-Beckhoff *et al.*, 2009). Moreover, 35% of the Dutch GPs reported that they ever had a consultation concerning EMF. In about one third of the cases, the patients blamed their health issues on EMF (Slottje *et al.*, 2017).

3.3.4. Information needs

Austrian GPs mentioned magazines (54%) and newspapers (53%) as the most frequently used sources of information regarding EMF. While scientific sources were used by a quarter of the GPs, official bodies only played a minor role (4%) regarding information gathering (Leitgeb *et al.*, 2005). Similarly, in the French study, GPs were reported to use mass media more often than medical literature when searching for information concerning EMF (Lambrozo *et al.*, 2013).

Among the German GPs, 33.8% of the participants reported that they had used any source of information about EMF within the last year. Medical journals (84.7%) were the most frequently stated source of information, followed by newspapers (62.8%). The internet was used by 49.6% of GPs for information purposes. Being asked about their own level of information about EMF, GPs described their level of information as very good, good or rather good in 32.0% (long questionnaire) and 47.5% (short questionnaire) of the cases (Berg-Beckhoff *et al.*, 2009). This proportion was lower among the Swiss physicians, with only 26% assessing their information level as good (Huss und Röösli, 2006).

Table 1. Characteristics of the included original studies.

Author (year)	Country	Data collection period	Study design	Sample size (response rate)	Survey methods	Data items	Funding and competing interests
Leitgeb *et al.* (2005)	Austria	February 2003	Cross-sectional	n = 196 (49%)	Self-administered questionnaire (14 items)	Risk perception, relevance in practice/frequency of EMF-related consultations, information needs	Funding: not provided Competing interests: not provided
Huss & Röösli (2006)	Switzerland	May – June 2005	Cross-sectional	n = 342 (28.2%)	Computer-assisted telephone interviews	Risk perception, relevance in practice /frequency of EMF-related consultations, information needs	Funding: Federal Office of Public Health Competing interests: none declared
Berg-Beckhoff *et al.* (2009) Berg-Beckhoff *et al.* (2010) Kowall *et al.* (2010) Berg-Beckhoff *et al.* (2014) Kowall *et al.* (2015)	Germany	March – May 2008	Cross-sectional	Short questionnaire: n = 456 (49.1%), Long questionnaire: n = 435 (23.3%)	Self-administered questionnaire with short version (1 page) and long version (4 pages)	Level of knowledge, risk perception, relevance in practice /frequency of EMF-related consultations, information needs	Funding: Federal Office for Radiation Protection Competing interests: none declared
Lambrozo *et al.* (2013)	France	September – October 2010	Cross-sectional	n = 600	Self-administered questionnaire (24 items)	Level of knowledge, relevance in practice /frequency of EMF-related consultations, information needs	Funding: Service des études médicales d'EDF Competing interests: none declared
Slottje *et al.* (2017)	The Netherlands	October 2013 – January 2014	Cross-sectional	n = 2398 (29%)	Self-administered questionnaire	Risk perception, relevance in practice/frequency of EMF-related consultations, information needs	Funding: Netherlands Organization for Health Research and Development (ZonMW) Competing interests: not provided

Nevertheless, also among the German GPs most participants stated their wish to receive more information on health consequences as well as general information on EMF (Berg-Beckhoff *et al.*, 2009, 2010). Similarly, in the French study, 89% of the GPs reported they did not have enough information on EMF, whereas in the Dutch study 72% of the participants said they felt insufficiently informed (Slottje *et al.*, 2017).

3.3.5. Determinants

In addition to the above-mentioned descriptive measures, all included studies also aimed to identify potential determinants of the knowledge levels, attitude and risk perception of GPs towards EMF. In this context, the most investigated factors were age, sex, alternative medical training, subjective level of information and location of the practice (urban *vs.* rural).

3.3.5.1 Age

In the German study, participants aged 45 to 54 yr mainly believed that there are people with health problems caused by EMF (Berg-Beckhoff *et al.*, 2009) while in the Swiss study predominantly younger GPs believed that exposure to EMF occurring under everyday conditions can cause symptoms (Huss and Röösli, 2006). The same trend was seen when being asked whether GPs had ever been consulted regarding EMF. However, in both the Swiss and the Dutch study, age was not associated with GPs' assessment at the last consultation whether a link between symptoms and EMF was plausible or not (Huss and Röösli, 2006; Slottje *et al.*, 2017).

3.3.5.2 Sex

In the German study, there were slightly more women than men believing there are people with health problems caused by EMF (Berg-Beckhoff *et al.*, 2009). The proportion of male GPs was highest in the group, with mostly correct answers to the knowledge questions identified by the latent class analysis (Berg-Beckhoff *et al.*, 2014). Likewise, the French study also reported that knowledge of EMF sources was higher among male GPs than among their female counterparts (Lambrozo *et al.*, 2013).

Furthermore, in the Swiss study there were also more women believing that everyday exposure to EMF can cause symptoms. On the other hand, there was no evidence that sex had an influence on the assessment of GPs at the last consultation whether a link between symptoms and EMF was plausible or not (Huss und Röösli, 2006). The latter also applies to the Dutch study (Slottje *et al.*, 2017)

3.3.5.3 Alternative medical training

In the Austrian study, GPs who had alternative medical training precluded a relation between EMF, other environmental factors and health issues less common than GPs who usually used conventional medicine (Leitgeb *et al.*, 2005). Similarly, German GPs with an alternative medical training believed more often than GPs without an additional alternative education that there are people who get health-related problems because of EMF. Furthermore, GPs with alternative medical training knew less about EMF exposure in the population regarding legal limits and brain-temperature rises due to EMF. Additionally, they reported more frequently about EMF consultations and agreed less often that health issues attributed to EMF are predominantly psychosomatic. Stratification by type of alternative medical training yielded evidence that these associations were strongest in GPs with homeopathic medical training but nonetheless also existed in GPs with acupuncture and naturopathy education (Berg-Beckhoff *et al.*, 2009, Berg-Beckhoff *et al.*, 2014, Kowall *et al.*, 2015). In line with those findings, also in the Swiss study GPs with alternative medical training had more consultations regarding EMF. They reported more often that, in their opinion, EMF can cause symptoms in everyday conditions and more frequently evaluated a connection between these two variables as possible (Huss und Röösli, 2006). The results in the Dutch study were similar (Slottje *et al.*, 2017).

3.3.5.4 Subjective level of information

Altogether, the studies report mixed or even conflicting results concerning the question if physicians' subjective level of information is associated with their level of concern about EMF-related health effects. In detail, Swiss GPs with a higher level of subjective information reported a higher count of EMF-related consultations. Moreover, the number of GPs who believed that EMF can cause symptoms under everyday conditions was highest among the group with a medium subjective information level. In contrast, the number of GPs who did not believe in EMF-related health issues was slightly lower in the group with rather good or bad subjective level of information (Huss und Röösli, 2006). In contrast, Dutch GPs who thought they were informed sufficiently evaluated the relation between EMF and symptoms during the latest consultation as rather less plausible (Slottje *et al.*, 2017). In Germany, a few more GPs with higher subjective information level thought that there are people who develop health problems because of EMF (Berg-Beckhoff *et al.*, 2009). However, there is another publication from the same data that reported an opposite association (Kowall *et al.*, 2010).

3.3.5.5 Localisation of the physicians' practice

The Austrian study reported no difference between GPs whose practices were located in a rural compared to an urban setting with respect to the question if EMF can cause health problems (Leitgeb *et al.*, 2005). In the Swiss study, more GPs whose patients predominantly came from rural areas believed that EMF can lead to symptoms under everyday exposure levels. These GPs also reported more often that they had at least one consultation related to EMF (Huss und Röösli, 2006). The German study found no relation between the location of the practice (rather rural, rather urban or mixed) and the belief of GPs that there are individuals whose health complaints are caused by EMF exposure (Berg-Beckhoff *et al.*, 2009).

In addition, there were additional factors that were each investigated by just one study, such as general environmental concern (Berg-Beckhoff *et al.*, 2009), level of trust in authorities (Berg-Beckhoff *et al.*, 2009), work experience (Slottje *et al.*, 2017) or temporal trends (Huss und Röösli, 2006). None of them was reported to play a major role in the attitudes of GPs towards EMF and associated health risks.

4 Discussion

The present work aimed to summarise the current evidence regarding the knowledge, risk perception, information needs of GPs as well as the relevance of questions around EMF in their occupational practice. In total, we identified a small number of studies that investigated these topics. The results of these studies indicate that among GPs, on the one hand, there is a considerable concern about possible negative health effects caused by EMF and, on the other hand, information needs are covered insufficiently and knowledge levels are rather low. Moreover, a considerable part of the GPs already has been consulted concerning potential health effects of EMF.

The most striking and consistent findings are the high proportions of GPs who considered it, at least to some extent, as plausible that EMF can have detrimental effects on health in most of the studies, especially in the surveys among Austrian, German and Swiss physicians and the considerable numbers of GPs who regarded their information needs as unmet. On the one hand, the observed risk perception among the GPs is in line with the relatively high concern regarding health effects of EMF in the general population (as observed, for instance, by surveys in Germany (Götte und Ludewig, 2019)). On the other hand, such high levels of concern stand in contrast to the rather limited scientific evidence for an association between EMF exposure and various health outcomes.

When trying to interpret the high levels of concern among GPs, one may argue that the numbers reported by at least some of the studies may be biased by selective (non-)participation. This view is supported by the low response rates of less than 50 per cent in all studies. One top of that, in the German survey, the proportion of GPs who stated that, in their view, EMF can have detrimental health effects was markedly higher among those participants who completed the full questionnaire compared to those who answered the short version of the questionnaire (Berg-Beckhoff *et al.*, 2009). This can be interpreted as an indication that GPs who are more skeptical about EMF had a higher interest in joining the study than their less concerned peers.

Nevertheless, if one assumes that the high levels of concern cannot not only be explained by bias, the question arises which other factors may account for the attitudes of GPs towards EMF. All studies included in our review tried to elucidate the role of at least some explanatory factors. The only variable with relatively consistent evidence was alternative medical training as physicians having received such training indicated higher levels of concern than their peers. Besides, there is barely any scientific knowledge on what determines the views of GPs on EMF and health.

When aiming to close this research gap, we consider it especially interesting and promising to include the perspective of communication studies. In fact, EMF research touches on an interface between health and communication studies. The latter investigates, among other things, media use and related effects and, in this context, which factors influence the use and effects of media on an individual level. These include attitudes towards media (*e.g.*, the individual acceptance of media and their technologies) as well as users' (health-related) media literacy, in this case, the competent use of media for professional (information seeking) and private purposes among physicians.

Specifically, various research questions that are typically investigated by communication scholars could make substantial contributions to a better understanding of GPs' attitudes towards EMF and underlying determinants. Physician-patient communication may be worthwhile to be explored in the context of physicians' counselling on EMF since there is evidence that a good relationship between physician and patient goes along with improved information brokering (Riedl and Schüßler, 2017). With respect to EMF, GPs' media health literacy (Levin-Zamir *et al.*, 2011) may be a crucial determinant of their risk perception. The concept constitutes an interplay between media literacy (defined as the ability to reflect on the advantages and disadvantages of media consumption and use opportunities that media offer, *e.g.*, with regard to individual health behaviour) and health literacy, which includes numerous factors that determine how people find, understand and deal with information relevant for health (Parker *et al.*, 1995, Baker *et al.*, 1999). While there are first results on how media health literacy is associated with patients' individual self-management of chronic diseases (Rossmann *et al.*, 2019), there is no data yet on physicians' media health literacy. Furthermore, future studies may collect information on the technology acceptance of GPs as this may be a determinant of their attitudes towards the use of phones and other devices and as health-related information is increasingly searched online (Jia *et al.*, 2021).

Another intriguing aspect are conspiracy beliefs. Numerous conspiracy theories are circulating in the media about the link between EMF exposure and adverse health effects, such as an increased risk of cancer [28]. In the context of the COVID-19 pandemic, exposure to 5G radiation was particularly addressed in non-science-based theories [29]. These include assumptions that EMF exposure could weaken the immune system or that 5G was the direct cause of a COVID-19 infection [30]. Hence, it would be interesting to scrutinise the extent to which GPs are influenced by such conspiracy theories.

The second major finding from our synthesis, that high proportions of GPs do not feel satisfactorily informed about EMF and potential health effects, bears the danger that, at least in some instances, patients may receive counselling that is not solely based on scientific evidence. This concern is highlighted by the low levels of knowledge concerning health risks in association with EMF reported by the German and French studies and the significant proportions of GPs across several studies reporting to use non-scientific sources like mass media when seeking information on EMF. To overcome this danger, appropriate institutions like governmental bodies, radiation protection authorities or occupational associations must find ways to cover GPs' information needs better. One approach may be to address potential health effects of EMF more extensively in medical curricula. Of course, in many cases, this would be a complex undertaking as universities and medical faculties would have to adapt their entire curricula. Another approach would be to improve informing GPs who are already practising *via* advanced training, workshops or information events. For appropriate authorities to plan and implement such

measures, future studies that shed further light on physicians' knowledge levels and attitudes by closing research gaps and overcoming limitations of the existing studies would be helpful.

Regarding those limitations, apart from the lack of a communication studies perspective, it is striking that, except for the Dutch survey, all studies were conducted more than 10 yr ago. During this period, there have been significant changes in the media usage patterns of the general population. The use of mobile internet and services such as WhatsApp instead of SMS for communication purposes (Langer *et al.*, 2017) (Südwest, 2021) has drastically increased and technical standards have evolved by new developments like 5G. Additionally, the results of today's most popular and relevant studies on health effects of EMF were published after the surveys included in this review had been conducted (Interphone Study Group, 2010, Interphone Study Group, 2011, Auvinen *et al.*, 2019, Tettamanti *et al.*, 2020, Castaño-Vinyals *et al.*, 2021). In the meantime, a different state of scientific evidence concerning EMF and health exists. To what extent GPs are familiar with these studies and the latest state of scientific evidence (including current risk assessment provided by authorities like ICNIRP) has not yet been elucidated.

In addition, all studies were conducted exclusively among GPs in the field of adult medicine, while there are no scientific findings on the attitudes of paediatricians with regard to EMF and health. Children and adolescents could, however, play a special role in the question of potentially harmful effects of EMF exposure as they are possibly particularly vulnerable to such effects (Kheifets *et al.*, 2005). For example, children and adolescents do not only show clearly different patterns in the use of mobile communication technologies than their parents' generation (Eeftens *et al.*, 2018) but also accumulate a higher lifetime exposure than many of today's adults due to the increasingly early onset of smartphone and tablet use (Eeftens *et al.*, 2023). Due to this possible special vulnerability of children and adolescents, as well as the fact that some of the outcomes discussed in connection with EMF (*e.g.*, behavioural problems or ADHD) relate specifically to childhood, it appears conceivable that the attitudes of paediatricians may differ from their colleagues in the field of adult medicine.

What is also lacking is a qualitative research approach since all studies solely used quantitative methods. Qualitative interviews such as focus groups are particularly suitable for investigating attitudes, opinions and behaviours because it is often challenging to articulate habituated actions as well as complex and unconscious perceptions or to scale agreement or disagreement (Meyen *et al.*, 2011, Flick, 2018). Lastly, since all studies so far were conducted in Central/Western European countries, it may be hard to extrapolate their findings to other regions of the world.

Limitations of this review itself include the sole use of one electronic database. While we are confident that PubMed is by far the most relevant source for searching for any kind of research on EMF and health, we may have missed relevant publications, especially reports published in languages other than English and German. In fact, we identified one study whose abstract was available in English but the full text was provided only in French. Even though we are confident that we were able to extract the relevant data from this manuscript correctly, we cannot preclude that there are some misinterpretations due to the lack of a native speaker among the authors. Lastly, the fact that we retrieved only a small number of eligible studies leads our conclusions to be drawn on a relatively weak basis of evidence.

Nevertheless, a variety of implications can be derived from this review. First, there is a practical need to improve the fulfilment of GPs' information needs. Furthermore, further research is necessary for a mere update of the scientific knowledge about general practitioners' risk perception, subjective and objective information level and information needs regarding potential health effects of EMF. On top of that, the scientific state of evidence concerning physicians' EMF risk perception should not only be refreshed but also deepened through the inclusion of novel aspects like media health literacy or conspiracy beliefs and methods not used by previous research such as qualitative methods.

5 Conclusion

In summary, the results from our review point towards considerable levels of concern regarding potential health effects of EMF among general practitioners. At the same time, their information needs concerning EMF and health seem to be insufficiently fulfilled. Thus far, it remains unclear what factors determine their concern. Likewise, there is little data on the actual level of knowledge on EMF and health among GPs. To gain better understanding, future studies may take new perspectives like concepts and theories from communication science and use additional methods such as qualitative techniques. Such research may help responsible bodies and authorities to find better ways to transfer and communicate scientific evidence about EMF and health towards general practitioners. This is particularly important in order to ensure that patients receive counselling on EMF and health that is rigorously based on the current state of scientific evidence.

Conflict of interest

The authors declare that they have no conflict of interest.

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Ethical approval

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Author contributions

Lyn Ermel: Investigation, Resources, Data Curation, Validation, Writing – Original Draft. **Felix Forster:** Conceptualization, Methodology, Formal analysis, Investigation, Resources, Data Curation, Writing – Original Draft. **Ronny Jung:** Validation, Writing – Original Draft. **Katharina Lüthy:** Formal analysis, Investigation, Data Curation, Writing – Original Draft. **Claudia Riesmeyer:** Conceptualization, Methodology, Investigation, Writing – Original Draft, Supervision, Funding acquisition. **Tobias Weinmann:** Conceptualization, Methodology, Investigation, Writing – Original Draft, Supervision, Funding acquisition. **Pia Wullinger:** Formal analysis, Investigation, Data Curation, Writing – Original Draft.

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Appendix A: Search string for the literature search in PubMed.

("Physicians" [MeSH] OR "Physicians, Primary Care" [MeSH] OR "Pediatricians" [MeSH] OR "General Practitioners" [MeSH] OR "Doctors" [Title/Abstract]) AND ("Electromagnetic Fields" [MeSH] OR "Electromagnetic Radiation" [MeSH] OR "Radio-frequency fields" [Title/Abstract] OR "Extremely low frequency fields" [Title/Abstract] OR "Cell Phone" [MeSH] OR "Mobile Phone" [Title/Abstract] OR "Power lines" [Title/Abstract] OR "Electromagnetic Hypersensitivity" [Title/Abstract]) AND ("Health Knowledge, Attitudes, Practice"[MeSH] OR "Attitude of Health Personnel" [MeSH] OR "Guideline Adherence" [MeSH] OR "Knowledge" [Title/Abstract] OR "Information" [Title/Abstract] OR "Disease Management" [Title/Abstract] OR "Risk perception" [Title/Abstract] OR "Risk Assessment" [Title/Abstract] OR "Needs" [Title/Abstract]) NOT "App" [Title/Abstract] NOT "Apps" [Title/Abstract].

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