2020

Oregon Health Authority Report

Oregon Senate Bill 283

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Executive Summary

Senate Bill 283 directs the Oregon Health Authority (OHA) to review studies of the health effects of exposure to microwave radiation (subsequently referred to as radiofrequency radiation or RFR), particularly from the use of wireless network technologies in schools or similar environments.

At OHA, we focused our review on epidemiology studies that examined a relationship between RFR exposure and various endpoints that include cancer or tumor formation, noncancer toxicity effects, mental health, and sleep. Few studies were available that specifically included children; therefore, we included all studies in humans not including occupational settings due to the high exposures of the latter.

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Most studies that we reviewed relied on exposure to mobile phones or other devices that emit RFR without measuring RFR. We identified relevant RFR emissions to be in the frequency range of mobile phones and Wi-Fi, or approximately between 1.6 gigahertz and 30 gigahertz.

We found insufficient evidence to indicate a causal relationship between mobile phone exposures and cancer endpoints. Although an association between long-term mobile phone use and various brain cancers was found in some studies, more studies found no association between long-term use and cancers. Moreover, findings were not consistent among studies and some studies found an increase in tumor incidence that would be expected to surface after a longer period of exposure than reported in some studies in association with RFR. Further, most studies were not able to measure actual RFR for any one individual and relied on personal recollection of habits that were translated into exposure measures.

We also reviewed the literature for a potential effect on noncancer endpoints and functions, such as auditory function, cognitive function, nervous system, miscarriage, reproductive system, sleep, mental health, and others. Like the studies that examined cancer endpoints, most noncancer studies were not able to measure actual RFR for any one individual and relied on personal recollection of habits that were translated into exposure measures. Moreover, many of the studies are cross-sectional looking at a slice of time rather than following people over time to look at changes. This makes it difficult to draw conclusions about the effects of RFR exposure on health.

There was some indication of an effect of RFR on specific brain wave signals, but this was not observed in all studies and it was limited to studies where a cell phone was applied to the head for a period of time. There were also reported effects on reproductive endpoints, but these studies were also not consistent in their findings and were unable to account for many potential confounders. For example, longer use of phones associated with increased sperm abnormalities in men might be a result of longer periods of sitting down or having a running laptop in contact with the body for extended periods rather than RFR from the phone or a router.

We noticed a variety of effects among studies looking at health outcomes associated with phone use and screen time (including TV, laptops, etc.). There is a good evidence to suggest that screen and phone time are associated with poorer mental health indicators and sleep. AndT the exact attributes associated with the use of these devices (RFR exposure, content, etc.) need to be explored further in longitudinal (long term follow-up) studies, in-depth health assessments, double blind studies, and RFR exposure assessments.

Background

Senate Bill 283 (SB 283) directs the Oregon Health Authority (OHA) to review peer-reviewed, independently funded scientific studies of the health effects of exposure to microwave radiation, particularly from the use of wireless network technologies in schools or similar environments, including those that examined the potential health effects in children. In addition, SB 283 directs OHA to report the results of this review to an interim committee of the Legislative Assembly related to education by January 2, 2021.

The electromagnetic spectrum is split into two main categories: ionizing and non-ionizing radiation. Ionizing radiation is a form of high energy particles and waves that interacts with atoms and molecules by removing electrons or breaking chemical bonds. Non-ionizing radiation is low energy waves that do not have enough energy to remove electrons from atoms or break chemical bonds. The spectrum is illustrated with examples in Figure 1 (FDA, 2020).

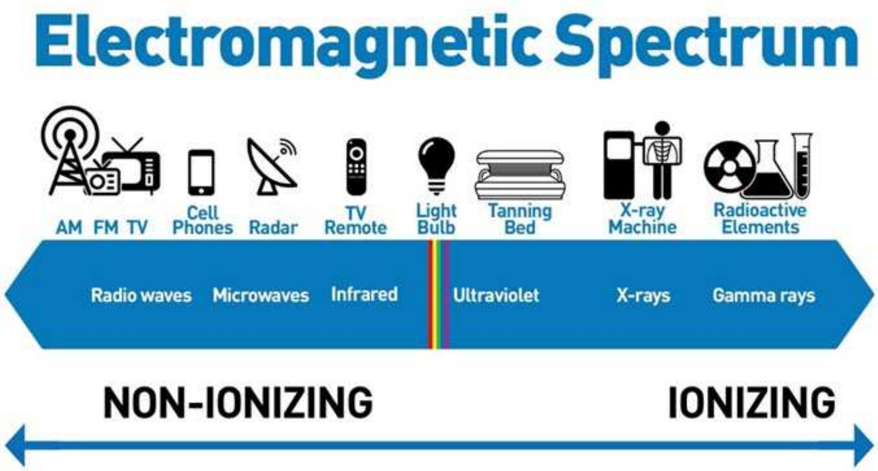
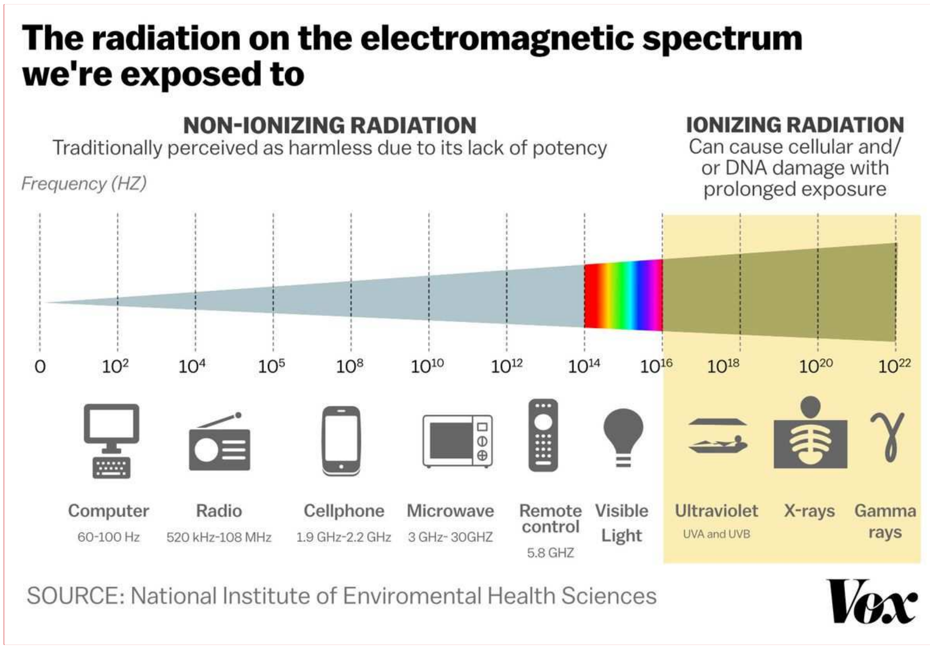


Figure 1: Electromagnetic Spectrum



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The scope of SB 283 includes microwave fields and wireless network technologies which fall under the non-ionizing portion of the electromagnetic spectrum. Microwaves are used to detect speeding cars, to send telephone and television communications, and in microwave ovens. In broad terms, radiofrequency (RF) is used to transmit signals carrying information via radio waves. The radio waves are broadcast using a transmitter, sent out to a receiver, and then the signal is converted back to its original form. Microwave and RF energy may cause tissue damage from overheating. This can occur when RF energy is very strong such as when using industrial equipment. Cell phones and wireless networks also produce RF energy, but not at levels that cause significant heating.

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We focused our review on epidemiology studies that examined a relationship between RFR exposure and various endpoints that include cancer or tumor formation, noncancer toxicity effects, mental health, and sleep. Establishing causal relationships between exposures and health outcomes relies on effective epidemiology study designs. A major epidemiology study subtype is observational studies, which include descriptive studies, ecological studies, cross-sectional studies, case-control studies, cohort studies (both prospective and retrospective), and others. The other major epidemiology study subtype is experimental studies, which include randomized controlled trials (RCTs), non-randomized trials, and other types. Observational studies are most common for nonclinical health settings. While reviewing studies, it is important to consider the weight of the causal evidence in the context of study design, also known as the "hierarchy of evidence." Though a consensus view does not exist, generally, meta-analyses, RCTs, and cohort studies are considered the highest quality of evidence due to reduced risk of bias. Case-control studies are also considered to be a higher quality of evidence, while descriptive, ecological, and cross-sectional studies provide less support for causal evidence.

Causal inference in epidemiology is not an exact science and there is no single definition of what constitutes a causal exposure-outcome relationship. Beyond study design, a variety of other contextual factors can be utilized to examine causal relationships: 1) Solid exposure assessment to characterize environmental exposures; 2) A dose-response gradient, where increasing exposure dose results in increased risk of adverse health outcomes, although not all environmental exposures behave as such; 3) Accounting for covariates such as co-exposures, demographic factors, or other parameters that could confound or cloud the relationship outcome; 4) Chronology in exposure and effect (e.g., did exposure happen before effect and is the latency between exposure and effect meaningful?); 5) Consistency in study results. In summary, for review of causal epidemiologic evidence, study design, dose-response, and consistency are a few of the most important determinants. These concepts are integrated into our review of the evidence of a relationship between RFR and health endpoints.

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Reference: Burns PB, Rohrich RJ, Chung KC. The Levels of Evidence and their role in Evidence-Based Medicine. *Plast Reconstr Surg*. 2011;128(1):305-310. doi:10.1097/PRS.0b013e318219c171

Commented [BRB5]: Reference: 1. Rothman KJ, Lanes SF. *Causal Inference*. Kenneth Rothman; 1988.

Methods

We searched the scientific literature for an association between exposure to radiofrequency radiation (RFR) commonly found in school environments and cancer- and noncancer health effects. We limited our search to peer-reviewed studies in English that investigated human health endpoints. Few studies were available that specifically included children; therefore, we included all studies in humans not including occupational settings due to the high exposures of the latter. We identified relevant RFR emissions to be in the frequency range of mobile phones and Wi-Fi, or approximately between 1.6 gigahertz and 30 gigahertz. This frequency range includes both ultra-high and super-high radio frequencies that the majority of current fifth generation (5G) networks utilize.[1] We reviewed studies that were published between January 1, 1993 and April 24, 2020. This date range targets the timeframe between rollout of 2G networks in the United States (1993) and the time we started this review. When necessary, we also included several more recent studies during the synthesis of our review. We searched two scientific article databases, PubMed and IEEE Xplore because they are most likely to capture the relevant articles. Following are the search and review methods for cancer and occupational studies.

Cancer Studies

PubMed search terms

“wi-fi"[ALL FIELDS] OR “wifi”[ALL FIELDS] OR "wlan"[ALL FIELDS] OR “mobile phones”[MeSH] OR (“mobile”[ALL FIELDS] AND “phones”[ALL FIELDS) OR “cell phones”[MeSH] OR (“cell”[ALL FIELDS] AND “phones”[ALL FIELDS]) AND (“cancer”[ALL FIELDS]) AND “1993/01/01”[Date -

Publication] : "2020/04/24"[Date - Publication]) AND English[lang] NOT (“Mobile Applications”[MeSH] OR “Text Messaging”[ALL FIELDS] OR “app”[ALL FIELDS] OR “monitoring”[ALL FIELDS] OR “screening”[ALL FIELDS] OR “signal transduction”[ALL FIELDS] OR “radar”[ALL FIELDS] OR “drug therapy”[ALL FIELDS] OR “software”[ALL FIELDS] OR “psychology”[ALL FIELDS] OR “dietary assessment”[ALL FIELDS] or “e-waste”[ALL FIELDS] OR “oncology”[ALL FIELDS] OR “imaging”[ALL FIELDS] OR “Comment”[Publication Type] OR “Letter”[Publication Type] OR “Editorial”[Publication Type] OR “News”[Publication Type])

This search found 176 papers. Use of the "humans" species filter reduced the number of papers to 137. Many papers removed were not original research or review articles, were human cell line studies, or focused on best practices for RFR exposure assessment. Titles of all 137 papers were reviewed, resulting in removal of 32 papers that were unrelated to the relationship between relevant RFR exposures and cancer or were outside the scope of this review. Further abstract review resulted in removal of 59 more studies. Articles not included after abstract filtering included those that did not contain exposures within the relevant RFR range, those that were not completed for human populations, and those that were not original research or review articles. We reviewed the references of the remaining 46 studies to capture research papers that we missed in our initial search. This resulted in 49 more studies for a total 97 cancer studies that we reviewed.

IEEE Xplore search terms

((((((("All Metadata":"wi-fi") OR "All Metadata":"wifi") OR "All Metadata":"wlan") OR "Mesh_Terms":"mobile phones") OR "All Metadata":"mobile" AND "All Metadata":"phones") OR "Mesh_Terms":"cell phones") OR "All Metadata":"cell" AND "All Metadata":"phones") AND "All Metadata":"cancer”)

The search found 159 papers. After using filters to only include journal articles, magazine articles, articles published in English, and those published in the selected date range, the number of papers was reduced to 50 papers. Review of the titles of the studies removed 13 studies of unrelated subject matter. After title filtering, we reviewed the abstracts of all remaining 37 studies and found no articles that were within the scope of this review, either due to the lack of cancer endpoints under direct study or to a focus limited to exposure assessment. Therefore, we did not include cancer studies from IEEE in this review.

Noncancer studies

Toxicity

PubMed and IEEE Xplore search terms

((((((((("wi-fi") OR "wifi") OR "wlan") OR "mobile phones"[MeSH Terms]) OR "mobile") AND "phones") OR "cell phones"[MeSH Terms]) OR "cell") AND "phones")) AND (((((("toxicity") OR "health effects") NOT "cancer") NOT "tumor") OR "organ") AND "cell") Filters: Publication date from 1993/01/01

The inclusion criteria were 1) exposure/independent variable as exposure to wifi, radio wave frequency, electromagnetic radiation, or radio frequency radiation; 2) outcome/dependent variable as biological changes in body, both at organ and cellular levels; 3) included human subject/participants; and 4) published during or after 1993. Studies were excluded if they were 1) studies without abstract, 2) non-peer-reviewed articles, 3) animals or vitro studies, and 4) articles not available in English.

A search of the two databases found 398 articles. After removing duplicate articles, 320 articles remained. Upon review of the 320 article titles and abstracts of found articles, 143 articles met the inclusion criteria. We also found 49 articles from a manual search for a total of 192 full text articles. Review of the articles resulted in a final inclusion tally of 52 articles.

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Mental health

PubMed and IEEE Xplore search terms

((((((((("wi-fi") OR "wifi") OR "wlan") OR "mobile phones"[MeSH Terms]) OR "mobile") AND "phones") OR "cell phones"[MeSH Terms]) OR "cell") AND "phones")) AND ((((((((("anxiety") OR "attention deficits") OR "ADHD") OR "depression") OR "mental health") OR "mental illness") OR "mental disorders") OR "mental distress") OR "mental impairment") OR "psychiatric") Filters: Publication date from 1993/01/01

The inclusion criteria were: 1) exposure Wi-Fi, radio wave frequency, electromagnetic radiation, radiofrequency radiation, cell phones, electronic devices that emit RFR, 2) examine the effects on mental health and mental illness-related symptoms, and 3) included human subjects and participants. We excluded studies if the articles were 1) studies without abstract, 2) non-peer-reviewed articles, 3) animals or vitro studies, and 4) articles not available in English.

A search of the two databases found 435 articles. After removing duplicate articles, 381 articles remained. A review of the titles and abstracts eliminated most resulting in 7 articles. We also found 19 articles from a manual search for a total of 26 articles. Further review resulted in a final inclusion tally of 21 articles.

Sleep

PubMed and IEEE Xplore search terms

((((((((("wi-fi") OR "wifi") OR "wlan") OR "mobile phones"[MeSH Terms]) OR "mobile") AND "phones") OR "cell phones"[MeSH Terms]) OR "cell") AND "phones")) AND (("sleep") OR "sleep quality") Filters: Publication date from 1993/01/01

The inclusion criteria were: 1) exposure Wi-Fi, radio wave frequency, electromagnetic radiation, radiofrequency radiation, cell phones, electronic devices that emit RFR, 2) examine the effects on sleep, 3) included human subjects and participants, and 4) published during or after 1993. We excluded studies if the articles were 1) without abstract, 2) non-peer-reviewed, 3) animal or vitro studies, and 4) not available in English.

A search of the two databases found 310 articles. After removing duplicate, 247 articles remained. Review of these titles and abstracts determined 30 articles to meet the inclusion criteria along with 11 articles from a manual search. Review of the full texts of these articles resulted in a final inclusion tally of 30 articles.

Results

Cancer endpoints

Super-high and ultra-high RFR are the frequencies most likely to be found in school environments. These frequencies can also be found in homes associated with WIFI, cell phones, routers, and other sources. The association between these frequencies and cancer is one of the most studied of those presented in this report. The cancer endpoints studied in the literature since the advent of 2G wireless technology in the U.S. include brain tumors, acoustic neuroma, vestibular schwannoma, parotid gland tumors, leukemia, and skin cancer among others. Because cell phone use has become ubiquitous in daily life, brain and head/neck tumors have been the most heavily studied over the past 25 years.

There is a need to differentiate between RFR and ionizing radiation, the latter having an established association with cancer (1). Ionizing radiation exposure has a clear mechanism that results in cancer: mutagenic DNA damage and carcinogenic cell changes (2). Radiofrequency radiation is non-ionizing, meaning it does not have sufficient energy to break bonds in DNA. A proposed carcinogenic mechanism is cellular heating (3), but existing research suggests that frequencies used by cell phones cause negligible heating beyond the skin (4). However, cellular heating is not an unanimously accepted sole mechanism for RFR potential carcinogenicity and further research is needed to confirm or refute this postulation and to determine the potential for RFR to act as a cancer promoter (enhances carcinogenicity) or a carcinogen. In the following sections, we reviewed studies examining relationships between super-high and ultra-high RFR exposure and cancer endpoints.

Childhood Cancer Studies

Like other health endpoints in subsequent sections of this report, there is a limited number of epidemiology studies that directly examined the health effects of RFR exposure on children.

Based on our search terms and the search time frame, there are 9 studies that examined the effects of RFR exposure on cancer in children (5–13). These studies cover a wide range of cancer endpoints including brain cancers, leukemia, bladder cancer, skin melanoma, and lymphoma, among others. Six of these studies were completed for RFR exposures that are outside of what children would commonly be exposed to in schools, such as close residence to high power radio and television transmitters (7,9–13). However, the results are still useful for examining the effects of higher doses of RFR on childhood cancers. The remaining 3 studies examined either exposure via child mobile phone use or exposure via residence near mobile phone base stations

Three studies with RFR exposures similar to those expected in schools have been completed in child populations (5,6,8). A large population-based case-control study completed by Li *et al*. (2012) in Taiwan between 2003 and 2007 examining the effects of mobile phone base station exposure on all types of childhood neoplasms found a weak association (8). The study included 1,397 cancer cases in children 4 years and under from the British cancer registry and 5,588 controls from the British national birth registry, individually matched by age and sex. Exposure was quantified via modeled power density from location of childhood residence and mobile phone base station location. The study found no association between mobile phone base station exposure and incidence of any specific type of cancer or overall combined cancer. Addition of a quadratic term to the continuous exposure models was of borderline significance (P=0.05) for brain and central nervous system cancer, for which risk was lower with higher estimated levels of exposure. The UK Department of Health and the mobile telecommunications industry jointly funded this study and approved its design.

Aydin *et al*. (2011) assessed mobile phone use and brain tumor incidence in children and adolescents in a multicenter study (5). The study included 352 cases diagnosed with a brain tumor between 2004 and 2008 and 646 controls from national population registries of participating countries. The study reported no increased risk of brain tumors ~~risk increase~~ with duration of mobile phone use or in~~with~~ areas of the brain closest to a handheld mobile phone. However, in a subset of study participants for whom operator recorded data were available, brain tumor risk was related to the time elapsed since the mobile phone subscription was started but not to the amount of use.

Three of the 6 studies where RFR exposures were higher than what would be expected in schools found no association between any of the childhood cancers studied and RFR exposures. Of note, a large case-control study by Merzenich *et al*. (2008) examined childhood leukemia near high-power AM and FM radio transmitters and television broadcast towers between 1984 and 2003 in Germany (10). The study included 1,959 cases of childhood leukemia in children 14 years and younger from a German national childhood cancer registry and 5,848 controls randomly selected from population registries and individually matched by sex, age, year of diagnosis, and study region. Exposure was quantified via location-based power modeling using the field strengths of transmitters. The study found no elevated odds of leukemia among populations of children living near radio transmitters or television broadcast towers.

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Another case-control study by Ha *et al*. (2007) in South Korea found a relationship between close residence (within 2 kilometers) to and overall frequency of AM radio transmitters and antennas and childhood leukemia (7). The study included 1,928 childhood leukemia and 956 childhood brain cancer cases in children under 15 years diagnosed between 1993 and 1999 in 14 South Korea hospitals. Controls were recruited from children with respiratory diseases in the same hospitals and individually matched to cases by age, sex, and year of diagnosis. Exposure to AM radio was quantified using a validated location-based model of 31 transmitters and 49 antennas with at least 20-kilowatts of power and children's residences. Residence within 2 kilometers to AM transmitters/antennas was associated with 115% increase in odds of leukemia versus residence at 20 kilometers. There was no association between AM radio exposure and brain cancers. This study also suggested a dose-response relationship between AM radio exposure and leukemia, where children living further from transmitters and antennas had lower risk.

Briefly, we found only 3 studies that examined the cancer effects of RFR exposures like those in schools, although none of these studies were conducted in schools or assessed RFR exposures in school children. These studies showed either none, weak, or contradictory (e.g., less risk with higher use of cell phones) effects of RFR on cancer in children. There were 6 other studies that examined a similar relationship, albeit at higher RFR levels than those expected in schools. Those studies showed equivocal outcomes in terms of an association between RFR and cancer in children.

Overall, 9 studies examined the relationship between RFR exposures and childhood cancer endpoints with mixed results. These studies had several methodological limitations that included poor assessment of and control for individualized RFR exposures and confounding from other RFR sources. For example, modeled field strength and other location-based exposure assessments are ineffective at capturing RFR exposures of individual children. This likely resulted in misclassification bias in some of the studies we reviewed above. Further, translation of some of the findings to possible health effects of mobile phones and Wi-Fi is not possible. For example, AM and FM radiofrequency exposures exist at frequency bands that are at between 10 and 100 times lower than the frequency bands of mobile phones and Wi-Fi. The low number of available studies and methodological problems are further compounded by the fact that findings have been inconsistent among studies and adjusting for environmental exposures that are associated with some childhood cancers was not performed. Due to these factors, it is important to also review the many adult RFR-cancer studies to determine if relationships become clearer, particularly since adults are also present at schools potentially for more years than children (e.g., teacher, custodian, administrator). Below is a review of a selection of important adult studies.

Adult Cancer Studies

Many descriptive, ecological, case-control, and cohort studies have examined the association between RFR exposure and tumor or cancer incidence in adults.

A 2010 study by Inskip *et al*. examined brain cancer incidence trends in the United States as they related to widespread phone use over time (14). The study included 38,788 cases of brain cancers among White patients diagnosed between 1977 and 2006. No exposure assessment was completed for mobile phone use. The study found no evidence of a relationship between increasing use of mobile phone over time and brain cancers. The authors noted that there would likely be a noticeable increase in brain cancer incidence over the temporal span of the study if a causal relationship does indeed exist between mobile phone use and brain cancer. However, they could not determine such an increase with the respective data. The authors noted a temporal increase in overall brain cancer incidence that they attributed to improved diagnosis resulting from the introduction of computed tomography scanning and magnetic resonance imaging in the 1970s and 1980s respectively.

A similar study by Chapman *et al*. examined overall brain cancer incidence trends and phone use in Australia (15). The study included 34,080 diagnosed cases of brain cancer from 1982 to 2012. An exposure assessment was completed to determine the total number of mobile phone accounts with groupings into time related exposure categories. However, the exposure variable was not used for the main analysis. The study found no evidence of an increase in brain cancer incidence in any age group that could be attributed to mobile phone use. Incidence studies such as this do not account for individual mobile phone exposures, so deriving causal evidence is difficult.

A 2012 ecological study by Little *et al*. examined the relationship between mobile phone subscriptions and United States glioma incidence trends (16). The study included 24,813 cases of glioma among non-Hispanic white individuals diagnosed between 1992 and 2008. Mobile phone exposure was assessed at the population level via total mobile phone subscriptions between 1985 and 2010. The study found that U.S. glioma incidence rates are not high enough to indicate any effect of mobile phones. Results of this study may be affected by both sampling and assumption bias.

Two ecological studies by de Vocht *et al*. (2016 & 2019) examined the associations between brain cancers in England and mobile phone subscriptions (17,18). The 2016 study assessed the relationship between annual mobile phone subscriptions at the population level and annual 1984-2014 incidence of malignant glioma, glioblastoma multiforme, and malignant neoplasms of the temporal and parietal lobes. The study found a 35% increase in risk of malignant temporal lobe tumors as the number of phone subscriptions increased. The 2019 study assessed the relationship between annual mobile phone subscriptions and annual 1985-2005 incidence of glioblastoma (14,503 cases). The study found statistically non-significant risk increases of between 35% and 59% for temporal and frontal lobe tumors and tumors of the cerebellum. Both de Vocht studies used methodologies that are not easily reproducible or validated and contain possible assumption and interpretation bias. Further, ecological analyses may suffer from the ecological fallacy, where population health characteristics ascertained ecologically cannot be translated to the individual (19). In other words, because individual mobile phone exposures were not collected for these studies, causal inference from these studies is not possible.

Most of the case-control studies examining relationships between mobile phone exposures and cancer endpoints have been completed in European and Asian countries, but a few with sufficient sample sizes have been completed in the U.S. A U.S. case-control study by Muscat *et al*. examined the risk of brain cancer in association with cell phone use (20). The study included 469 cases from individuals ages 18 years to 80 years diagnosed with primary brain cancer in five medical institutions in New York City, Providence, and Boston between 1994 and 1998 and 422 controls from in-patients without cancer and cancer patients with other types of cancer besides brain in the same institutions. Controls were frequency-matched to cases by age, sex, race, and month of admission. Cell phone exposure was quantified via in-person questionnaires, with data on the number of years of cell phone use, minutes or hours used per month, year of first use, phone manufacturer, and average monthly phone bill. The study found no relationship between cell phone use and risk of brain cancers. Another U.S. case-control study by Inskip *et al*. examined the risk of glioma, meningioma, and acoustic neuroma as a result of mobile phone use in 782 cases, 18 years and older, diagnosed in 4 hospitals in Phoenix, Boston, and Pittsburgh between 1994 and 1998 and 799 controls admitted to the same hospitals for non-malignant conditions and frequency-matched by age, sex, race, and hospital proximity (21). Mobile phone exposure was quantified via computer-assisted face-to-face interviews, with data on regular phone use, years of regular use, make and model of device, average duration of calls, and number of calls collected. The study found no association between mobile phone use and any of the types of brain cancer studied.

Both retrospective and prospective cohort studies have been completed to examine the risk of cancer from mobile phone use. A retrospective cohort study by Johansen *et al*. examined risk of all types of cancers as a result of mobile phones by obtaining all Danish mobile phone subscriber records between 1982 and 1995 (22). Of the 420,095 subscribers in the time frame, 2,876 cases of diagnosed cancer among males were ascertained from the Danish Cancer Registry. Mobile phone exposure quantification was limited to subscription date and did not include frequency of use or other indicators of exposure. The study found no increased risk for cancers considered *a priori* to be possibly associated with mobile phones, which included brain tumors, salivary gland tumors, and leukemia. Another retrospective cohort study by Schüz *et al*. examined the risk of vestibular schwannoma as a result of long-term mobile phone use by obtaining all Danish mobile phone subscriber records between 1995 and 2006 (23). Of 2.9 million subscribers in the time frame, 806 cases of vestibular schwannoma were ascertained from a national tumor registry. Mobile phone exposure was quantified solely through subscriptions with no individual exposure quantification. The study found no evidence that use of mobile phones was related to risk of vestibular schwannoma.

Poulsen *et al* (2013) examined an association between skin cancer and cell phone use (24). The authors included all cases of skin cancers diagnosed in Denmark and having cell phone subscriptions starting between 1987 and 1995 (24). The cases were followed through 2007. The authors found no association between overall risk for melanoma of the head and neck, basal cell carcinoma, or squamous cell carcinoma.

A 2011 prospective cohort study by Frei *et al*. examined the risk of brain tumors as a result of mobile phone use by obtaining all records of people 30 years and older born in Denmark after 1925 (25). From these records, 358,403 mobile phone subscribers and 10,729 CNS cancer cases were ascertained. Mobile phone exposure quantification was again based only on subscription. The study generally found no increased risk of cancers of the CNS or tobacco-related cancers from mobile phone exposure. Among the many associations the study examined, it found several associations that indicated lower cancer risk associated with mobile phone use, overall increased risk for "other and unspecified tumor types", and other associations that were not consistent with duration of use.

Another prospective study by Benson *et al*. examined the risk of intracranial CNS tumors as a result of mobile phone use (26). The study included 791,710 middle-aged U.K. women recruited between 1996 and 2001 via a National Health Service breast cancer screening program. Mobile phone exposure was quantified via 3 surveys completed at baseline, midpoint, and the end of follow-up. During 7 years of follow-up, 51,860 incident cases of cancer and 1,261 incident CNS tumors were observed. The study found no difference in risk of CNS tumors between never and ever users of mobile phones for all intracranial tumors, for specified tumor type, or for cancer at 18 other specified sites. No increased risk of glioma or meningioma was found for long-term users, but a risk for pituitary tumors was increased for short term (under 5 years) duration mobile phone users without a further increase in risk with longer use. The authors did report an increased acoustic neuroma risk with long-term use (10+ years) versus never use and the risk increased with duration of use. However, the authors later conducted an extended analysis of the data that lowered the acoustic neuroma risk and rendered it not statistically significant. There was also no acoustic neuroma risk increase with duration of use (27).

Generally, cohort studies are considered the highest quality epidemiology evidence, with prospective cohorts as the gold standard observational study type.[53] However, the results of 3 of the cohort studies above are less reliable due to poor mobile phone exposure assessment. The Benson *et al*. study is one of the higher quality studies completed to date with fewer limitations, but participation bias, reporting bias, and confounding are still possible due to low survey response rates, changes in individual mobile phone use over time, and differences in socioeconomic status between exposed and unexposed groups, respectively.

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Several INTERPHONE and Hardell group studies (discussed below) found an association between long-term exposure to mobile phones and increased risk of CNS cancer.

Hardell Research Group

The Hardell research group of Sweden published 15 epidemiology papers directly related to the present review that examined relationships between analog, cordless, and mobile phones and types of brain, head, and neck tumors (28–42). Fourteen of the papers reported results from case-control studies and twelve found positive associations between various types of phone exposure and adult brain/head and neck cancers. Papers written for the case-control studies used similar methods and therefore share the same methodological strengths and weaknesses.

A major strength of the Hardell group case-control studies is the use of blinding for exposure interviews, which is somewhat rare among case-control studies on this subject (43). Noted weaknesses of the Hardell group case-control studies include pooling of case-control results, recall bias, participation bias, reporting bias, sampling bias, and selection bias (44). Five of the 15 papers were pooled analyses of previous case-control studies, which exposed them to further likelihood of selection and classification bias in comparison to the non-pooled studies (32,33,35,39,42). We reviewed a selection of studies by this research group below.

One of the earliest papers by the Hardell group was released in 2002 from a 1997 to 2000 population-based case-control study of 4 regions in Sweden examining the risk of brain cancers from analog, cordless, and digital phone use (29). The study included 1,429 brain cancer cases from 4 Swedish regional cancer registries encompassing all individuals 20 to 80 years diagnosed with brain tumors, while 1,470 controls were ascertained from the national population registry and frequency matched by sex, age, and region. Exposure was quantified via written questionnaire and supplementary telephone interviews for certain cases and controls. Data on type of phone, years of use, make and model, mean number and length of daily calls, and cumulative use in hours were collected. The study found no association between brain cancer incidence and digital or cordless phones but found a 30% increased risk from analog cell phones in "ever" users and 80% increased risk among those with 10+ year induction periods. The authors also found increased risk of tumors on side of head where cell phone was used.

Another paper by the Hardell group was released in 2006 from a 2000 to 2003 population-based case-control study of 2 regions in Sweden examining the risk of malignant brain tumors from analog, cordless, and digital phone use (31). The study included 317 malignant brain cancer cases from 2 Swedish regional cancer registries encompassing all individuals 20 to 80 years diagnosed with brain tumors and 692 controls from the national population registry and frequency matched by age. Like the 2002 study, exposure was quantified via written questionnaire and supplementary telephone interviews for certain cases and controls. The study found analog (160% increase), digital (90% increase), and cordless phones (110% increase) all increased risk of malignant brain cancer, with higher risk for each with greater than 10-year latency period between start of phone use and tumor diagnosis.

A more recent paper by the Hardell group was released in 2013 from a 2007 to 2009 population-based case-control study of all Swedish regions examining the risk of meningioma brain tumors from exposure to mobile and cordless phones (36). The study included 390 meningioma cases from 6 Swedish cancer registries encompassing all individuals aged 18 years to 75 years diagnosed with meningiomas and 1,368 controls from the national population registry, frequency matched by age and sex. Like other Hardell group studies, exposure was quantified via written questionnaire and supplementary telephone interviews for certain cases and controls. The study found an extremely small but statistically significant increase in risk for every 100 hours of cordless and mobile phone use.

A consistent theme among Hardell group studies is that high exposure levels and long-term exposure to mobile phones is associated with brain and head/neck cancers. A few studies on long-term phone exposure studies from the INTERPHONE group (discussed below) and other researchers have replicated these results, but the association is not unanimous and it remains unclear whether there is a true positive effect or bias and unmeasured confounding. The Hardell group's overall consistently positive and statistically significant associations are not consistent with the broader case-control literature on mobile phones and cancer endpoints. This becomes clearer when considering meta-analysis study results that showed no statistically significant increase in brain or head/neck cancer risk from use of wireless phones (45). Hardell group study results have been questioned due to possible systematic bias, which could be related to the use of a single data source limited to one population for multiple influential publications (44,45). Specifically, authors of a 2012 systematic review noted that no validation studies have been completed for the case-control study methods used by Hardell *et al*., meaning that the extent and direction of bias is impossible to know (45). A recent review of the literature by the FDA found that multiple papers by Hardell group authors suffer from overinterpretation bias, where study interpretations are speculative or not supported by results, including two studies from 2013, one from 2015, and one from 2017 (36,39,40,42,44). These factors reduce the ability to infer a causal relationship between phone exposure and cancer endpoints as a result of the studies. In addition, arriving at a conclusion for the United States population based solely on case-control results from European cancer studies is difficult due to differences in U.S. and European standards in the infancy of mobile phone technology (46), which is the time frame when the majority of these case-control studies were completed.

Interphone Study Group

The INTERPHONE study group was commissioned by the World Health Organization to conduct multiple international case-control studies on mobile phone exposure and cancer endpoints in sixteen study centers and thirteen countries across all continents. The studies took place in the years 1999 to 2004 and focused on cancer in people ages 30 years to 59 years living in urban settings, as these populations were expected to have the highest exposure to mobile phones. Results of the INTERPHONE group case-control studies have been published in 19 papers, with six finding positive statistically significant associations between mobile phones and cancer endpoints (47–62). Like the Hardell group case-controls, INTERPHONE case-control studies have several methodological limitations including selection bias, recall bias, sampling bias, interviewer bias, and reporting bias, among others. Despite this, these studies have some of the largest sample sizes of any RFR-cancer case-control studies completed to date. Below, we review a selection of INTERPHONE studies.

The largest INTERPHONE study (2010) integrated cases and controls from all 16 study locations to examine the risk of glioma and meningioma as a result of mobile phone use (62). The study included 2,708 glioma cases, 2,409 meningioma cases, 2,971 glioma controls, and 2,662 meningioma controls. Cases were ascertained from neurological and neurosurgical centers in all locations and confirmed via histology or diagnostic imaging. In 12 of the 13 countries in this study, controls were individual- or frequency-matched by age, sex, and region. All controls were ascertained from population-based databases. Mobile phone exposure was quantified via face-to-face and printed interviews. Data collected included information about regular use (use at least once a week for 6 months or more), number of cellular telephones used regularly, start and stop dates of use, and cumulative hours of use. The study found no increase of risk of glioma and meningioma across most exposure categories and the meningioma global model. However, the highest exposure (1,640 cumulative hours or more) category showed an increase in glioma risk. The other large INTERPHONE case-control study (2011) followed a similar methodology to the 2010 study and examined the risk of acoustic neuroma as a result of mobile phone use in 1,105 cases and 2,145 controls (52). The study found increased odds ratios observed at the highest level of cumulative call time, but no increase in risk of acoustic neuroma with ever regular use of a mobile phone or for users who began regular use 10 years or more before date of diagnosis.

An INTERPHONE population-based case-control study completed in 5 northern European countries between 1999 and 2004 examined the risk of acoustic neuroma as a result of mobile phone use (48). It included 678 cases of acoustic neuroma ascertained from medical centers in the respective countries and 3553 controls from national population registers and frequency matched by age, sex, and region. Exposure to mobile phones was quantified via face-to-face and phone interviews. Data collected included start and end date of use, average use time, and average number of calls. The study found no substantial risk of acoustic neuroma in the first decade after starting mobile phone use but found an 80% increase in odds of acoustic neuroma among the highest and longest exposure group. However, no dose-response relationship was found.

A population-based case-control study completed in the Australian, Canadian, French, Israeli, and New Zealand components of the INTERPHONE study examined the risk of glioma and meningioma as a result of mobile phone use (51). The study included 553 glioma and 676 meningioma cases ascertained from neurological and ontological centers in each country and 1,762 glioma controls and 1911 meningioma controls from locally appropriate population-based sampling frames. Exposure was quantified with highly detailed interviews that collected data on use patterns, conditions of use, mobile phone models, and network operators. Unlike other INTERPHONE research, this study also employed an algorithm to estimate actual radiofrequency radiation dose for each case and control. The study found increased risk of glioma (91% odds increase) and a small statistically non-significant increase in meningioma risk in long-term mobile phone users in the highest exposure quintile. However, no dose-response relationship was found for either cancer.

A 2017 advanced modeling re-analysis of the 2001 to 2004 Canadian portion of the INTERPHONE study examined the risk of glioma, meningioma, and parotid gland tumors as a result of mobile phone use (47). The study included 405 cases from hospitals in participating Canadian provinces and 516 controls from provincial population registries and frequency matched by age and region. Exposure was quantified via face-to-face interviews and data on telephone network operator, patterns of mobile phone use, mobile phone use in rural and urban areas, and use of hands-free devices was collected. The study found no evidence of an increase in the risk of meningioma, acoustic neuroma, or parotid gland tumors in relation to mobile phone use. This re-analysis employed methodological corrections to reduce the recall and selection biases present in the Canadian INTERPHONE study.

Like the Hardell group studies, a number of INTERPHONE studies found a relationship between high and long-term exposure to mobile phones and types of brain and head/neck cancers (48,51,52,62). However, none of the studies found a dose-response relationship, which is a feature that commonly exists for exposures with causal relationships to cancer endpoints (63–65), including that for ionizing radiation and cancer (66). Some INTERPHONE studies also found that mobile phones provided a "protective" effect on cancer, which indicates significant and multifactorial bias (44). Based solely on case-control results from the Hardell and INTERPHONE study groups, there is insufficient evidence to indicate a causal relationship between mobile phone radiofrequencies and cancer due to: 1) the biases present in these studies, 2) the lack of consistency in results among studies, 3) the fact that there were few individuals among controls that could be truly "unexposed" to RFR even before mobile phones became ubiquitous (67), and 4) poor evidence of a dose-response relationship.

Summary of Cancer Endpoints

Overall, there is insufficient evidence to indicate a causal relationship between mobile phone exposures and any cancer endpoint. Most studies that we reviewed found no association between ultra-high and super-high RFR exposures and cancer endpoints. Although an association between long-term mobile phone use and various brain cancers was found in some studies, more studies found no association between long-term use and cancers. Further, many of the studies have several limitations that reduce the ability to deduce causation.

To summarize the overall limitations of observational RFR-cancer studies, it is important to first mention the unifying limitations in many studies: misclassification bias and unmeasured confounding of RFR exposure. Accurately classifying individual RFR exposure without direct dosimetry is difficult and the use of basic exposure variables makes studies prone to these biases. This is a particularly problematic aspect of the child case-control, adult ecological, and adult retrospective cohort studies reviewed, as many used location-based assessments or phone subscriptions as the exposure variable, which are inadequate for capturing individual exposures. In contrast, every adult case-control study used individual questionnaire responses as the basis of their exposure assessments. Though this improves the accuracy of RFR exposure assessment and better captures confounding RFR exposures, no studies we reviewed validated their questionnaires or interviews via dosimetry to rule out recall bias and interviewer bias. Beyond overall limitations, the RFR-cancer case-control studies reviewed above have methodological issues that are common for case-controls, including selection bias due to high control refusal rates, recall bias, interviewer bias from non-blinded interviews, and lack of adjustment for confounding.

The available epidemiology studies with positive associations are not enough to conclude a causal association for long-term mobile phone use, especially for U.S. populations, in part due to differences between U.S. and European phone standards, the lack of a dose-response relationship in most studies, and the overall inconsistent results. However, as the global population continues to be exposed to RFR from various sources, more high quality prospective cohort studies are needed to inform the weight of evidence for any effects of long-term RFR exposure on cancer endpoints. These studies would need to account for the changing exposures to RFR; for example, people might be less likely to have a phone close to their heads nowadays than they did 20 years ago. A summary of cancer studies that we reviewed are in Tables 1 and 2 of the Appendix.

Noncancer endpoints

In the following sections, we discuss studies that examined the relationship between RFR exposure or exposure of RFR-emitting devices and effects on different human body systems and functions, such as auditory function, cognitive function, nervous system, miscarriage, reproductive system, sleep, mental health, and others.

Auditory function/system

In a cross-sectional study, Sievert *et al*. (2005) examined whether mobile phone emission of RFR could affect cochlear or auditory brain stem functions in 12 healthy adults with normal hearing and auditory brain stem reflex (68). All participants were exposed to RFR from two mobile phone, one on each ear, with GSM Signal (8896 MHz). Participants were exposed to pulsed and continuous RFR. Before each new session of RFR exposure, there was a pause of three minutes. The authors found no changes to absolute and interpeak latency from each wave of measure from either pulsed or continuous signal. Long-term exposure effects were not determined.

Pau *et al*. (2005) conducted a cross-sectional study examining the effect of RFR on the tissues exposed to RFR when using a mobile phone among 13 healthy adults with no evidence of vestibular disorders (69). Participants were exposed to RFR from a simulated GSM signal (889.6 MHz/2.2 W) at both ears at different times. The authors reported that there was insufficient heating to cause nystagmus by the vestibular organs. Authors pointed to previous research that indicated temperature effects only next to the radiation source (antenna).

Bhagat *et al*. (2016) and Panda *et al*. (2010), did not report effects on auditory functions, although Panda *et al*. reported high-frequency loss and absent distortion product otoacoustic emissions with an increase in the duration of mobile phone use, excessive use of mobile phones, and being >30 years old (70,72). It is not clear if these observations are related to RFR, physical pressure, or noise effects. One study found effects on the cochlear nerve in patients with open skulls (craniotomies) (73) which might correspond to a direct thermal effect due to the exposed brain tissue.

Brain/cognitive function

In a cross-sectional study, Riddervold *et al.* (2008) found that exposure to RFR did not affect cognitive function (74). The purpose of the study was to assess the effect of RFR from 3G telecommunications base station on symptoms and cognitive function in adults and adolescents. The cognitive function test, Trail Making B, where participants had to draw lines alternating between numbers and letters in consecutive order, was administered after the exposure to RFR. The authors found no effect of RFR on test performance.

Thomas *et al.* (2010) conducted a survey to investigate mobile phone use behaviors over a period of 1 year in a cohort of 238 adolescents living in Australia (75). The authors also assessed cognitive function by a computerized test battery and the Stroop Color-Word test. The authors found associations between reported use of mobile phones and changes in some of the cognitive outcomes, especially changes in test response times but not in accuracy. Participants with more voice calls and SMS at baseline, but no increase in exposure over the 1-year period, demonstrated lesser reductions in response times over the 1-year period in some of the test tasks. However, no associations were seen between mobile phone use and the Stroop Color-Word test. Of note is that the authors found statistically significant outcomes only in 2 of 32 cognitive function tests. When considering that cell phone exposure was based on survey, we find that no firm conclusions can be drawn from this study on effects of mobile phones on cognitive function. The authors suggested that while change in cognitive functions were observed, the change could be due to statistical regression to the mean and not to effects of mobile phone exposure.

An earlier study that examined the effect of exposure to a GSM mobile phone, active or inactive (no signal) on cognitive effects in 32 children found no effect of these exposures on a battery of cognitive tests (76) (Haarala *et al.*, 2005).

Commented [HAK11]: Haarala C, Bergman M, Laine M, Revonsuo A, Koivisto M, Hämäläinen H. Electromagnetic field emitted by 902 MHz mobile phones shows no effects on children's cognitive function. Bioelectromagnetics. 2005;Suppl 7:S144-50

Foerster et al. (2018) found assoications between cell phone use and effects on figural memory in Swiss adolescent schoolchildren (77). However, the statistically significant effects were small, there were very large differences between reported phone use and phone use records, and many other statistical group comparisons were not statistically significant.

Finally, Zubko *et al.* (2016) reviewed studies that compared RFR vs sham exposures on working memory of health human subjects and found no exposure-related effect of the three memory tasks that they examined (78). Likewise, Barth *et al.* (2007) found small magnitude and mixed effects of cell phone RFR exposure in association with neurobehavioral effects in a meta-analysis of 10 studies (79).

Commented [HAK12]: Zubko O, Gould RL, Gay HC, Cox HJ, Coulson MC, Howard RJ. Effects of electromagnetic fields emitted by GSM phones on working memory: a meta-analysis. Int J Geriatr Psychiatry. 2017 Feb;32(2):125-135.

Nervous system

Several studies examined the effect of RFR exposure on the autonomic nervous system, heart rate, and respiratory rate. For example, Choi *et al.* (2014) exposed 26 adults and 26 teenagers to either RFR via a WCDMA module (average power, 250 mW at 1950 MHz; specific absorption rate, 1.57 W/kg) within a headset placed on the head, 3 millimeters away from the ear, for 32 min vs sham exposures (no RFR) (80). Sham and real exposures were conducted on separate days at the same time of day with no difference in temperature and humidity among comparison groups. The authors concluded that short-term WCDMA RFR generated no significant changes in heart rate, respiration, heart rate variability (HRV), or subjective symptoms. Moreover, study participants could not reliably tell if they were in the real or sham exposed groups.

Fang *et al*. (2016) conducted a cross-sectional study examining the effect of extremely low frequency pulse RFR on the human cardiac signal in 22 healthy adults lying in the supine position immediately on top of three magnetic coils spanning neck to feet (81). Participants were exposed to RFR with 16 Hz operating frequency for 10 minutes followed by a 30-second ECG recording. The authors reported a small change in the RR interval of the ECG but not in other intervals. If this is a true association, the health relevance is unclear especially given the mode of exposure in this study and its incomparability to exposures in a school setting.

Béres *et al*. (2018) conducted a cross-sectional study investigating the acute effects of pulsed microwave radiation from a commercial cellular phone (1800 MHz GSM network , 217 Hz pulse rate, 0.577 µs pulse width) on HRV and heart rate asymmetry in 20 healthy participants (82). The mobile phone was attached to the participants' right ear and 5 consecutive 6-minute ECG strips were record for each volunteer randomly at various stages of the study. There were no consistent significant effects of exposure on HRV and there were no effects on heart asymmetry. The validity of this association is not clear when considering that many other HRV indicators showed no change and the reported change presented with very large variability among subjects.

Kwon *et al*. (2012) used a double blind study design to assess physiological effects associated with exposure to a dummy phone containing a WCDMA module (average power, 24 dBm at 1950 MHz; specific absorption rate, 1.57 W/kg) in volunteer subjects with self-reported electromagnetic hypersensitivity or without (83). The phone was placed in a headset on the head for 32 minutes. The authors reported no cell phone exposure effect on physiological changes (heart rate, HRV, and respiration rate), eight subjective symptoms, or perception of RFR during real and sham exposure sessions.

Commented [OA13]: Spell out abbreviation when first using.

Durusoy *et al*. (2017) examined associations between RFR in the school environment (measured with Aaronia Spectran HF-4060 device) and health symptoms collected by survey questionnaire from 2,150 school children in Turkey (84). The authors found that headache, concentration difficulties, fatigue, sleep disturbances and warming of the ear increased with the number of calls per day, total duration of calls per day, and total number of text messages per day. However, they found limited associations between vicinity to base stations and health symptoms and no association with school RFR levels.

Hossmann & Hermann (2003) reviewed studies that assessed RFR of mobile phones on neuronal electrical activity, energy metabolism, genomic responses, neurotransmitter balance, blood‑brain barrier permeability, cognitive function, and sleep (85). The authors concluded that most reported effects were small if radiation intensity was in the nonthermal range and pointed to other established health risks associated with cell phone use, such as distracted driving.

In a meta-analysis that included 5 studies examining cell phone exposure on HRV in adolescents, Geronikolou *et al*. (2020) concluded that duration of exposure to mobile phone call did not affect overall HRV or sympathovagal balance (86).

Reproductive health endpoints

Li *et al*. (2010) examined the effect of RFR exposure on sperm quality in a population-based case control study of 148 participants (76 with abnormal semen and 72 with normal semen) (87). Participants wore an EMDEX-LITE meter for 24 hours to measure the exposure to RFR. The authors adjusted for demographic factors such as age, education, occupation, marital status, income, body mass index, smoker, alcohol consumption, steam bath use, living environment, and sexual activity. The authors reported a two-fold increased risk of abnormal sperm motility and morphology in the 90th percentile exposed versus low exposed groups. In addition, they reported an inverse relationship between RFR exposure and semen quality indicators (e.g., volume, pH, density, vitality, morphology, and motility).

Li *et al*. (2017) reported an increased risk of miscarriage in women exposed to stronger magnetic fields than those exposed to weaker fields monitored on a "typical" day (88). This study has several merits including personal exposure assessment of RFR exposures and identifying typical days and warrants replication and further exploration, although uncertainties remain in terms of covariates that could have been associated with miscarriages. For example, a "typical" day might also bring other "typical" experiences or environmental exposures. Moreover, the magnetic field exposure occurred during a very narrow window of the pregnancy, which lends uncertainty to the representativeness of exposure. A recent study by Ingle *et al*. (2020) recruited 119 women who underwent in vitro fertilization, assessed their personal exposure to magnetic fields for up to three consecutive 24-hour periods separated by several weeks and examined Implantation, clinical pregnancy, live birth, and pregnancy loss in association with the exposures in a longitudinal repeated-measures design (89). The authors found no statistically significant associations between magnetic field exposure metrics and fertility treatment or pregnancy outcomes. Both studies raise the need for further exploration of this question.

Agarwal *et al*. (2009) showed that exposure of human semen to cell phone radiation from a phone in "talk mode" for an hour decreased sperm motility and viability but had no effect on DNA damage when compared to sham exposure (90). This kind of study tells us very little about how this same phone in talk mode would affect sperm inside the body when they are shielded by multiple tissue layers. Another study by Agarwal *et al*. (2008) showed an inverse association between reported duration of daily phone talk time and sperm motility, viability, and normal morphology. However, RFR exposure was not assessed and the authors (as most studies examining this association) did not account for numerous variables that are known to affect sperm quality (91). For example, the Mayo Clinic lists several environmental agents or

Commented [HAK14]: Geronikolou SA, Johansson Ö, Chrousos G, Kanaka-Gantenbein C, Cokkinos D. Cellular Phone User's Age or the Duration of Calls Moderate Autonomic Nervous System? A Meta-Analysis. Adv Exp Med Biol. 2020;1194:475-488.

Commented [HAK15]: Ingle ME, Mínguez-Alarcón L, Lewis RC, Williams PL, Ford JB, Dadd R, Hauser R, Meeker JD; EARTH Study Team. Association of personal exposure to power-frequency magnetic fields with pregnancy outcomes among women seeking fertility treatment in a longitudinal cohort study. Fertil Steril. 2020 Oct 6:S0015-0282(20)30535-5.

Commented [HAK16]: Agarwal A, Desai NR, Makker K, Varghese A, Mouradi R, Sabanegh E, Sharma R. Effects of radiofrequency electromagnetic waves (RF-EMW) from cellular phones on human ejaculated semen: an in vitro pilot study. Fertil Steril. 2009 Oct;92(4):1318-1325.

Commented [HAK17]: https://www.mayoclinic.org/diseases-conditions/low-sperm-count/symptoms-causes/syc-20374585 accessed on October 30, 2020 conditions that are associated with poor sperm quality, including some industrial chemicals, heavy metals, radiation or X-rays, overheating of the testicles such as from sitting for long periods, wearing tight clothes, or working on a laptop computer for long stretches of time. The latter is in the situation where the laptop is sitting directly on the body and radiating heat (92). There are also many medical causes that include varicocele, infection, ejaculation problems, etc.

Most studies included in this section (and more summarized in Appendix Table 3) are cross-sectional in nature relying on personal recall and reporting of proxy RFR exposures rather than actual measurement of RFR exposure. This limits any strong conclusions for RFR toxicity outcomes. More longitudinal studies and double-blind randomized studies with good exposure assessment are needed to make better determinations in these domains. Moreover, most studies we found involved adult subjects that may not be relevant to everybody in a school environment, especially if children are more susceptible than adults to RFR exposure health effects. A summary of studies reviewed in this section is available in Appendix Table 3.

Mental health

Vahedi and Saiphoo (2018) conducted a meta-analysis of 39 independent studies examining an association between smartphone use and stress (93). The authors reported that smartphone use had a small to medium association with stress and anxiety. It is important to note that the study was not able to distinguish the effect of smartphone use on stress and anxiety independently and RFR exposure was not measured. The authors found stronger correlation between anxiety and stress and "problematic" phone use such as compulsion and addiction than "nonproblematic" use such as number of texts sent or received. The authors stated that because the studies included in this analysis were mostly cross-sectional in nature, it is not possible to determine whether problematic smartphone use causes increased stress and anxiety or if increased stress and anxiety levels lead to problematic smartphone use.

Twenge and Campbell (2018) examined the association between screen time and psychological well-being among children and adolescents between the ages of 2 years and 17 years (94). Caregivers and parents of 40,337 children and adolescents in the US National Survey of Children's Health (NSCH) were included in the analysis. The survey asked about the time children or adolescents spend in front of TV, computers, cell phones, handheld video games, and other electronic devices and psychological well-being, including anxiety. The study outcomes suggested that moderate use of electronic devices was related to a higher risk for anxiety among 14-17 years old. The survey also found the use of electronic devices is related to depression and several other undesirable mental health indicators. This study is challenged with recall bias about how long a child spends with a screen. It does not discuss RFR exposures nor assesses them. Based on this study, one can only make conclusions about screen time and not RFR exposure. Children who spend more time on a screen might have symptoms associated with that behavior including what they see on the screen. Underlying conditions or attributes might also determine the time spent on screen. Likewise, a review by Keles *et al.* (95) found an association between online social media use and mental health problems in adolescents. They also found that time spent on online social media increased risk for depression, anxiety, and psychological distress. Similar outcomes were found by Augner and Hackner (2012), but all these studies share similar limitations that make conclusions on RFR impossible (96).

Wdowiak *et al*. (2018) examined the influence of RFR generated by wireless connectivity systems on the occurrence of emotional disorders, including anxiety, among women working in the health service and trade (97). Participants included 200 women ages 25-35 years. Participants responded to the International Physical Activity Questionnaire, Beck Depression Inventory, and Stat-Trait Anxiety Inventory. RFR exposure was measured by a dosimeter over 10 hours, which registered the frequency and level of the electric components of RFR in a person's close environment (e.g., GSM, UMTS, DECT, and WLAN). The study found that anxiety correlated negatively with exposure to GSM900 but positively with exposure to GSM1800 among women working in shopping centers. Anxiety was also correlated positively with daily mobile phone use time. This study had a narrow exposure assessment window of 10 hours and disorders examined are subject to variability in assessment and grading. Moreover, most comparison tests of exposure and health condition showed no association. It is difficult to draw firm conclusions of RFR effects from this study when considering the complex environmental, genetic, demographic, and domestic factors contributing to anxiety and depression.

Alternatively, Minagawa and Saito (2014) found lower levels of depressive symptoms among elderly women (but not men) and Pearson *et al*. (2017) found an association between cellphone ownership and increased wellbeing (98,99). These studies also suffer from the same shortcomings in terms of association with RFR since only phone use or ownership were examined.

Among the studies examining the relationship between RFR exposure and mental health, most relied on surveys to assess exposure to wireless devices rather than directly measure RFR. Moreover, many of the studies are cross-sectional studies making it difficult to draw conclusions about the effects of RFR or cell phone use on mental health. Screen time appears to have strong associations with various mental health indicators and the exact attributes associated with the use of these devices need to be explored further in longitudinal studies, in-depth mental health assessments, double blind studies, and solid RFR exposure assessments.

Wilmer *et al*. (2017) reviewed the research that investigates associations between mobile technology habits and cognitive abilities without consideration for RFR exposure (100). The authors indicated that there is no firm evidence of cognitive effects from cell phone use and stressed the need to differentiate between different cell phone uses such as for text messaging, email, and social media vs gaming or browsing the web highlighting the potential considerable effect of what people do on their devices rather than the associated RFR exposure.

A summary of studies reviewed in this section is available in Appendix Table 4.

Sleep

Commented [HAK18]: Augner C, Hacker GW. Associations between problematic mobile phone use and psychological parameters in young adults. Int J Public Health. 2012 Apr;57(2):437-41.

Commented [HAK19]: Wilmer, H.H.; Sherman, L.E.; Chein, J.M. Smartphones and Cognition: A Review of Research Exploring the
Links between Mobile Technology Habits and Cognitive Functioning. Front. Psychol. **2017**, 8, 605.

Huss *et al*. (2015) evaluated if exposure to RFR (modeled) was associated with reported quality of sleep in 2,361 children, aged 7 years from the Amsterdam Born Children and their Development (ABCD) cohort, a community-based prospective cohort study (101). The authors reported that sleep duration scores, but not sleep onset delay, night wakenings, parasomnias and daytime sleepiness was associated with residential exposure to RFR from base stations (outside the home). Base station RFR exposure was associated with lower risk of sleep disordered breathing, but using Wi-Fi indoors has a higher risk. The authors also found that higher use of mobile phones was associated with less favorable sleep duration, night wakenings and parasomnias, and bedtime resistance. Cordless phone use was not related to any of the sleeping scores. The authors concluded that the study outcomes do not support the hypothesis that exposure to RFR *per se* affects sleep quality in 7-year old children, but that potentially other factors related to mobile phone use do.

Fobian *et al*. (2016) examined the effect of media use on sleep-related variables among 55 adolescents (mean age, 15 years) by using a self-reported survey of Media Use Scale to access average daily media use and actigraphy (detects sleep movements) to measure sleep quality and quantity (102). The authors found that sleep efficiency was negatively correlated to daily time spent text messaging, media use after bed, and number of nighttime awakenings by mobile phones. Of the children surveyed, 75% reported having 4 or more media sources at home and 84% reported using media for an average of 34 minutes after going to bed each night, and 35% reporting waking up to a cell phone once nightly. This study did not monitor RFR exposures in the children. The study underscores the pervasiveness of media sources in daily life and their potential influence on sleep. No conclusions can be made related to RFR effects.

Carter *et al*. (2016) conducted a meta-analysis of 20 studies that examined the relationship between sleep-related outcomes and bedtime media device use in children (103). The authors found that children who used bedtime media devices generally slept less with poorer sleep quality than those who did not. This study did not account for differences in RFR exposure among children and the results cannot be separated from the simple effect of using a device, responding to light from the device, or the influence of materials that the children interact with while on the device.

Huber *et al*. (2002) exposed 16 healthy young males (ages, 20-25 years) to sham or RFR (pulse-modulated 900 MHz electromagnetic field vs continuous wave; 1 W/kg specific absorption rate) for 30 minutes by attaching a dummy phone to a headset worn on the head before sleep (104). The study authors reported no effect from either RFR exposure on sleep vs sham exposures but noted a statistically significant effect of pulsed RFR on sleep EEG. Loughran *et al*. (2019) exposed 36 healthy adults to sham, low RFR (1 W/kg specific absorption rate), or high RFR (2 W/kg specific absorption rate) and found an effect of the high RFR (but not low) exposure in increased alpha EEG activity and increased finger (but not skin) temperature. As the authors concluded, the relevance to sleep and health of this exposure-related small variation in EEG signal is unknown. Moreover, exposures to RFR at schools are likely much lower than the high exposure associated with effects in this study.

Hung *et al*. (2007) examined the relationship between RFR exposure and electroencephalogram readings during sleep in 10 healthy males (mean age, 22 years) (105). Participants were exposed to RFR for 30 minutes with a 90 minutes sleep opportunity after. The authors reported that the exposure to the phone in “listen” (0.015 W/kg) and “standby” (< 0.001 W/kg) modes had no influence on sleep latency, but “talk” (talk = 0.133 W/kg) mode doubled the sleep latency period. In other words, exposure to RFR from a phone in “talk” mode resulting in higher RFR exposure, was associated with a delay in time to fall sleep. Note that this was not observed by Huber *et al*. (2002) (104).

Some controlled exposure studies found small effects on sleep indicators associated with RFR while others did not. Other studies that looked at device and screen time among children found associations with poor sleep quality and quantity. At this time, it is not possible to make conclusions about the possible effect of RFR exposure on health, although phone use and other screen time spent appears to be more reliably associated with poor sleep outcomes. Further studies might attempt to distinguish between RFR and blue light effects from cell phones, computers, tablets, and TV since the latter has been associated with insomnia (106) and might suppress melatonin secretion, thereby affecting sleep quality (107). Finally, many studies we reviewed used cross-sectional study design which limits the ability of the studies to determine relationship. Unlike longitudinal study and prospective cohort study design, cross-sectional cannot determine temporal relationship between the exposure and the outcomes variables. A summary of studies reviewed in this section is available in Appendix Table 5.

Toxicity

Auditory function/system

In a cross-sectional study, Sievert *et al*. (2005) examined whether mobile phone emission of RFR could affect cochlear or auditory brain stem functions in 12 healthy adults with normal hearing and auditory brain stem reflex. All participants were exposed to RFR from two mobile phone, one on each ear, with GSM Signal (8896 MHz). Participants were exposed to pulsed and continuous RFR. Before each new session of RFR exposure, there was a pause of three minutes. The authors found no changes to absolute and interpeak latency from each wave of measure from either pulsed or continuous signal. Long-term exposure effects were not determined.

Pau *et al*. (2005) conducted a cross-sectional study examining the effect of RFR on the tissues exposed to RFR when using a mobile phone among 13 healthy adults with no evidence of vestibular disorders. Participants were exposed to RFR from a simulated GSM signal (889.6 MHz/2.2 W) at both ears at different times. The authors reported that there was insufficient heating to cause nystagmus by the vestibular organs. Authors pointed to previous research that indicated temperature effects only next to the radiation source (antenna).

(68–72), did not report effects on auditory functions, although Panda *et al*. reported high-frequency loss and absent distortion product otoacoustic emissions with an increase in the duration of mobile phone use, excessive use of mobile phones, and being >30 years old. It is not clear if these observations are related to RFR, physical pressure, or noise effects. One study found effects on the cochlear nerve in patients with open skulls (craniotomies) (73) which might correspond to a direct thermal effect due to the exposed brain tissue.

Brain/cognitive function

In a cross-sectional study, Riddervold *et al*. (2008) found that exposure to RFR did not affect cognitive function. The purpose of the study was to assess the effect of RFR from 3G telecommunications base station on symptoms and cognitive function in adults and adolescents. The cognitive function test, Trail Making B, where participants had to draw lines alternating between numbers and letters in consecutive order, was administered after the exposure to RFR. The authors found no effect of RFR on test performance.

Thomas *et al*. (2010) conducted a survey to investigate mobile phone use behaviors over a period of 1 year in a cohort of 238 adolescents living in Australia. The authors also assessed cognitive function by a computerized test battery and the Stroop Color-Word test. The authors found associations between reported use of mobile phones and changes in some of the cognitive outcomes, especially changes in test response times but not in accuracy. Participants with more voice calls and SMS at baseline, but no increase in exposure over the 1-year period, demonstrated lesser reductions in response times over the 1-year period in some of the test tasks. However, no associations were seen between mobile phone use and the Stroop Color-Word test. Of note is that the authors found statistically significant outcomes only in 2 of 32 cognitive function tests. When considering that cell phone exposure was based on survey, we find that no firm conclusions can be drawn from this study on effects of mobile phones on cognitive function. The authors suggested that while change in cognitive functions were observed, the change could be due to statistical regression to the mean and not to effects of mobile phone exposure.

An earlier study that examined the effect of exposure to a GSM mobile phone, active or inactive (no signal) on cognitive effects in 32 children found no effect of these exposures on a battery of cognitive tests (Haarala *et al*., 2005).

(77,108)

Finally, Zubko *et al*. (2016) reviewed studies that compared RFR vs sham exposures on working memory of health human subjects and found no exposure-related effect of the three memory tasks that they examined. Likewise, Barth *et al*. (2007) found small magnitude and mixed effects of cell phone RFR exposure in association with neurobehavioral effects in a meta-analysis of 10 studies.

Nervous system

Commented [HAK20]: Haarala C, Bergman M, Laine M, Revonsuo A, Koivisto M, Hämäläinen H. Electromagnetic field emitted by 902 MHz mobile phones shows no effects on children's cognitive function. Bioelectromagnetics. 2005;Suppl 7:S144-50

Commented [HAK21]: Zubko O, Gould RL, Gay HC, Cox HJ, Coulson MC, Howard RJ. Effects of electromagnetic fields emitted by GSM phones on working memory: a meta-analysis. Int J Geriatr Psychiatry. 2017 Feb;32(2):125-135.

Several studies examined the effect of RFR exposure on the autonomic nervous system, heart rate, and respiratory rate. For example, Choi *et al*. (2014) exposed 26 adults and 26 teenagers to either RFR via a WCDMA module (average power, 250 mW at 1950 MHz; specific absorption rate, 1.57 W/kg) within a headset placed on the head, 3 millimeters away from the ear, for 32 min vs sham exposures (no RFR). Sham and real exposures were conducted on separate days at the same time of day with no difference in temperature and humidity among comparison groups. The authors concluded that short-term WCDMA RFR generated no significant changes in heart rate, respiration, heart rate variability (HRV), or subjective symptoms. Moreover, study participants could not reliably tell if they were in the real or sham exposed groups.

Fang *et al*. (2016) conducted a cross-sectional study examining the effect of extremely low frequency pulse RFR on the human cardiac signal in 22 healthy adults lying in the supine position immediately on top of three magnetic coils spanning neck to feet. Participants were exposed to RFR with 16 Hz operating frequency for 10 minutes followed by a 30-second ECG recording. The authors reported a small change in the RR interval of the ECG but not in other intervals. If this is a true association, the health relevance is unclear especially given the mode of exposure in this study and its incomparability to exposures in a school setting.

Béres *et al*. (2018) conducted a cross-sectional study investigating the acute effects of pulsed microwave radiation from a commercial cellular phone (1800 MHz GSM network , 217 Hz pulse rate, 0.577 µs pulse width) on HRV and heart rate asymmetry in 20 healthy participants. The mobile phone was attached to the participants' right ear and 5 consecutive 6-minute ECG strips were record for each volunteer randomly at various stages of the study. There were no consistent significant effects of exposure on HRV and there were no effects on heart asymmetry. The validity of this association is not clear when considering that many other HRV indicators showed no change and the reported change presented with very large variability among subjects.

Kwon *et al*. (2012) used a double blind study design to assess physiological effects associated with exposure to a dummy phone containing a WCDMA module (average power, 24 dBm at 1950 MHz; specific absorption rate, 1.57 W/kg) in volunteer subjects with self-reported electromagnetic hypersensitivity or without. The phone was placed in a headset on the head for 32 minutes. The authors reported no cell phone exposure effect on physiological changes (heart rate, HRV, and respiration rate), eight subjective symptoms, or perception of RFR during real and sham exposure sessions.

Durusoy *et al*. (2017) examined associations between RFR in the school environment (measured with Aaronia Spectran HF-4060 device) and health symptoms collected by survey questionnaire from 2,150 school children in Turkey. The authors found that headache, concentration difficulties, fatigue, sleep disturbances and warming of the ear increased with the number of calls per day, total duration of calls per day, and total number of text messages per day. However, they found limited associations between vicinity to base stations and health symptoms and no association with school RFR levels.

Hossmann & Hermann (2003) reviewed studies that assessed RFR of mobile phones on neuronal electrical activity, energy metabolism, genomic responses, neurotransmitter balance, blood‑brain barrier permeability, cognitive function, and sleep. The authors concluded that most reported effects were small if radiation intensity was in the nonthermal range and pointed to other established health risks associated with cell phone use, such as distracted driving.

In a meta-analysis that included 5 studies examining cell phone exposure on HRV in adolescents, Geronikolou *et al*. (2020) concluded that duration of exposure to mobile phone call did not affect overall HRV or sympathovagal balance.

Commented [HAK22]: Geronikolou SA, Johansson Ö, Chrousos G, Kanaka-Gantenbein C, Cokkinos D. Cellular Phone User's Age or the Duration of Calls Moderate Autonomic Nervous System? A Meta-Analysis. Adv Exp Med Biol. 2020;1194:475-488.

Reproductive health endpoints

Li *et al*. (2010) examined the effect of RFR exposure on sperm quality in a population-based case control study of 148 participants (76 with abnormal semen and 72 with normal semen). Participants wore an EMDEX-LITE meter for 24 hours to measure the exposure to RFR. The authors adjusted for demographic factors such as age, education, occupation, marital status, income, body mass index, smoker, alcohol consumption, steam bath use, living environment, and sexual activity. The authors reported a two-fold increased risk of abnormal sperm motility and morphology in the 90th percentile exposed versus low exposed groups. In addition, they reported an inverse relationship between RFR exposure and semen quality indicators (e.g., volume, pH, density, vitality, morphology, and motility).

Li *et al*. (2017) reported an increased risk of miscarriage in women exposed to stronger magnetic fields than those exposed to weaker fields monitored on a "typical" day. This study has several merits including personal exposure assessment of RFR exposures and identifying typical days and warrants replication and further exploration, although uncertainties remain in terms of covariates that could have been associated with miscarriages. For example, a "typical" day might also bring other "typical" experiences or environmental exposures. Moreover, the magnetic field exposure occurred during a very narrow window of the pregnancy, which lends uncertainty to the representativeness of exposure. A recent study by Ingle *et al*. (2020) recruited 119 women who underwent in vitro fertilization, assessed their personal exposure to magnetic fields for up to three consecutive 24-hour periods separated by several weeks and examined Implantation, clinical pregnancy, live birth, and pregnancy loss in association with the exposures in a longitudinal repeated-measures design. The authors found no statistically significant associations between magnetic field exposure metrics and fertility treatment or pregnancy outcomes. Both studies raise the need for further exploration of this question.

Commented [HAK23]: Ingle ME, Mínguez-Alarcón L, Lewis RC, Williams PL, Ford JB, Dadd R, Hauser R, Meeker JD; EARTH Study Team. Association of personal exposure to power-frequency magnetic fields with pregnancy outcomes among women seeking fertility treatment in a longitudinal cohort study. Fertil Steril. 2020 Oct 6:S0015-0282(20)30535-5.

Agarwal *et al*. (2009) showed that exposure of human semen to cell phone radiation from a phone in "talk mode" for an hour decreased sperm motility and viability but had no effect on DNA damage when compared to sham exposure. This kind of study tell us very little about how this same phone in talk mode would affect sperm inside the body when they are shielded by multiple tissue layers. Another study by Agarwal *et al*. (2008) showed an inverse association between reported duration of daily phone talk time and sperm motility, viability, and normal

Commented [HAK24]: Agarwal A, Desai NR, Makker K, Varghese A, Mouradi R, Sabanegh E, Sharma R. Effects of radiofrequency electromagnetic waves (RF-EMW) from cellular phones on human ejaculated semen: an in vitro pilot study. Fertil Steril. 2009 Oct;92(4):1318-1325.

morphology. However, RFR exposure was not assessed and the authors (as most studies examining this association) did not account for numerous variables that are known to affect sperm quality. For example, the Mayo Clinic lists several environmental agents or conditions that are associated with poor sperm quality, including some industrial chemicals, heavy metals, radiation or X-rays, overheating of the testicles such as from sitting for long periods, wearing tight clothes, or working on a laptop computer for long stretches of time. The latter is in the situation where the laptop is sitting directly on the body and radiating heat. There are also many medical causes that include varicocele, infection, ejaculation problems, etc.

Commented [HAK25]: https://www.mayoclinic.org/diseases-conditions/low-sperm-count/symptoms-causes/syc-20374585 accessed on October 30, 2020

Most studies included in this section (and more summarized in Appendix Table 3) are cross-sectional in nature relying on personal recall and reporting of proxy RFR exposures rather than actual measurement of RFR exposure. This limits any strong conclusions for RFR toxicity outcomes. More longitudinal studies and double blind randomized studies with good exposure assessment are needed to make better determinations in these domains. Moreover, most studies we found involved adult subjects that may not be relevant to everybody in a school environment, especially if children are more susceptible than adults to RFR exposure health effects. A summary of studies reviewed in this section is available in Appendix Table 3.

Mental health

Vahedi and Saiphoo (2018) conducted a meta-analysis of 39 independent studies examining an association between smartphone use and stress. The authors reported that smartphone use had a small to medium association with stress and anxiety. It is important to note that the study was not able to distinguish the effect of smartphone use on stress and anxiety independently and RFR exposure was not measured. The authors found stronger correlation between anxiety and stress and "problematic" phone use such as compulsion and addiction than "nonproblematic" use such as number of texts sent or received. The authors stated that because the studies included in this analysis were mostly cross-sectional in nature, it is not possible to determine whether problematic smartphone use causes increased stress and anxiety or if increased stress and anxiety levels lead to problematic smartphone use.

Twenge and Campbell (2018) examined the association between screen time and psychological well-being among children and adolescents between the ages of 2 years and 17 years. Caregivers and parents of 40,337 children and adolescents in the US National Survey of Children's Health (NSCH) were included in the analysis. The survey asked about the time children or adolescents spend in front of TV, computers, cell phones, handheld video games, and other electronic devices and psychological well-being, including anxiety. The study outcomes suggested that moderate use of electronic devices was related to a higher risk for anxiety among 14-17 years old. The survey also found the use of electronic devices is related to depression and several other undesirable mental health indicators. This study is challenged with recall bias about how long a child spends with a screen. It does not discuss RFR exposures nor assesses them. Based on this study, one can only make conclusions about screen time and not RFR exposure. Children who spend more time on a screen might have symptoms associated with that behavior including what they see on the screen. Underlying conditions or attributes might also determine the time spent on screen. Likewise, a review by Keles *et al*. (95) found an association between online social media use and mental health problems in adolescents. They also found that time spent on online social media increased risk for depression, anxiety, and psychological distress. Similar outcomes were found by Augner and Hackner (2012), but all these studies share similar limitations that make conclusions on RFR impossible.

Commented [HAK26]: Augner C, Hacker GW. Associations between problematic mobile phone use and psychological parameters in young adults. Int J Public Health. 2012 Apr;57(2):437-41.

Wdowiak *et al*. (2018) examined the influence of RFR generated by wireless connectivity systems on the occurrence of emotional disorders, including anxiety, among women working in the health service and trade. Participants included 200 women ages 25-35 years. Participants responded to the International Physical Activity Questionnaire, Beck Depression Inventory, and Stat-Trait Anxiety Inventory. RFR exposure was measured by a dosimeter over 10 hours, which registered the frequency and level of the electric components of RFR in a person's close environment (e.g., GSM, UMTS, DECT, and WLAN). The study found that anxiety correlated negatively with exposure to GSM900 but positively with exposure to GSM1800 among women working in shopping centers. Anxiety was also correlated positively with daily mobile phone use time. This study had a narrow exposure assessment window of 10 hours and disorders examined are subject to variability in assessment and grading. Moreover, most comparison tests of exposure and health condition showed no association. It is difficult to draw firm conclusions of RFR effects from this study when considering the complex environmental, genetic, demographic, and domestic factors contributing to anxiety and depression.

Alternatively, Minagawa and Saito (2014) found lower levels of depressive symptoms among elderly women (but not men) and Pearson *et al*. (2017) found an association between cellphone ownership and increased wellbeing. These studies also suffer from the same shortcomings in terms of association with RFR since only phone use or ownership were examined.

Among the studies examining the relationship between RFR exposure and mental health, most relied on surveys to assess exposure to wireless devices rather than directly measure RFR. Moreover, many of the studies are cross-sectional studies making it difficult to draw conclusions about the effects of RFR or cell phone use on mental health. Screen time appears to have strong associations with various mental health indicators and the exact attributes associated with the use of these devices need to be explored further in longitudinal studies, in-depth mental health assessments, double blind studies, and solid RFR exposure assessments.

Wilmer *et al*. (2017) reviewed the research that investigates associations between mobile technology habits and cognitive abilities without consideration for RFR exposure. The authors indicated that there is no firm evidence of cognitive effects from cell phone use and stressed the need to differentiate between different cell phone uses such as for text messaging, email, and social media vs gaming or browsing the web highlighting the potential considerable effect of what people do on their devices rather than the associated RFR exposure.

Commented [HAK27]: Wilmer, H.H.; Sherman, L.E.; Chein, J.M. Smartphones and Cognition: A Review of Research Exploring the Links between Mobile Technology Habits and Cognitive Functioning. Front. Psychol. **2017**, 8, 605.

A summary of studies reviewed in this section is available in Appendix Table 4.

Sleep

Huss *et al*. (2015) evaluated if exposure to RFR (modeled) was associated with reported quality of sleep in 2,361 children, aged 7 years from the Amsterdam Born Children and their Development (ABCD) cohort, a community-based prospective cohort study. The authors reported that sleep duration scores, but not sleep onset delay, night wakenings, parasomnias and daytime sleepiness was associated with residential exposure to RFR from base stations (outside the home). Base station RFR exposure was associated with lower risk of sleep disordered breathing, but using Wi-Fi indoors has a higher risk. The authors also found that higher use of mobile phones was associated with less favorable sleep duration, night wakenings and parasomnias, and bedtime resistance. Cordless phone use was not related to any of the sleeping scores. The authors concluded that the study outcomes do not support the hypothesis that exposure to RFR *per se* affects sleep quality in 7-year old children, but that potentially other factors related to mobile phone use do.

Fobian *et al*. (2016) examined the effect of media use on sleep-related variables among 55 adolescents (mean age, 15 years) by using a self-reported survey of Media Use Scale to access average daily media use and actigraphy (detects sleep movements) to measure sleep quality and quantity. The authors found that sleep efficiency was negatively correlated to daily time spent text messaging, media use after bed, and number of nighttime awakenings by mobile phones. Of the children surveyed, 75% reported having 4 or more media sources at home and 84% reported using media for an average of 34 minutes after going to bed each night, and 35% reporting waking up to a cell phone once nightly. This study did not monitor RFR exposures in the children. The study underscores the pervasiveness of media sources in daily life and their potential influence on sleep. No conclusions can be made related to RFR effects.

Carter *et al*. (2016) conducted a meta-analysis of 20 studies that examined the relationship between sleep-related outcomes and bedtime media device use in children. The authors found that children who used bedtime media devices generally slept less with poorer sleep quality than those who did not. This study did not account for differences in RFR exposure among children and the results cannot be separated from the simple effect of using a device, responding to light from the device, or the influence of materials that the children interact with while on the device.

Huber *et al*. (2002) exposed 16 healthy young males (ages, 20-25 years) to sham or RFR (pulse-modulated 900 MHz electromagnetic field vs continuous wave; 1 W/kg specific absorption rate) for 30 minutes by attaching a dummy phone to a headset worn on the head before sleep. The study authors reported no effect from either RFR exposure on sleep vs sham exposures but noted a statistically significant effect of pulsed RFR on sleep EEG. Loughran *et al*. (2019) exposed 36 healthy adults to sham, low RFR (1 W/kg specific absorption rate), or high RFR (2 W/kg specific absorption rate) and found an effect of the high RFR (but not low) exposure in increased alpha EEG activity and increased finger (but not skin) temperature. As the authors concluded, the relevance to sleep and health of this exposure-related small variation in EEG signal is unknown. Moreover, exposures to RFR at schools are likely much lower than the high exposure associated with effects in this study.

Hung *et al*. (2007) examined the relationship between RFR exposure and electroencephalogram readings during sleep in 10 healthy males (mean age, 22 years). Participants were exposed to RFR for 30 minutes with a 90 minutes sleep opportunity after. The authors reported that the exposure to the phone in “listen” (0.015 W/kg) and “standby” (< 0.001 W/kg) modes had no influence on sleep latency, but “talk” (talk = 0.133 W/kg) mode doubled the sleep latency period. In other words, exposure to RFR from a phone in “talk” mode resulting in higher RFR exposure, was associated with a delay in time to fall sleep. Note that this was not observed by Huber *et al*. (2002).

Some controlled exposure studies found small effects on sleep indicators associated with RFR while others did not. Other studies that looked at device and screen time among children found associations with poor sleep quality and quantity. At this time, it is not possible to make conclusions about the possible effect of RFR exposure on health, although phone use and other screen time spent appears to be more reliably associated with poor sleep outcomes. Further studies might attempt to distinguish between RFR and blue light effects from cell phones, computers, tablets, and TV since the latter has been associated with insomnia (106) and might suppress melatonin secretion, thereby affecting sleep quality (107). Finally, many studies we reviewed used cross-sectional study design which limits the ability of the studies to determine relationship. Unlike longitudinal study and prospective cohort study design, cross-sectional cannot determine temporal relationship between the exposure and the outcomes variables. A summary of studies reviewed in this section is available in Appendix Table 5.

References

1. Gilbert D, Coussens C, Merchant J. Rebuilding the unity of health and the environment in rural America: workshop summary. National Academies Press; 2006.

2. National Research Council (US) Committee on the Biological Effects of Ionizing Radiation (BEIRNational Research Council (US) Committee on the Biological Effects of Ionizing Radiation (BEIR NRC (US) C on the BE of IR (BEIR. Mechanisms of Radiation-Induced Cancer [Internet]. Health Effects of Exposure to Low Levels of Ionizing Radiation: Beir V. National Academies Press (US); 1990 [cited 2020 Jul 20]. Available from: https://www.ncbi.nlm.nih.gov/books/NBK218707/

3. Repacholi MH. Radiofrequency field exposure and cancer: what do the laboratory studies suggest? Environ Health Perspect. 1997 Dec;105(Suppl 6):1565–8.

4. World Health Organization. Fact Sheet: Electromagnetic fields and public health: mobile phones [Internet]. 2014. Available from: https://www.who.int/news-room/fact-sheets/detail/electromagnetic-fields-and-public-health-mobile-phones

5. Aydin D, Feychting M, Schüz J, Tynes T, Andersen TV, Schmidt LS, et al. Mobile phone use and brain tumors in children and adolescents: a multicenter case-control study. Journal of the National Cancer Institute. 2011;103(16):1264–76.

6. Elliott P, Toledano MB, Bennett J, Beale L, Hoogh K de, Best N, et al. Mobile phone base stations and early childhood cancers: case-control study. BMJ [Internet]. 2010 Jun 22 [cited 2020 May 4];340. Available from: https://www.bmj.com/content/340/bmj.c3077

7. Ha M, Im H, Lee M, Kim HJ, Kim B-C, Gimm Y-M, et al. Radio-frequency radiation exposure from AM radio transmitters and childhood leukemia and brain cancer. Am J Epidemiol. 2007 Aug 1;166(3):270–9.

8. Li C-Y, Liu C-C, Chang Y-H, Chou L-P, Ko M-C. A population-based case-control study of radiofrequency exposure in relation to childhood neoplasm. Sci Total Environ. 2012 Oct 1;435–436:472–8.

9. Maskarinec G, Cooper J, Swygert L. Investigation of increased incidence in childhood leukemia near radio towers in Hawaii: preliminary observations. J Environ Pathol Toxicol Oncol. 1994;13(1):33–7.

10. Merzenich H, Schmiedel S, Bennack S, Brüggemeyer H, Philipp J, Blettner M, et al. Childhood leukemia in relation to radio frequency electromagnetic fields in the vicinity of TV and radio broadcast transmitters. Am J Epidemiol. 2008 Nov 15;168(10):1169–78.

11. Michelozzi P, Capon A, Kirchmayer U, Forastiere F, Biggeri A, Barca A, et al. Adult and childhood leukemia near a high-power radio station in Rome, Italy. Am J Epidemiol. 2002 Jun 15;155(12):1096–103.

12. Dolk H, Shaddick G, Walls P, Grundy C, Thakrar B, Kleinschmidt I, et al. Cancer Incidence near Radio and Television Transmitters in Great Britain I. Sutton Coldfield Transmitter. Am J Epidemiol. 1997 Jan 1;145(1):1–9.

13. Dolk H, Elliott P, Shaddick G, Walls P, Thakrar B. Cancer Incidence near Radio and Television Transmitters in Great Britain II. All High Power Transmitters. Am J Epidemiol. 1997 Jan 1;145(1):10–7.

14. Inskip PD, Hoover RN, Devesa SS. Brain cancer incidence trends in relation to cellular telephone use in the United States. Neuro Oncol. 2010 Nov 1;12(11):1147–51.

15. Chapman S, Azizi L, Luo Q, Sitas F. Has the incidence of brain cancer risen in Australia since the introduction of mobile phones 29 years ago? Cancer Epidemiology. 2016 Jun 1;42:199–205.

16. Little MP, Rajaraman P, Curtis RE, Devesa SS, Inskip PD, Check DP, et al. Mobile phone use and glioma risk: comparison of epidemiological study results with incidence trends in the United States. BMJ [Internet]. 2012 Mar 8 [cited 2020 Apr 19];344. Available from: https://www.bmj.com/content/344/bmj.e1147

17. de Vocht F. Inferring the 1985–2014 impact of mobile phone use on selected brain cancer subtypes using Bayesian structural time series and synthetic controls. Environment International. 2016 Dec 1;97:100–7.

18. de Vocht F. Analyses of temporal and spatial patterns of glioblastoma multiforme and other brain cancer subtypes in relation to mobile phones using synthetic counterfactuals. Environmental research. 2019;168:329–35.

19. Piantadosi S, Byar DP, Green SB. The ecological fallacy. American journal of epidemiology. 1988;127(5):893–904.

20. Muscat JE, Malkin MG, Thompson S, Shore RE, Stellman SD, McRee D, et al. Handheld Cellular Telephone Use and Risk of Brain Cancer. JAMA. 2000 Dec 20;284(23):3001–7.

21. Inskip PD, Tarone RE, Hatch EE, Wilcosky TC, Shapiro WR, Selker RG, et al. Cellular-Telephone Use and Brain Tumors. New England Journal of Medicine. 2001 Jan 11;344(2):79–86.

22. Johansen C, Boice JD, McLaughlin JK, Olsen JH. Cellular Telephones and Cancer—a Nationwide Cohort Study in Denmark. J Natl Cancer Inst. 2001 Feb 7;93(3):203–7.

23. Schüz J, Steding-Jessen M, Hansen S, Stangerup S-E, Cayé-Thomasen P, Poulsen AH, et al. Long-Term Mobile Phone Use and the Risk of Vestibular Schwannoma: A Danish Nationwide Cohort Study. Am J Epidemiol. 2011 Aug 15;174(4):416–22.

24. Poulsen AH, Friis S, Johansen C, Jensen A, Frei P, Kjaear SK, et al. Mobile phone use and the risk of skin cancer: a nationwide cohort study in Denmark. Am J Epidemiol. 2013 Jul 15;178(2):190–7.

25. Frei P, Poulsen AH, Johansen C, Olsen JH, Steding-Jessen M, Schüz J. Use of mobile phones and risk of brain tumours: update of Danish cohort study. BMJ [Internet]. 2011 Oct 20 [cited 2020 Apr 19];343. Available from: https://www.bmj.com/content/343/bmj.d6387

26. Benson VS, Pirie K, Schüz J, Reeves GK, Beral V, Green J. Mobile phone use and risk of brain neoplasms and other cancers: prospective study. Int J Epidemiol. 2013 Jun 1;42(3):792–802.

27. Benson VS, Pirie K, Schüz J, Reeves GK, Beral V, Green J. Authors' response to: the case of acoustic neuroma: comment on mobile phone use and risk of brain neoplasms and other cancers. International journal of epidemiology. 2014;43(1):275–275.

28. Hardell L, Näsman A, Påhlson A, Hallquist A, Hansson Mild K. Use of cellular telephones and the risk for brain tumours: A case-control study. Int J Oncol. 1999 Jul;15(1):113–6.

29. Hardell L, Hallquist A, Mild KH, Carlberg M, Påhlson A, Lilja A. Cellular and cordless telephones and the risk for brain tumours. European Journal of Cancer Prevention. 2002 Aug;11(4):377–386.

30. Hardell L, Carlberg M, Mild KH. Case-Control Study on Cellular and Cordless Telephones and the Risk for Acoustic Neuroma or Meningioma in Patients Diagnosed 2000–2003. NED. 2005;25(3):120–8.

31. Hardell L, Carlberg M, Mild KH. Case–control study of the association between the use of cellular and cordless telephones and malignant brain tumors diagnosed during 2000–2003. Environmental Research. 2006 Feb 1;100(2):232–41.

32. Hardell L, Carlberg M, Hansson Mild K. Pooled analysis of two case-control studies on the use of cellular and cordless telephones and the risk of benign brain tumours diagnosed during 1997-2003. International Journal of Oncology. 2006 Feb 1;28(2):509–18.

33. Hardell L, Carlberg M, Hansson Mild K. Pooled analysis of two case–control studies on use of cellular and cordless telephones and the risk for malignant brain tumours diagnosed in 1997–2003. Int Arch Occup Environ Health. 2006 Sep 1;79(8):630–9.

34. Hardell L, Carlberg M, Mild KH. Mobile Phone Use and the Risk for Malignant Brain Tumors: A Case-Control Study on Deceased Cases and Controls. NED. 2010;35(2):109–14.

35. Hardell L, Carlberg M, Hansson Mild K. Pooled analysis of case-control studies on malignant brain tumours and the use of mobile and cordless phones including living and deceased subjects. International Journal of Oncology. 2011 May 1;38(5):1465–74.

36. Carlberg M, Söderqvist F, Hansson Mild K, Hardell L. Meningioma patients diagnosed 2007–2009 and the association with use of mobile and cordless phones: a case–control study. Environmental Health. 2013 Jul 19;12(1):60.

37. Carlberg M, Hardell L. Decreased survival of glioma patients with astrocytoma grade IV (glioblastoma multiforme) associated with long-term use of mobile and cordless phones. International journal of environmental research and public health. 2014;11(10):10790–805.

38. Söderqvist F, Carlberg M, Hardell L. Use of wireless phones and the risk of salivary gland tumours: a case–control study. European Journal of Cancer Prevention. 2012 Nov;21(6):576–579.

39. Hardell L, Carlberg M. Mobile phone and cordless phone use and the risk for glioma – Analysis of pooled case-control studies in Sweden, 1997–2003 and 2007–2009. Pathophysiology. 2015 Mar 1;22(1):1–13.

40. Hardell L, Carlberg M. Mobile phones, cordless phones and rates of brain tumors in different age groups in the Swedish National Inpatient Register and the Swedish Cancer Register during 1998-2015. PLOS ONE. 2017 Oct 4;12(10):e0185461.

41. Hardell L, Carlberg M, Söderqvist F, Mild KH. Case-control study of the association between malignant brain tumours diagnosed between 2007 and 2009 and mobile and cordless phone use. International journal of oncology. 2013;43(6):1833–45.

42. Hardell L, Carlberg M, Söderqvist F, Mild KH. Pooled analysis of case-control studies on acoustic neuroma diagnosed 1997-2003 and 2007-2009 and use of mobile and cordless phones. International Journal of Oncology. 2013;43(4):1036–44.

43. Myung S-K, Ju W, McDonnell DD, Lee YJ, Kazinets G, Cheng C-T, et al. Mobile Phone Use and Risk of Tumors: A Meta-Analysis. JCO. 2009 Oct 13;27(33):5565–72.

44. FDA. Review of Published Literature between 2008 and 2018 of Relevance to Radiofrequency Radiation and Cancer. 2020;113.

45. Repacholi MH, Lerchl A, Röösli M, Sienkiewicz Z, Auvinen A, Breckenkamp J, et al. Systematic review of wireless phone use and brain cancer and other head tumors. Bioelectromagnetics. 2012;33(3):187–206.

46. Kelsh MA, Shum M, Sheppard AR, Mcneely M, Kuster N, Lau E, et al. Measured radiofrequency exposure during various mobile-phone use scenarios. Journal of exposure science & environmental epidemiology. 2011;21(4):343–54.

47. Momoli F, Siemiatycki J, McBride ML, Parent M-É, Richardson L, Bedard D, et al. Probabilistic Multiple-Bias Modeling Applied to the Canadian Data From the Interphone Study of Mobile Phone Use and Risk of Glioma, Meningioma, Acoustic Neuroma, and Parotid Gland Tumors. Am J Epidemiol. 2017 Oct 1;186(7):885–93.

48. Schoemaker MJ, Swerdlow AJ, Ahlbom A, Auvinen A, Blaasaas KG, Cardis E, et al. Mobile phone use and risk of acoustic neuroma: results of the Interphone case–control study in five North European countries. British Journal of Cancer. 2005 Oct;93(7):842–8.

49. Schüz J, Böhler E, Berg G, Schlehofer B, Hettinger I, Schlaefer K, et al. Cellular Phones, Cordless Phones, and the Risks of Glioma and Meningioma (Interphone Study Group, Germany). Am J Epidemiol. 2006 Mar 15;163(6):512–20.

50. Schüz J, Böhler E, Schlehofer B, Berg G, Schlaefer K, Hettinger I, et al. Radiofrequency Electromagnetic Fields Emitted from Base Stations of DECT Cordless Phones and the Risk of Glioma and Meningioma (Interphone Study Group, Germany). Radiation Research. 2006 Jul 1;166(1):116–9.

51. Cardis E, Armstrong BK, Bowman JD, Giles GG, Hours M, Krewski D, et al. Risk of brain tumours in relation to estimated RF dose from mobile phones: results from five Interphone countries. Occupational and Environmental Medicine. 2011 Sep 1;68(9):631–40.

52. INTERPHONE Study Group. Acoustic neuroma risk in relation to mobile telephone use: Results of the INTERPHONE international case–control study. Cancer Epidemiology. 2011 Oct 1;35(5):453–64.

53. Christensen HC, Schüz J, Kosteljanetz M, Poulsen HS, Boice JD, McLaughlin JK, et al. Cellular telephones and risk for brain tumors: a population-based, incident case-control study. Neurology. 2005 Apr 12;64(7):1189–95.

54. Klaeboe L, Blaasaas KG, Tynes T. Use of mobile phones in Norway and risk of intracranial tumours: European Journal of Cancer Prevention. 2007 Apr;16(2):158–64.

55. Lahkola A, Auvinen A, Raitanen J, Schoemaker MJ, Christensen HC, Feychting M, et al. Mobile phone use and risk of glioma in 5 North European countries. International Journal of Cancer. 2007;120(8):1769–75.

56. Hepworth SJ, Schoemaker MJ, Muir KR, Swerdlow AJ, Tongeren MJA van, McKinney PA. Mobile phone use and risk of glioma in adults: case-control study. BMJ. 2006 Apr 13;332(7546):883–7.

57. Lönn S, Ahlbom A, Hall P, Feychting M. Mobile Phone Use and the Risk of Acoustic Neuroma. Epidemiology. 2004;15(6):653–9.

58. Lönn S, Ahlbom A, Hall P, Feychting M. Long-Term Mobile Phone Use and Brain Tumor Risk. Am J Epidemiol. 2005 Mar 15;161(6):526–35.

59. Sadetzki S, Chetrit A, Jarus-Hakak A, Cardis E, Deutch Y, Duvdevani S, et al. Cellular phone use and risk of benign and malignant parotid gland tumors--a nationwide case-control study. Am J Epidemiol. 2008 Feb 15;167(4):457–67.

60. Schoemaker MJ, Swerdlow AJ. Risk of pituitary tumors in cellular phone users: a case-control study. Epidemiology. 2009 May;20(3):348–54.

61. Takebayashi T, Akiba S, Kikuchi Y, Taki M, Wake K, Watanabe S, et al. Mobile phone use and acoustic neuroma risk in Japan. Occupational and Environmental Medicine. 2006 Dec 1;63(12):802–7.

62. Group IS. Brain tumour risk in relation to mobile telephone use: results of the INTERPHONE international case-control study. International Journal of Epidemiology. 2010;39(3):675–94.

63. Fedak KM, Bernal A, Capshaw ZA, Gross S. Applying the Bradford Hill criteria in the 21st century: how data integration has changed causal inference in molecular epidemiology. Emerg Themes Epidemiol [Internet]. 2015 Sep 30 [cited 2020 Aug 6];12. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4589117/

64. Sasco AJ, Secretan MB, Straif K. Tobacco smoking and cancer: a brief review of recent epidemiological evidence. Lung Cancer. 2004 Aug 1;45:S3–9.

65. Rödelsperger K, Woitowitz H-J, Brückel B, Arhelger R, Pohlabeln H, Jöckel K-H. Dose-response relationship between amphibole fiber lung burden and mesothelioma. Cancer detection and prevention. 1999;23(3):183–93.

66. Ron E. Ionizing Radiation and Cancer Risk: Evidence from Epidemiology. Radiat Res. 1998 Nov 1;150(5s):S30–41.

67. Nageswari KS. Mobile Phone Radiation : Physiological & Pathophysiologcal Considerations. Indian J Physiol Pharmacol. 2015;11.

68. Sievert U, Eggert S, Pau HW. Can mobile phone emissions affect auditory functions of cochlea or brain stem? Otolaryngology - Head and Neck Surgery. 2005 Mar 1;132(3):451–5.

69. Pau HW, Sievert U, Eggert S, Wild W. Can electromagnetic fields emitted by mobile phones stimulate the vestibular organ? Otolaryngology - Head and Neck Surgery. 2005 Jan 1;132(1):43–9.

70. Bhagat S, Varshney S, Bist SS, Goel D, Mishra S, Jha VK. Effects on auditory function of chronic exposure to electromagnetic fields from mobile phones. 2016;95(8):6.

71. Medeiros LN, Sanchez TG. Tinnitus and cell phones: the role of electromagnetic radiofrequency radiation. Brazilian Journal of Otorhinolaryngology. 2016 Jan;82(1):97–104.

72. Panda NK, Jain R, Bakshi J, Munjal S. Audiologic Disturbances in Long-Term Mobile Phone Users. Journal of Otolaryngology. 2010;39(1):9.

73. Colletti V, Mandalà M, Manganotti P, Ramat S, Sacchetto L, Colletti L. Intraoperative observation of changes in cochlear nerve action potentials during exposure to electromagnetic fields generated by mobile phones. Journal of Neurology, Neurosurgery and Psychiatry; London. 2011 Jul;82(7):766.

74. Riddervold IS, Pedersen GF, Andersen NT, Pedersen AD, Andersen JB, Zachariae R, et al. Cognitive function and symptoms in adults and adolescents in relation to rf radiation from UMTS base stations. Bioelectromagnetics. 2008 May;29(4):257–67.

75. Thomas S, Benke G, Dimitriadis C, Inyang I, Sim MR, Wolfe R, et al. Use of mobile phones and changes in cognitive function in adolescents. Occupational and Environmental Medicine. 2010;67(12):861–6.

76. C H, M B, M L, A R, M K, H H. Electromagnetic field emitted by 902 MHz mobile phones shows no effects on children's cognitive function. Bioelectromagnetics. 2005 Jan 1;Suppl 7:S144-50.

77. Foerster M, Thielens A, Joseph W, Eeftens M, Röösli M. A Prospective Cohort Study of Adolescents' Memory Performance and Individual Brain Dose of Microwave Radiation from Wireless Communication. Environ Health Perspect [Internet]. 2018 Jul 23 [cited 2020 Jun 9];126(7). Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6108834/

78. Zubko O, Gould RL, Gay HC, Cox HJ, Coulson MC, Howard RJ. Effects of electromagnetic fields emitted by GSM phones on working memory: a meta-analysis. Int J Geriatr Psychiatry. 2017;32(2):125–35.

79. Barth A, Winker R, Ponocny-Seliger E, Mayrhofer W, Ponocny I, Sauter C, et al. A meta-analysis for neurobehavioral effects due to electromagnetic field exposure emitted by GSM mobile phones. Occup Environ Med. 2008 Jun 1;65:342–6.

80. Choi SB, Kwon MK, Chung JW, Park JS, Chung K, Kim DW. Effects of short-term radiation emitted by WCDMA mobile phones on teenagers and adults. BMC Public Health; London. 2014;14:438.

81. Fang Q, Mahmoud SS, Yan J, Li H. An Investigation on the Effect of Extremely Low Frequency Pulsed Electromagnetic Fields on Human Electrocardiograms (ECGs). Int J Environ Res Public Health [Internet]. 2016 Nov [cited 2020 Jun 9];13(11). Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5129380/

82. Béres S, Németh Á, Ajtay Z, Kiss I, Németh B, Hejjel L. Cellular Phone Irradiation of the Head Affects Heart Rate Variability Depending on Inspiration/Expiration Ratio. In Vivo. 2018;32(5):1145–53.

83. Kwon MK, Choi JY, Kim SK, Yoo TK, Kim DW. Effects of radiation emitted by WCDMA mobile phones on electromagnetic hypersensitive subjects. Environmental Health; London. 2012;11:69.

84. Durusoy R, Hassoy H, Özkurt A, Karababa AO. Mobile phone use, school electromagnetic field levels and related symptoms: a cross-sectional survey among 2150 high school students in Izmir. Environmental Health. 2017 Jun 2;16(1):51.

85. Hossmann K-A, Hermann DM. Effects of electromagnetic radiation of mobile phones on the central nervous system. Bioelectromagnetics. 2003 Jan;24(1):49–62.

86. Geronikolou SA, Johansson Ölle, Chrousos G, Kanaka-Gantenbein C, Cokkinos D. Cellular Phone User's Age or the Duration of Calls Moderate Autonomic Nervous System? A Meta-Analysis. Adv Exp Med Biol. 2020;1194:475–88.

87. Li D-K, Yan B, Li Z, Gao E, Miao M, Gong D, et al. Exposure to magnetic fields and the risk of poor sperm quality. Reproductive Toxicology. 2010 Jan 1;29(1):86–92.

88. Li D-K, Chen H, Ferber JR, Odouli R, Quesenberry C. Exposure to Magnetic Field Non-Ionizing Radiation and the Risk of Miscarriage: A Prospective Cohort Study. Sci Rep. 2017 Dec;7(1):17541.

89. Ingle ME, Mínguez-Alarcón L, Lewis RC, Williams PL, Ford JB, Dadd R, et al. Association of personal exposure to power-frequency magnetic fields with pregnancy outcomes among women seeking fertility treatment in a longitudinal cohort study. Fertility and Sterility. 2020 Nov 1;114(5):1058–66.

90. Agarwal A, Desai NR, Makker K, Varghese A, Mouradi R, Sabanegh E, et al. Effects of radiofrequency electromagnetic waves (RF-EMW) from cellular phones on human ejaculated semen: an in vitro pilot study. Fertil Steril. 2009 Oct;92(4):1318–25.

91. Agarwal A, Deepinder F, Sharma RK, Ranga G, Li J. Effect of cell phone usage on semen analysis in men attending infertility clinic: an observational study. Fertility and Sterility. 2008 Jan 1;89(1):124–8.

92. Low sperm count - Symptoms and causes [Internet]. Mayo Clinic. [cited 2020 Nov 15]. Available from: https://www.mayoclinic.org/diseases-conditions/low-sperm-count/symptoms-causes/syc-20374585

93. Vahedi Z, Saiphoo A. The association between smartphone use, stress, and anxiety: A meta-analytic review. Stress & Health: Journal of the International Society for the Investigation of Stress. 2018 Aug;34(3):347–58.

94. Twenge JM, Campbell WK. Associations between screen time and lower psychological well-being among children and adolescents: Evidence from a population-based study. Preventive Medicine Reports. 2018 Dec 1;12:271–83.

95. Keles B, McCrae N, Grealish A. A systematic review: the influence of social media on depression, anxiety and psychological distress in adolescents. International Journal of Adolescence and Youth. 2020 Dec 31;25(1):79–93.

96. Augner C, Hacker GW. Associations between problematic mobile phone use and psychological parameters in young adults. Int J Public Health. 2012 Apr;57(2):437–41.

97. Wdowiak A, Błachnio A, Raczkiewicz D, Misztal P, Iwanowicz-Palus G, Bień A, et al. The influence of electromagnetic fields generated by wireless connectivity systems on the occurrence of emotional disorders in women: A preliminary report. 2018;39(8):11.

98. Minagawa Y, Saito Y. An Analysis of the Impact of Cell Phone Use on Depressive Symptoms among Japanese Elders. Gerontology; Basel. 2014 Oct;60(6):539–47.

99. Pearson AL, Mack E, Namanya J. Mobile Phones and Mental Well-Being: Initial Evidence Suggesting the Importance of Staying Connected to Family in Rural, Remote Communities in Uganda. Chen Y, editor. PLoS ONE. 2017 Jan 17;12(1):e0169819.

100. Wilmer HH, Sherman LE, Chein JM. Smartphones and Cognition: A Review of Research Exploring the Links between Mobile Technology Habits and Cognitive Functioning. Front Psychol [Internet]. 2017 Apr 25 [cited 2020 Nov 15];8. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5403814/

101. Huss A, van Eijsden M, Guxens M, Beekhuizen J, van Strien R, Kromhout H, et al. Environmental Radiofrequency Electromagnetic Fields Exposure at Home, Mobile and Cordless Phone Use, and Sleep Problems in 7-Year-Old Children. Carpenter DO, editor. PLoS ONE. 2015 Oct 28;10(10):e0139869.

102. Fobian AD, Avis K, Schwebel DC. Impact of Media Use on Adolescent Sleep Efficiency: Journal of Developmental & Behavioral Pediatrics. 2016 Jan;37(1):9–14.

103. Carter B, Rees P, Hale L, Bhattacharjee D, Paradkar M. A meta-analysis of the effect of media devices on sleep outcomes. JAMA Pediatr. 2016 Dec 1;170(12):1202–8.

104. Huber R, Treyer V, Borbely AA, Schuderer J, Gottselig JM, Landolt H-P, et al. Electromagnetic fields, such as those from mobile phones, alter regional cerebral blood flow and sleep and waking EEG. J Sleep Res. 2002 Dec;11(4):289–95.

105. Hung C-S, Anderson C, Horne JA, McEvoy P. Mobile phone 'talk-mode' signal delays EEG-determined sleep onset. Neuroscience Letters. 2007 Jun 21;421(1):82–6.

106. Shechter A, Kim EW, St-Onge M-P, Westwood AJ. Blocking nocturnal blue light for insomnia: A randomized controlled trial. J Psychiatr Res. 2018 Jan;96:196–202.

107. Mortazavi S a. R, Parhoodeh S, Hosseini MA, Arabi H, Malakooti H, Nematollahi S, et al. Blocking Short-Wavelength Component of the Visible Light Emitted by Smartphones' Screens Improves Human Sleep Quality. J Biomed Phys Eng. 2018 Dec;8(4):375–80.

108. Kalafatakis F, Bekiaridis-Moschou D, Gkioka E, Tsolaki M. Mobile phone use for 5 minutes can cause significant memory impairment in humans. Hell J Nucl Med. 2017 Dec;20 Suppl:146–54.

109. Barchana M, Margaliot M, Liphshitz I. Changes in Brain Glioma Incidence and Laterality Correlates with Use of Mobile Phones - a Nationwide Population Based Study in Israel. Asian Pacific Journal of Cancer Prevention. 2012;13(11):5857–63.

110. Cooke R, Laing S, Swerdlow AJ. A case–control study of risk of leukaemia in relation to mobile phone use. British Journal of Cancer. 2010 Nov;103(11):1729–35.

111. de Vocht F. Cell Phones and Parotid Cancer Trends in England. Epidemiology. 2011 Jul;22(4):608–609.

112. Deltour I, Auvinen A, Feychting M, Johansen C, Klaeboe L, Sankila R, et al. Mobile Phone Use and Incidence of Glioma in the Nordic Countries 1979—2008: Consistency Check. Epidemiology. 2012;23(2):301–7.

113. Deltour I, Johansen C, Auvinen A, Feychting M, Klaeboe L, Schüz J. Time Trends in Brain Tumor Incidence Rates in Denmark, Finland, Norway, and Sweden, 1974–2003. J Natl Cancer Inst. 2009 Dec 16;101(24):1721–4.

114. Hallberg Ö. Adverse health indicators correlating with sparsely populated areas in Sweden. European Journal of Cancer Prevention. 2007 Feb;16(1):71–76.

115. Hsu M-H, Syed-Abdul S, Scholl J, Jian W-S, Lee P, Iqbal U, et al. The incidence rate and mortality of malignant brain tumors after 10 years of intensive cell phone use in Taiwan: European Journal of Cancer Prevention. 2013 Nov;22(6):596–8.

116. Johansen C. Electromagnetic fields and health effects—epidemiologic studies of cancer, diseases of the central nervous system and arrhythmiarelated heart disease. Scandinavian Journal of Work, Environment & Health. 2004;30:1–80.

117. Kim SJ-H, Ioannides SJ, Elwood JM. Trends in incidence of primary brain cancer in New Zealand, 1995 to 2010. Australian and New Zealand Journal of Public Health. 2015;39(2):148–52.

118. Muscat JE, Hinsvark M, Malkin M. Mobile Telephones and Rates of Brain Cancer. NED. 2006;27(1):55–6.

119. Vocht F de, Burstyn I, Cherrie JW. Time trends (1998–2007) in brain cancer incidence rates in relation to mobile phone use in England. Bioelectromagnetics. 2011;32(5):334–9.

120. Auvinen A, Hietanen M, Luukkonen R, Koskela R-S. Brain Tumors and Salivary Gland Cancers Among Cellular Telephone Users. Epidemiology. 2002 May;13(3):356–359.

121. Christensen HC, Schüz J, Kosteljanetz M, Poulsen HS, Thomsen J, Johansen C. Cellular telephone use and risk of acoustic neuroma. Am J Epidemiol. 2004 Feb 1;159(3):277–83.

122. Cook A, Woodward A, Pearce N, Marshall C. Cellular telephone use and time trends for brain, head and neck tumours. N Z Med J. 2003 Jun 6;116(1175):U457.

123. Coureau G, Bouvier G, Lebailly P, Fabbro-Peray P, Gruber A, Leffondre K, et al. Mobile phone use and brain tumours in the CERENAT case-control study. Occup Environ Med. 2014 Jul 1;71(7):514–22.

124. Hartikka H, Heinävaara S, Mäntylä R, Kähärä V, Kurttio P, Auvinen A. Mobile phone use and location of glioma: A case–case analysis. Bioelectromagnetics. 2009;30(3):176–82.

125. Lehrer S, Green S, Stock RG. Association between number of cell phone contracts and brain tumor incidence in nineteen U.S. States. J Neurooncol. 2011 Feb 1;101(3):505–7.

126. Muscat JE, Malkin MG, Shore RE, Thompson S, Neugut AI, Stellman SD, et al. Handheld cellular telephones and risk of acoustic neuroma. NEUROLOGIE. 2002 Apr 23;58(8):1304–6.

127. Abdus-salam A, Elumelu T, Adenipekun A. Mobile phone radiation and the risk of cancer; a review. Afr J Med Med Sci. 2008 Jun;37(2):107–18.

128. Auvinen A, Toivo T, Tokola K. Epidemiological risk assessment of mobile phones and cancer: where can we improve? European Journal of Cancer Prevention. 2006 Dec;15(6):516–523.

129. Carpenter DO. Electromagnetic Fields and Cancer: The Cost of Doing Nothing. Reviews on Environmental Health [Internet]. 2010 Jan [cited 2020 Apr 19];25(1). Available from: https://www.degruyter.com/view/j/reveh.2010.25.1/reveh.2010.25.1.75/reveh.2010.25.1.75.xml

130. Carpenter DO. Human disease resulting from exposure to electromagnetic fields. Reviews on Environmental Health. 2013 Dec 1;28(4):159–72.

131. Corle C, Makale M, Kesari S. Cell phones and glioma risk: a review of the evidence. J Neurooncol. 2012 Jan 1;106(1):1–13.

132. Habash RWY, Elwood JM, Krewski D, Lotz WG, McNamee JP, Prato FS. Recent Advances in Research on Radiofrequency Fields and Health: 2004–2007. Journal of Toxicology and Environmental Health, Part B. 2009 Aug 28;12(4):250–88.

133. Hardell L, Carlberg M. Using the Hill viewpoints from 1965 for evaluating strengths of evidence of the risk for brain tumors associated with use of mobile and cordless phones1). Reviews on Environmental Health [Internet]. 2013 Jan 1 [cited 2020 Apr 19];28(2–3). Available from: https://www.degruyter.com/view/j/reveh.2013.28.issue-2-3/reveh-2013-0006/reveh-2013-0006.xml

134. Heynick LN, Johnston SA, Mason PA. Radio frequency electromagnetic fields: Cancer, mutagenesis, and genotoxicity. Bioelectromagnetics. 2003;24(S6):S74–100.

135. Karger CP. Mobile phones and health: A literature overview. Zeitschrift für Medizinische Physik. 2005 Jan 1;15(2):73–85.

136. Khurana VG, Hardell L, Everaert J, Bortkiewicz A, Carlberg M, Ahonen M. Epidemiological Evidence for a Health Risk from Mobile Phone Base Stations. INT J OCCUP ENVIRON HEALTH. 2010;16(3):5.

137. Kohli DR, Sachdev A, Vats HS. Cell phones and tumor: still in no man's land. Indian J Cancer. 2009 Mar;46(1):5–12.

138. Krewski D, Glickman BW, Habash RWY, Habbick B, Lotz WG, Mandeville R, et al. Recent Advances in Research on Radiofrequency Fields and Health: 2001–2003. Journal of Toxicology and Environmental Health, Part B. 2007 May 30;10(4):287–318.

139. Kundi Michael. The Controversy about a Possible Relationship between Mobile Phone Use and Cancer. Environmental Health Perspectives. 2009 Mar 1;117(3):316–24.

140. Blettner M, Schlehofer B, Samkange-Zeeb F, Berg G, Schlaefer K, Schüz J. Medical exposure to ionising radiation and the risk of brain tumours: Interphone study group, Germany. European Journal of Cancer. 2007 Sep 1;43(13):1990–8.

141. Miller AB, Morgan LL, Udasin I, Davis DL. Cancer epidemiology update, following the 2011 IARC evaluation of radiofrequency electromagnetic fields (Monograph 102). Environmental Research. 2018 Nov;167:673–83.

142. Moussa MMR. Review on health effects related to mobile phones. Part II: results and conclusions. The Journal Of The Egyptian Public Health Association. 2011 Dec;86(5 and 6):79–89.

143. Ostrom QT, Gittleman H, Stetson L, Virk SM, Barnholtz-Sloan JS. Epidemiology of Gliomas. In: Raizer J, Parsa A, editors. Current Understanding and Treatment of Gliomas [Internet]. Cham: Springer International Publishing; 2015 [cited 2020 Apr 19]. p. 1–14. (Cancer Treatment and Research). Available from: https://doi.org/10.1007/978-3-319-12048-5_1

144. Otto M, von Mühlendahl KE. Electromagnetic fields (EMF): Do they play a role in children's environmental health (CEH)? International Journal of Hygiene and Environmental Health. 2007 Oct 31;210(5):635–44.

145. Szmigielski S. Cancer risks related to low-level RF/MW exposures, including cell phones. Electromagnetic Biology and Medicine. 2013 Sep 1;32(3):273–80.

146. Wood AW. How dangerous are mobile phones, transmission masts, and electricity pylons? Archives of Disease in Childhood. 2006 Apr 1;91(4):361–6.

147. Elwood JM. Epidemiological studies of radio frequency exposures and human cancer. Bioelectromagnetics. 2003;24(S6):S63–73.

148. Kan P, Simonsen SE, Lyon JL, Kestle JRW. Cellular phone use and brain tumor: a meta-analysis. J Neurooncol. 2008 Jan 1;86(1):71–8.

149. Khurana VG, Teo C, Kundi M, Hardell L, Carlberg M. Cell phones and brain tumors: a review including the long-term epidemiologic data. Surgical Neurology. 2009 Sep 1;72(3):205–14.

150. Lahkola A, Tokola K, Auvinen A. Meta-analysis of mobile phone use and intracranial tumors. Scand J Work Environ Health. 2006 Jun;32(3):171–7.

151. Morgan LL, Miller AB, Sasco A, Davis DL. Mobile phone radiation causes brain tumors and should be classified as a probable human carcinogen (2A) (Review). International Journal of Oncology. 2015 May 1;46(5):1865–71.

152. Söderqvist F, Carlberg M, Hardell L. Review of four publications on the Danish cohort study on mobile phone subscribers and risk of brain tumors. Reviews on Environmental Health. 2012 Apr 1;27(1):51–8.

153. Wiedemann P, Schütz H. Children's health and RF EMF exposure. Views from a risk assessment and risk communication perspective. Wien Med Wochenschr. 2011 May 1;161(9):226–32.

154. Ahlbom A, Green A, Kheifets L, Savitz D, Swerdlow A. Epidemiology of Health Effects of Radiofrequency Exposure. Environ Health Perspect. 2004 Dec;112(17):1741–54.

155. Al-Quzwini OF, Al-Taee HA, Al-Shaikh SF. Male fertility and its association with occupational and mobile phone towers hazards: An analytic study. Middle East Fertility Society Journal. 2016 Dec 1;21(4):236–40.

156. Baby NM, Koshy G, Mathew A. The Effect of Electromagnetic Radiation due to Mobile Phone Use on Thyroid Function in Medical Students Studying in a Medical College in South India. Indian J Endocrinol Metab. 2017;21(6):797–802.

157. Bergamaschi A, Magrini A, Ales G, Coppeta L, Somma G. Are Thyroid Dysfunctions Related to Stress or Microwave Exposure (900 Mhz)? Int J Immunopathol Pharmacol. 2004 May;17(2_suppl):31–6.

158. Bortkiewicz A, Gadzicka E, Szymczak W, Zmyslony M. Changes in Tympanic Temperature During the Exposure to Electromagnetic Fields Emitted by Mobile Phone. International Journal of Occupational Medicine and Environmental Health; Heidelberg. 2012 Jun;25(2):145–50.

159. Brzozek C, Benke KK, Zeleke BM, Croft RJ, Dalecki A, Dimitriadis C, et al. Uncertainty Analysis of Mobile Phone Use and Its Effect on Cognitive Function: The Application of Monte Carlo Simulation in a Cohort of Australian Primary School Children. International Journal of Environmental Research and Public Health; Basel [Internet]. 2019 [cited 2020 Apr 28];16(13). Available from: http://search.proquest.com/docview/2329436388/abstract/11129A8F7353496EPQ/1

160. Cho YM, Lim HJ, Jang H, Kim K, Choi JW, Shin C, et al. A cross-sectional study of the association between mobile phone use and symptoms of ill health. Environ Health Toxicol [Internet]. 2016 Oct 26 [cited 2020 Jun 9];31. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5144583/

161. Curcio G, Mazzucchi E, Marca GD, Vollono C, Rossini PM. Electromagnetic fields and EEG spiking rate in patients with focal epilepsy. Clinical Neurophysiology. 2015 Apr 1;126(4):659–66.

162. de Seze R, Ayoub J, Peray P, Miro L, Touitou Y. Evaluation in humans of the effects of radiocellular telephones on the circadian patterns of melatonin secretion, a chronobiological rhythm marker. J Pineal Res. 1999 Nov;27(4):237–42.

163. Deniz OG, Kaplan S, Selçuk MB, Terzi M, Altun G, Yurt KK, et al. Effects of short and long term electromagnetic fields exposure on the human hippocampus. J Microsc Ultrastruct. 2017;5(4):191–7.

164. Goldwein O, Aframian D. The influence of handheld mobile phones on human parotid gland secretion. Oral Diseases. 2010 Mar;16(2):146–50.

165. Hardell. Exposure to wireless phone emissions and serum β-trace protein. Int J Mol Med [Internet]. 2010 Jun 18 [cited 2020 Jun 9];26(2). Available from: http://www.spandidos-publications.com/ijmm/26/2/301

166. Huber R, Treyer V, Schuderer J, Berthold T, Buck A, Kuster N, et al. Exposure to pulse-modulated radio frequency electromagnetic fields affects regional cerebral blood flow. European Journal of Neuroscience. 2005 Feb 15;21(4):1000–6.

167. Khalil AM, Abu Khadra KM, Aljaberi AM, Gagaa MH, Issa HS. Assessment of oxidant/antioxidant status in saliva of cell phone users. Electromagnetic Biology and Medicine. 2014 Jun;33(2):92–7.

168. Li D-K, Ferber JR, Odouli R, Quesenberry CP. A Prospective Study of In-utero Exposure to Magnetic Fields and the Risk of Childhood Obesity. Sci Rep. 2012 Dec;2(1):540.

169. Mahmoudabadi FS, Ziaei S, Firoozabadi M, Kazemnejad A. Use of mobile phone during pregnancy and the risk of spontaneous abortion. J Environ Health Sci Eng [Internet]. 2015 Apr 21 [cited 2020 Jun 9];13. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4416385/

170. Perentos N, Croft RJ, McKenzie RJ, Cvetkovic D, Cosic I. Comparison of the effects of continuous and pulsed mobile phone like RF exposure on the human EEG. Australasian Physical & Engineering Sciences in Medicine; Dordrecht. 2007 Dec;30(4):274–80.

171. Redmayne M, Smith E, Abramson MJ. The relationship between adolescents' well-being and their wireless phone use: a cross-sectional study. Environ Health. 2013 Oct 22;12:90.

172. Ren Y, Chen J, Miao M, Li D-K, Liang H, Wang Z, et al. Prenatal exposure to extremely low frequency magnetic field and its impact on fetal growth. Environ Health [Internet]. 2019 Jan 11 [cited 2020 Jun 9];18. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6329146/

173. Röösli M, Moser M, Baldinini Y, Meier M, Braun-Fahrländer C. Symptoms of ill health ascribed to electromagnetic field exposure – a questionnaire survey. International Journal of Hygiene and Environmental Health. 2004 Jan;207(2):141–50.

174. Schoeni A, Roser K, Röösli M. Symptoms and Cognitive Functions in Adolescents in Relation to Mobile Phone Use during Night. PLoS One [Internet]. 2015 Jul 29 [cited 2020 Jun 9];10(7). Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4519186/

175. Söderqvist F, Carlberg M, Hardell L. Use of wireless telephones and self-reported health symptoms: a population-based study among Swedish adolescents aged 15–19 years. Environ Health. 2008 May 21;7:18.

176. Wdowiak A, Wdowiak L, Wiktor H. EVALUATION OF THE EFFECT OF USING MOBILE PHONES ON MALE FERTILITY. 2007;4.

177. Zarei S, Vahab M, Oryadi-Zanjani MM, Alighanbari N, Mortazavi SMJ. Mother's Exposure to Electromagnetic Fields before and during Pregnancy is Associated with Risk of Speech Problems in Offspring. J Biomed Phys Eng. 2019 Feb 1;9(1):61–8.

178. Cho YM, Lim HJ, Jang H, Kim K, Choi JW, Shin C, et al. A follow-up study of the association between mobile phone use and symptoms of ill health. Environmental Health and Toxicology. :8.

179. Ikeda K, Nakamura K. Association between mobile phone use and depressed mood in Japanese adolescents: a cross-sectional study. Environmental Health and Preventive Medicine. 20140500;19(3):187–93.

180. Kleinlogel H, Dierks T, Koenig T, Lehmann H, Minder A, Berz R. Effects of weak mobile Phone-Electromagnetic fields (GSM, UMTS) on well-being and resting EEG. Bioelectromagnetics. 2008 Sep;29(6):479–87.

181. Ranjbaran M, Soleimani B, Mohammadi M, Ghorbani N, Khodadost M, Mansori K, et al. Association between general health and mobile phone dependency among medical university students: A cross-sectional study in Iran. Int J Prev Med. 2019;10(1):126.

182. Sauter C, Dorn H, Bahr A, Hansen M-L, Peter A, Bajbouj M, et al. Effects of exposure to electromagnetic fields emitted by GSM 900 and WCDMA mobile phones on cognitive function in young male subjects. Bioelectromagnetics. 2011 Apr;32(3):179–90.

183. Tamura H, Nishida T, Tsuji A, Sakakibara H. Association between Excessive Use of Mobile Phone and Insomnia and Depression among Japanese Adolescents. International journal of environmental research and public health [Internet]. 2017 [cited 2020 May 12];14(7). Available from: http://search.proquest.com/docview/1914847370?rfr_id=info%3Axri%2Fsid%3Aprimo

184. Thomée S, Dellve L, Härenstam A, Hagberg M. Perceived connections between information and communication technology use and mental symptoms among young adults - a qualitative study. BMC Public Health; London. 2010;10:66.

185. Thomée S, Härenstam A, Hagberg M. Mobile phone use and stress, sleep disturbances, and symptoms of depression among young adults--a prospective cohort study. BMC public health. 2011;11:66.

186. Zhu Y, Jin W, Liu H, Peng D, Ding Z, Tang Z, et al. Effects of electromagnetic fields from mobile phones on depression and anxiety after titanium mesh cranioplasty among patients with traumatic brain injury. Brain Injury. 2016 Jan 2;30(1):66–73.

187. Vernon L, Modecki KL, Barber BL. Mobile Phones in the Bedroom: Trajectories of Sleep Habits and Subsequent Adolescent Psychosocial Development. Child Development. 2018;89(1):66–77.

188. Bartel K, Scheeren R, Gradisar M. Altering Adolescents' Pre-Bedtime Phone Use to Achieve Better Sleep Health. Health Communication. 2019 Mar 21;34(4):456–62.

189. Danker-Hopfe H, Dorn H, Bahr A, Anderer P, Sauter C. Effects of electromagnetic fields emitted by mobile phones (GSM 900 and WCDMA/UMTS) on the macrostructure of sleep: Electromagnetic fields of mobile phones and sleep. Journal of Sleep Research. 2011 Mar;20(1pt1):73–81.

190. Danker-Hopfe H, Dorn H, Sauter C, Schmid G, Eggert T. An experimental study on effects of radiofrequency electromagnetic fields on sleep in healthy elderly males and females: Gender matters! Environmental Research. 2020 Apr 1;183:109181.

191. Durusoy R, Hassoy H, Özkurt A, Karababa AO. Mobile phone use, school electromagnetic field levels and related symptoms: a cross-sectional survey among 2150 high school students in Izmir. Environ Health. 2017 02;16(1):51.

192. Exelmans L, Van den Bulck J. Bedtime mobile phone use and sleep in adults. Social Science & Medicine. 2016 Jan 1;148:93–101.

193. Gamble AL, D'Rozario AL, Bartlett DJ, Williams S, Bin YS, Grunstein RR, et al. Adolescent Sleep Patterns and Night-Time Technology Use: Results of the Australian Broadcasting Corporation's Big Sleep Survey. Federici S, editor. PLoS ONE. 2014 Nov 12;9(11):e111700.

194. Jech R, Šonka K, Růžička E, Nebuželský A, Böhm J, Juklíčková M, et al. Electromagnetic field of mobile phones affects visual event related potential in patients with narcolepsy: Mobile Phone Affects ERP in Narcolepsy. Bioelectromagnetics. 2001 Oct;22(7):519–28.

195. Kato T, Yorifuji T, Yamakawa M, Inoue S. National data showed that delayed sleep in six-year-old children was associated with excessive use of electronic devices at 12 years. Acta Paediatr. 2018 Aug;107(8):1439–48.

196. Lange K, Cohrs S, Skarupke C, Görke M, Szagun B, Schlack R. Electronic media use and insomnia complaints in German adolescents: gender differences in use patterns and sleep problems. J Neural Transm. 2017 Feb 1;124(1):79–87.

197. Lebedeva NN, Sulimov AV, Sulimova OP, Korotkovskaya TI, Gailus T. Investigation of Brain Potentials in Sleeping Human Exposed to the Electromagnetic Field of Mobile Phones. Critical Reviews in Biomedical Engineering [Internet]. 2001 [cited 2020 May 4];29(1). Available from: https://access.library.oregonstate.edu/pdf/1171437.pdf

198. Loughran SP, Wood AW, Barton JM, Croft RJ, Thompson B, Stough C. The effect of electromagnetic fields emitted by mobile phones on human sleep: NeuroReport. 2005 Nov;16(17):1973–6.

199. Lowden A, Nagai R, Åkerstedt T, Hansson Mild K, Hillert L. Effects of evening exposure to electromagnetic fields emitted by 3G mobile phones on health and night sleep EEG architecture. J Sleep Res. 2019 Aug;28(4):e12813.

200. Lustenberger C, Murbach M, Dürr R, Schmid MR, Kuster N, Achermann P, et al. Stimulation of the Brain With Radiofrequency Electromagnetic Field Pulses Affects Sleep-Dependent Performance Improvement. Brain Stimulation. 2013 Sep 1;6(5):805–11.

201. Lustenberger C, Murbach M, Tüshaus L, Wehrle F, Kuster N, Achermann P, et al. Inter-individual and intra-individual variation of the effects of pulsed RF EMF exposure on the

human sleep EEG: Reproducibility of RF EMF Exposure Effects. Bioelectromagnetics. 2015 Apr;36(3):169–77.

202. Mak YW, Wu CST, Hui DWS, Lam SP, Tse HY, Yu WY, et al. Association between screen viewing duration and sleep duration, sleep quality, and excessive daytime sleepiness among adolescents in Hong Kong. International journal of environmental research and public health. 2014;11(11):11201–19.

203. Munezawa T, Kaneita Y, Osaki Y, Kanda H, Minowa M, Suzuki K, et al. The Association between Use of Mobile Phones after Lights Out and Sleep Disturbances among Japanese Adolescents: A Nationwide Cross-Sectional Survey. Sleep. 2011 Aug;34(8):1013–20.

204. Nakatani-Enomoto S, Furubayashi T, Ushiyama A, Groiss SJ, Ueshima K, Sokejima S, et al. Effects of electromagnetic fields emitted from W-CDMA-like mobile phones on sleep in humans: Effects of Mobile Phones (W-CDMA) on Human Sleep. Bioelectromagnetics. 2013 Dec;34(8):589–98.

205. Perentos N, Croft RJ, McKenzie RJ, Cvetkovic D, Cosic I. Comparison of the effects of continuous and pulsed mobile phone like RF exposure on the human EEG. Australas Phys Eng Sci Med. 2007 Dec;30(4):274–80.

206. Rosen L, Carrier LM, Miller A, Rokkum J, Ruiz A. Sleeping with technology: cognitive, affective, and technology usage predictors of sleep problems among college students. Sleep Health. 2016 Mar 1;2(1):49–56.

207. Saling LL, Haire M. Are you awake? Mobile phone use after lights out. Computers in Human Behavior. 2016 Nov 1;64:932–7.

208. Thomée S, Härenstam A, Hagberg M. Mobile phone use and stress, sleep disturbances, and symptoms of depression among young adults--a prospective cohort study. BMC public health. 2011;11:66.

209. Wagner P, Röschke J, Mann K, Fell J, Hiller W, Frank C, et al. Human sleep EEG under the influence of pulsed radio frequency electromagnetic fields. Results from polysomnographies using submaximal high power flux densities. Neuropsychobiology. 2000;42(4):207–12.

~~Cancer studies~~

~~1. Gilbert D, Coussens C, Merchant J. Rebuilding the unity of health and the environment in rural America: workshop summary. National Academies Press; 2006.~~

2. National Research Council (US) Committee on the Biological Effects of Ionizing Radiation (BEIRNational Research Council (US) Committee on the Biological Effects of Ionizing Radiation (BEIR NRC (US) C on the BE of IR (BEIR. Mechanisms of Radiation-Induced Cancer [Internet]. Health Effects of Exposure to Low Levels of Ionizing Radiation: Beir V. National Academies Press (US); 1990 [cited 2020 Jul 20]. Available from: https://www.ncbi.nlm.nih.gov/books/NBK218707/

3. Repacholi MH. Radiofrequency field exposure and cancer: what do the laboratory studies suggest? Environ Health Perspect. 1997 Dec;105(Suppl 6):1565–8.

4. World Health Organization. Fact Sheet: Electromagnetic fields and public health: mobile phones [Internet]. 2014. Available from: https://www.who.int/news-room/fact-sheets/detail/electromagnetic-fields-and-public-health-mobile-phones

5. Aydin D, Feychting M, Schüz J, Tynes T, Andersen TV, Schmidt LS, et al. Mobile phone use and brain tumors in children and adolescents: a multicenter case-control study. Journal of the National Cancer Institute. 2011;103(16):1264–76.

6. Elliott P, Toledano MB, Bennett J, Beale L, Hoogh K de, Best N, et al. Mobile phone base stations and early childhood cancers: case-control study. BMJ [Internet]. 2010 Jun 22 [cited 2020 May 4];340. Available from: https://www.bmj.com/content/340/bmj.c3077

7. Ha M, Im H, Lee M, Kim HJ, Kim B-C, Gimm Y-M, et al. Radio-frequency radiation exposure from AM radio transmitters and childhood leukemia and brain cancer. Am J Epidemiol. 2007 Aug 1;166(3):270–9.

8. Li C-Y, Liu C-C, Chang Y-H, Chou L-P, Ko M-C. A population-based case-control study of radiofrequency exposure in relation to childhood neoplasm. Sci Total Environ. 2012 Oct 1;435–436:472–8.

9. Maskarinec G, Cooper J, Swygert L. Investigation of increased incidence in childhood leukemia near radio towers in Hawaii: preliminary observations. J Environ Pathol Toxicol Oncol. 1994;13(1):33–7.

10. Merzenich H, Schmiedel S, Bennack S, Brüggemeyer H, Philipp J, Blettner M, et al. Childhood leukemia in relation to radio frequency electromagnetic fields in the vicinity of TV and radio broadcast transmitters. Am J Epidemiol. 2008 Nov 15;168(10):1169–78.

11. Michelozzi P, Capon A, Kirchmayer U, Forastiere F, Biggeri A, Barca A, et al. Adult and childhood leukemia near a high-power radio station in Rome, Italy. Am J Epidemiol. 2002 Jun 15;155(12):1096–103.

12. Dolk H, Shaddick G, Walls P, Grundy C, Thakrar B, Kleinschmidt I, et al. Cancer Incidence near Radio and Television Transmitters in Great Britain I. Sutton Coldfield Transmitter. Am J Epidemiol. 1997 Jan 1;145(1):1–9.

13. Dolk H, Elliott P, Shaddick G, Walls P, Thakrar B. Cancer Incidence near Radio and Television Transmitters in Great Britain II. All High Power Transmitters. Am J Epidemiol. 1997 Jan 1;145(1):10–7.

14. Inskip PD, Hoover RN, Devesa SS. Brain cancer incidence trends in relation to cellular telephone use in the United States. Neuro Oncol. 2010 Nov 1;12(11):1147–51.

15. Chapman S, Azizi L, Luo Q, Sitas F. Has the incidence of brain cancer risen in Australia since the introduction of mobile phones 29 years ago? Cancer Epidemiology. 2016 Jun 1;42:199–205.

16. Little MP, Rajaraman P, Curtis RE, Devesa SS, Inskip PD, Check DP, et al. Mobile phone use and glioma risk: comparison of epidemiological study results with incidence trends in the United States. BMJ [Internet]. 2012 Mar 8 [cited 2020 Apr 19];344. Available from: https://www.bmj.com/content/344/bmj.e1147

17. de Vocht F. Inferring the 1985–2014 impact of mobile phone use on selected brain cancer subtypes using Bayesian structural time series and synthetic controls. Environment International. 2016 Dec 1;97:100–7.

18. de Vocht F. Analyses of temporal and spatial patterns of glioblastoma multiforme and other brain cancer subtypes in relation to mobile phones using synthetic counterfactuals. Environmental research. 2019;168:329–35.

19. Piantadosi S, Byar DP, Green SB. The ecological fallacy. American journal of epidemiology. 1988;127(5):893–904.

20. Muscat JE, Malkin MG, Thompson S, Shore RE, Stellman SD, McRee D, et al. Handheld Cellular Telephone Use and Risk of Brain Cancer. JAMA. 2000 Dec 20;284(23):3001–7.

21. Inskip PD, Tarone RE, Hatch EE, Wilcosky TC, Shapiro WR, Selker RG, et al. Cellular-Telephone Use and Brain Tumors. New England Journal of Medicine. 2001 Jan 11;344(2):79–86.

22. Johansen C, Boice JD, McLaughlin JK, Olsen JH. Cellular Telephones and Cancer—a Nationwide Cohort Study in Denmark. J Natl Cancer Inst. 2001 Feb 7;93(3):203–7.

23. Schüz J, Steding-Jessen M, Hansen S, Stangerup S-E, Cayé-Thomasen P, Poulsen AH, et al. Long-Term Mobile Phone Use and the Risk of Vestibular Schwannoma: A Danish Nationwide Cohort Study. Am J Epidemiol. 2011 Aug 15;174(4):416–22.

24. Poulsen AH, Friis S, Johansen C, Jensen A, Frei P, Kjaear SK, et al. Mobile phone use and the risk of skin cancer: a nationwide cohort study in Denmark. Am J Epidemiol. 2013 Jul 15;178(2):190–7.

25. ~~Frei P, Poulsen AH, Johansen C, Olsen JH, Steding-Jessen M, Schüz J. Use of mobile phones and risk of brain tumours: update of Danish cohort study. BMJ [Internet]. 2011 Oct 20 [cited 2020 Apr 19];343. Available from: https://www.bmj.com/content/343/bmj.d6387~~

26. ~~Benson VS, Pirie K, Schüz J, Reeves GK, Beral V, Green J. Mobile phone use and risk of brain neoplasms and other cancers: prospective study. Int J Epidemiol. 2013 Jun 1;42(3):792–802.~~

27. ~~Benson VS, Pirie K, Schüz J, Reeves GK, Beral V, Green J. Authors' response to: the case of acoustic neuroma: comment on mobile phone use and risk of brain neoplasms and other cancers. International journal of epidemiology. 2014;43(1):275–275.~~

28. ~~Hardell L, Näsman A, Påhlson A, Hallquist A, Hansson Mild K. Use of cellular telephones and the risk for brain tumours: A case-control study. Int J Oncol. 1999 Jul;15(1):113–6.~~

29. ~~Hardell L, Hallquist A, Mild KH, Carlberg M, Påhlson A, Lilja A. Cellular and cordless telephones and the risk for brain tumours. European Journal of Cancer Prevention. 2002 Aug;11(4):377–386.~~

30. ~~Hardell L, Carlberg M, Mild KH. Case-Control Study on Cellular and Cordless Telephones and the Risk for Acoustic Neuroma or Meningioma in Patients Diagnosed 2000–2003. NED. 2005;25(3):120–8.~~

31. ~~Hardell L, Carlberg M, Mild KH. Case–control study of the association between the use of cellular and cordless telephones and malignant brain tumors diagnosed during 2000–2003. Environmental Research. 2006 Feb 1;100(2):232–41.~~

32. ~~Hardell L, Carlberg M, Hansson Mild K. Pooled analysis of two case-control studies on the use of cellular and cordless telephones and the risk of benign brain tumours diagnosed during 1997-2003. International Journal of Oncology. 2006 Feb 1;28(2):509–18.~~

33. ~~Hardell L, Carlberg M, Hansson Mild K. Pooled analysis of two case–control studies on use of cellular and cordless telephones and the risk for malignant brain tumours diagnosed in 1997–2003. Int Arch Occup Environ Health. 2006 Sep 1;79(8):630–9.~~

34. ~~Hardell L, Carlberg M, Mild KH. Mobile Phone Use and the Risk for Malignant Brain Tumors: A Case-Control Study on Deceased Cases and Controls. NED. 2010;35(2):109–14.~~

35. ~~Hardell L, Carlberg M, Hansson Mild K. Pooled analysis of case-control studies on malignant brain tumours and the use of mobile and cordless phones including living and deceased subjects. International Journal of Oncology. 2011 May 1;38(5):1465–74.~~

36. ~~Carlberg M, Söderqvist F, Hansson Mild K, Hardell L. Meningioma patients diagnosed 2007–2009 and the association with use of mobile and cordless phones: a case–control study. Environmental Health. 2013 Jul 19;12(1):60.~~

37. Carlberg M, Hardell L. Decreased survival of glioma patients with astrocytoma grade IV (glioblastoma multiforme) associated with long-term use of mobile and cordless phones. International journal of environmental research and public health. 2014;11(10):10790–805.

38. Söderqvist F, Carlberg M, Hardell L. Use of wireless phones and the risk of salivary gland tumours: a case–control study. European Journal of Cancer Prevention. 2012 Nov;21(6):576–579.

39. Hardell L, Carlberg M. Mobile phone and cordless phone use and the risk for glioma – Analysis of pooled case-control studies in Sweden, 1997–2003 and 2007–2009. Pathophysiology. 2015 Mar 1;22(1):1–13.

40. Hardell L, Carlberg M. Mobile phones, cordless phones and rates of brain tumors in different age groups in the Swedish National Inpatient Register and the Swedish Cancer Register during 1998-2015. PLOS ONE. 2017 Oct 4;12(10):e0185461.

41. Hardell L, Carlberg M, Söderqvist F, Mild KH. Case-control study of the association between malignant brain tumours diagnosed between 2007 and 2009 and mobile and cordless phone use. International journal of oncology. 2013;43(6):1833–45.

42. Hardell L, Carlberg M, Söderqvist F, Mild KH. Pooled analysis of case-control studies on acoustic neuroma diagnosed 1997-2003 and 2007-2009 and use of mobile and cordless phones. International Journal of Oncology. 2013;43(4):1036–44.

43. Myung S-K, Ju W, McDonnell DD, Lee YJ, Kazinets G, Cheng C-T, et al. Mobile Phone Use and Risk of Tumors: A Meta-Analysis. JCO. 2009 Oct 13;27(33):5565–72.

44. FDA. Review of Published Literature between 2008 and 2018 of Relevance to Radiofrequency Radiation and Cancer. 2020;113.

45. Repacholi MH, Lerchl A, Röösli M, Sienkiewicz Z, Auvinen A, Breckenkamp J, et al. Systematic review of wireless phone use and brain cancer and other head tumors. Bioelectromagnetics. 2012;33(3):187–206.

46. Kelsh MA, Shum M, Sheppard AR, Mcneely M, Kuster N, Lau E, et al. Measured radiofrequency exposure during various mobile-phone use scenarios. Journal of exposure science & environmental epidemiology. 2011;21(4):343–54.

47. Momoli F, Siemiatycki J, McBride ML, Parent M-É, Richardson L, Bedard D, et al. Probabilistic Multiple-Bias Modeling Applied to the Canadian Data From the Interphone Study of Mobile Phone Use and Risk of Glioma, Meningioma, Acoustic Neuroma, and Parotid Gland Tumors. Am J Epidemiol. 2017 Oct 1;186(7):885–93.

48. Schoemaker MJ, Swerdlow AJ, Ahlbom A, Auvinen A, Blaasaas KG, Cardis E, et al. Mobile phone use and risk of acoustic neuroma: results of the Interphone case–control study in five North European countries. British Journal of Cancer. 2005 Oct;93(7):842–8.

49. Schüz J, Böhler E, Berg G, Schlehofer B, Hettinger I, Schlaefer K, et al. Cellular Phones, Cordless Phones, and the Risks of Glioma and Meningioma (Interphone Study Group, Germany). Am J Epidemiol. 2006 Mar 15;163(6):512–20.

50. Schüz J, Böhler E, Schlehofer B, Berg G, Schlaefer K, Hettinger I, et al. Radiofrequency Electromagnetic Fields Emitted from Base Stations of DECT Cordless Phones and the Risk of Glioma and Meningioma (Interphone Study Group, Germany). Radiation Research. 2006 Jul 1;166(1):116–9.

51. Cardis E, Armstrong BK, Bowman JD, Giles GG, Hours M, Krewski D, et al. Risk of brain tumours in relation to estimated RF dose from mobile phones: results from five Interphone countries. Occupational and Environmental Medicine. 2011 Sep 1;68(9):631–40.

52. INTERPHONE Study Group. Acoustic neuroma risk in relation to mobile telephone use: Results of the INTERPHONE international case–control study. Cancer Epidemiology. 2011 Oct 1;35(5):453–64.

53. Christensen HC, Schüz J, Kosteljanetz M, Poulsen HS, Boice JD, McLaughlin JK, et al. Cellular telephones and risk for brain tumors: a population-based, incident case-control study. Neurology. 2005 Apr 12;64(7):1189–95.

54. Klaeboe L, Blaasaas KG, Tynes T. Use of mobile phones in Norway and risk of intracranial tumours: European Journal of Cancer Prevention. 2007 Apr;16(2):158–64.

55. Lahkola A, Auvinen A, Raitanen J, Schoemaker MJ, Christensen HC, Feychting M, et al. Mobile phone use and risk of glioma in 5 North European countries. International Journal of Cancer. 2007;120(8):1769–75.

56. Hepworth SJ, Schoemaker MJ, Muir KR, Swerdlow AJ, Tongeren MJA van, McKinney PA. Mobile phone use and risk of glioma in adults: case-control study. BMJ. 2006 Apr 13;332(7546):883–7.

57. Lönn S, Ahlbom A, Hall P, Feychting M. Mobile Phone Use and the Risk of Acoustic Neuroma. Epidemiology. 2004;15(6):653–9.

58. Lönn S, Ahlbom A, Hall P, Feychting M. Long-Term Mobile Phone Use and Brain Tumor Risk. Am J Epidemiol. 2005 Mar 15;161(6):526–35.

59. Sadetzki S, Chetrit A, Jarus-Hakak A, Cardis E, Deutch Y, Duvdevani S, et al. Cellular phone use and risk of benign and malignant parotid gland tumors--a nationwide case-control study. Am J Epidemiol. 2008 Feb 15;167(4):457–67.

60. Schoemaker MJ, Swerdlow AJ. Risk of pituitary tumors in cellular phone users: a case-control study. Epidemiology. 2009 May;20(3):348–54.

61. Takebayashi T, Akiba S, Kikuchi Y, Taki M, Wake K, Watanabe S, et al. Mobile phone use and acoustic neuroma risk in Japan. Occupational and Environmental Medicine. 2006 Dec 1;63(12):802–7.

62. Group IS. Brain tumour risk in relation to mobile telephone use: results of the INTERPHONE international case-control study. International Journal of Epidemiology. 2010;39(3):675–94.

63. Fedak KM, Bernal A, Capshaw ZA, Gross S. Applying the Bradford Hill criteria in the 21st century: how data integration has changed causal inference in molecular epidemiology. Emerg Themes Epidemiol [Internet]. 2015 Sep 30 [cited 2020 Aug 6];12. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4589117/

64. Sasco AJ, Secretan MB, Straif K. Tobacco smoking and cancer: a brief review of recent epidemiological evidence. Lung Cancer. 2004 Aug 1;45:S3–9.

65. Rödelsperger K, Woitowitz H-J, Brückel B, Arhelger R, Pohlabeln H, Jöckel K-H. Dose-response relationship between amphibole fiber lung burden and mesothelioma. Cancer detection and prevention. 1999;23(3):183–93.

66. Ron E. Ionizing Radiation and Cancer Risk: Evidence from Epidemiology. Radiat Res. 1998 Nov 1;150(5s):S30–41.

67. Nageswari KS. Mobile Phone Radiation : Physiological & Pathophysiologcal Considerations. Indian J Physiol Pharmacol. 2015;11.

68. Barchana M, Margaliot M, Liphshitz I. Changes in Brain Glioma Incidence and Laterality Correlates with Use of Mobile Phones - a Nationwide Population Based Study in Israel. Asian Pacific Journal of Cancer Prevention. 2012;13(11):5857–63.

69. Cooke R, Laing S, Swerdlow AJ. A case–control study of risk of leukaemia in relation to mobile phone use. British Journal of Cancer. 2010 Nov;103(11):1729–35.

70. de Vocht F. Cell Phones and Parotid Cancer Trends in England. Epidemiology. 2011 Jul;22(4):608–609.

71. Deltour I, Auvinen A, Feychting M, Johansen C, Klaeboe L, Sankila R, et al. Mobile Phone Use and Incidence of Glioma in the Nordic Countries 1979—2008: Consistency Check. Epidemiology. 2012;23(2):301–7.

72. Deltour I, Johansen C, Auvinen A, Feychting M, Klaeboe L, Schüz J. Time Trends in Brain Tumor Incidence Rates in Denmark, Finland, Norway, and Sweden, 1974–2003. J Natl Cancer Inst. 2009 Dec 16;101(24):1721–4.

73. Hallberg Ö. Adverse health indicators correlating with sparsely populated areas in Sweden. European Journal of Cancer Prevention. 2007 Feb;16(1):71–76.

74. Hsu M-H, Syed-Abdul S, Scholl J, Jian W-S, Lee P, Iqbal U, et al. The incidence rate and mortality of malignant brain tumors after 10 years of intensive cell phone use in Taiwan: European Journal of Cancer Prevention. 2013 Nov;22(6):596–8.

75. Johansen C. Electromagnetic fields and health effects—epidemiologic studies of cancer, diseases of the central nervous system and arrhythmiarelated heart disease. Scandinavian Journal of Work, Environment & Health. 2004;30:1–80.

76. Kim SJ-H, Ioannides SJ, Elwood JM. Trends in incidence of primary brain cancer in New Zealand, 1995 to 2010. Australian and New Zealand Journal of Public Health. 2015;39(2):148–52.

77. Muscat JE, Hinsvark M, Malkin M. Mobile Telephones and Rates of Brain Cancer. NED. 2006;27(1):55–6.

78. Vocht F de, Burstyn I, Cherrie JW. Time trends (1998–2007) in brain cancer incidence rates in relation to mobile phone use in England. Bioelectromagnetics. 2011;32(5):334–9.

79. Auvinen A, Hietanen M, Luukkonen R, Koskela R-S. Brain Tumors and Salivary Gland Cancers Among Cellular Telephone Users. Epidemiology. 2002 May;13(3):356–359.

80. Christensen HC, Schüz J, Kosteljanetz M, Poulsen HS, Thomsen J, Johansen C. Cellular telephone use and risk of acoustic neuroma. Am J Epidemiol. 2004 Feb 1;159(3):277–83.

81. Cook A, Woodward A, Pearce N, Marshall C. Cellular telephone use and time trends for brain, head and neck tumours. N Z Med J. 2003 Jun 6;116(1175):U457.

82. Coureau G, Bouvier G, Lebailly P, Fabbro-Peray P, Gruber A, Leffondre K, et al. Mobile phone use and brain tumours in the CERENAT case-control study. Occup Environ Med. 2014 Jul 1;71(7):514–22.

83. Hartikka H, Heinävaara S, Mäntylä R, Kähärä V, Kurttio P, Auvinen A. Mobile phone use and location of glioma: A case–case analysis. Bioelectromagnetics. 2009;30(3):176–82.

84. Lehrer S, Green S, Stock RG. Association between number of cell phone contracts and brain tumor incidence in nineteen U.S. States. J Neurooncol. 2011 Feb 1;101(3):505–7.

85. Muscat JE, Malkin MG, Shore RE, Thompson S, Neugut AI, Stellman SD, et al. Handheld cellular telephones and risk of acoustic neuroma. NEUROLOGIE. 2002 Apr 23;58(8):1304–6.

86. Abdus-salam A, Elumelu T, Adenipekun A. Mobile phone radiation and the risk of cancer; a review. Afr J Med Med Sci. 2008 Jun;37(2):107–18.

87. Auvinen A, Toivo T, Tokola K. Epidemiological risk assessment of mobile phones and cancer: where can we improve? European Journal of Cancer Prevention. 2006 Dec;15(6):516–523.

88. Carpenter DO. Electromagnetic Fields and Cancer: The Cost of Doing Nothing. Reviews on Environmental Health [Internet]. 2010 Jan [cited 2020 Apr 19];25(1). Available from: https://www.degruyter.com/view/j/reveh.2010.25.1/reveh.2010.25.1.75/reveh.2010.25.1.75.xml

89. Carpenter DO. Human disease resulting from exposure to electromagnetic fields. Reviews on Environmental Health. 2013 Dec 1;28(4):159–72.

90. Corle C, Makale M, Kesari S. Cell phones and glioma risk: a review of the evidence. J Neurooncol. 2012 Jan 1;106(1):1–13.

91. Habash RWY, Elwood JM, Krewski D, Lotz WG, McNamee JP, Prato FS. Recent Advances in Research on Radiofrequency Fields and Health: 2004–2007. Journal of Toxicology and Environmental Health, Part B. 2009 Aug 28;12(4):250–88.

92. Hardell L, Carlberg M. Using the Hill viewpoints from 1965 for evaluating strengths of evidence of the risk for brain tumors associated with use of mobile and cordless phones1). Reviews on Environmental Health [Internet]. 2013 Jan 1 [cited 2020 Apr 19];28(2–3). Available from: https://www.degruyter.com/view/j/reveh.2013.28.issue-2-3/reveh-2013-0006/reveh-2013-0006.xml

93. Heynick LN, Johnston SA, Mason PA. Radio frequency electromagnetic fields: Cancer, mutagenesis, and genotoxicity. Bioelectromagnetics. 2003;24(S6):S74–100.

94. Karger CP. Mobile phones and health: A literature overview. Zeitschrift für Medizinische Physik. 2005 Jan 1;15(2):73–85.

95. Khurana VG, Hardell L, Everaert J, Bortkiewicz A, Carlberg M, Ahonen M. Epidemiological Evidence for a Health Risk from Mobile Phone Base Stations. INT J OCCUP ENVIRON HEALTH. 2010;16(3):5.

96. Kohli DR, Sachdev A, Vats HS. Cell phones and tumor: still in no man's land. Indian J Cancer. 2009 Mar;46(1):5–12.

97. Krewski D, Glickman BW, Habash RWY, Habbick B, Lotz WG, Mandeville R, et al. Recent Advances in Research on Radiofrequency Fields and Health: 2001–2003. Journal of Toxicology and Environmental Health, Part B. 2007 May 30;10(4):287–318.

98. Kundi Michael. The Controversy about a Possible Relationship between Mobile Phone Use and Cancer. Environmental Health Perspectives. 2009 Mar 1;117(3):316–24.

99. Blettner M, Schlehofer B, Samkange-Zeeb F, Berg G, Schlaefer K, Schüz J. Medical exposure to ionising radiation and the risk of brain tumours: Interphone study group, Germany. European Journal of Cancer. 2007 Sep 1;43(13):1990–8.

100. Miller AB, Morgan LL, Udasin I, Davis DL. Cancer epidemiology update, following the 2011 IARC evaluation of radiofrequency electromagnetic fields (Monograph 102). Environmental Research. 2018 Nov;167:673–83.

101. Moussa MMR. Review on health effects related to mobile phones. Part II: results and conclusions. The Journal Of The Egyptian Public Health Association. 2011 Dec;86(5 and 6):79–89.

102. Ostrom QT, Gittleman H, Stetson L, Virk SM, Barnholtz-Sloan JS. Epidemiology of Gliomas. In: Raizer J, Parsa A, editors. Current Understanding and Treatment of Gliomas [Internet]. Cham: Springer International Publishing; 2015 [cited 2020 Apr 19]. p. 1–14. (Cancer Treatment and Research). Available from: https://doi.org/10.1007/978-3-319-12048-5_1

103. Otto M, von Mühlendahl KE. Electromagnetic fields (EMF): Do they play a role in children's environmental health (CEH)? International Journal of Hygiene and Environmental Health. 2007 Oct 31;210(5):635–44.

104. Szmigielski S. Cancer risks related to low-level RF/MW exposures, including cell phones. Electromagnetic Biology and Medicine. 2013 Sep 1;32(3):273–80.

105. Wood AW. How dangerous are mobile phones, transmission masts, and electricity pylons? Archives of Disease in Childhood. 2006 Apr 1;91(4):361–6.

106. Elwood JM. Epidemiological studies of radio frequency exposures and human cancer. Bioelectromagnetics. 2003;24(S6):S63–73.

107. Kan P, Simonsen SE, Lyon JL, Kestle JRW. Cellular phone use and brain tumor: a meta-analysis. J Neurooncol. 2008 Jan 1;86(1):71–8.

108. Khurana VG, Teo C, Kundi M, Hardell L, Carlberg M. Cell phones and brain tumors: a review including the long-term epidemiologic data. Surgical Neurology. 2009 Sep 1;72(3):205–14.

109. Lahkola A, Tokola K, Auvinen A. Meta-analysis of mobile phone use and intracranial tumors. Scand J Work Environ Health. 2006 Jun;32(3):171–7.

110. Morgan LL, Miller AB, Sasco A, Davis DL. Mobile phone radiation causes brain tumors and should be classified as a probable human carcinogen (2A) (Review). International Journal of Oncology. 2015 May 1;46(5):1865–71.

111. Söderqvist F, Carlberg M, Hardell L. Review of four publications on the Danish cohort study on mobile phone subscribers and risk of brain tumors. Reviews on Environmental Health. 2012 Apr 1;27(1):51–8.

112. Wiedemann P, Schütz H. Children's health and RF EMF exposure. Views from a risk assessment and risk communication perspective. Wien Med Wochenschr. 2011 May 1;161(9):226–32.

Appendix

The following tables summarize the studies we reviewed on the different health endpoints associated with exposure to RFR or RFR sources and receivers. We include a column for whether an adverse effect was observed or not, but this does not indicate an effect of RFR necessarily. In most cases, studies did not measure RFR directly; rather, they relied on reported cell phone use, modeled RFR exposure, or other methods.

Table 1. Cancer studies: original research

Study Name **(Year)**	Authors	Funding Source	Study Type	Study Population	Study dates/ Follow-up length	Study Population Size	Endpoint Examined	Exposure Assessment	Adverse Effect Yes/ No	Comments **(if adverse effect, increase in odds/risk)**
Changes in Brain Glioma Incidence and Laterality Correlates with Use of Mobile Phones – a Nationwide Population Based Study in Israel **(2012)**	Barchana *et al.* (109)	No funding	Descriptive incidence study, ecological	All individuals diagnosed w/ brain gliomas in Israel 1980-2009	1980-2009	4,993	Incidence and laterality of gliomas	Completed convenience sample survey of 1000 Israelis to examine laterality of mobile phone use	No	Shift in laterality of brain tumors over period. Poor study design and poor explanation of methods. Weak study – descriptive design, results likely not worth including in review.
Mobile phone use and risk of brain neoplasms and other cancers: prospective study **(2013)**	Benson *et al.* (26)	Government and NGO	Prospective cohort	791,710 UK middle-aged women	1999-2009	791,710	Intracranial CNS tumors: acoustic neuroma, glioma, meningioma	Surveys on mobile phone use in 1999, 2005, 2009. Assessed both how often and how long mobile phone used.	Yes	Long term mobile phone use associated with increased risk of acoustic neuroma. Medium to strong study due to sample size and cohort design, though recall bias is possible and surveys at only 3 time points could exacerbate this. Interviewer bias (non-blinded) possible and study only included women so results may not generalize to full population. Possible reporting and participation biases and serious potential for confounding.
Authors' response to: The case of acoustic neuroma: comment on mobile phone use and risk of brain neoplasms and other cancers **(2014)**	Benson *et al.* (27)	Government and NGO	Prospective cohort	791,710 UK middle-aged women	1999-2011	791,710	Acoustic neuroma	Surveys on mobile phone use in 1999, 2005, 2009, 2011. Assessed both how often and how long mobile phone used.	No	Extended analysis rendered acoustic neuroma risk insignificant and there was no increased risk with duration of use.
Has the incidence of brain cancer risen in Australia	Chapman *et al.* (15)	No funding	Descriptive	19,858 males and 14,222 females diagnosed with	1982-2012	34,080	Brain cancer incidence	Based on annual reports of	No	No evidence of any rise in any age group that could be plausibly attributed to mobile

since the introduction of mobile phones 29 years ago? **(2016)**			incidence study	brain cancer in Australia between 1982 and 2012				mobile phone accounts, grouped into time-related exposure categories.		phones. Weak study – descriptive design, probably not worth including in review.
A case–control study of risk of leukaemia in relation to mobile phone use **(2010)**	Cooke *et al*. (110)	Government	Population-based Case-control	Cases: diagnosed leukemia, age 18-59, in southeast England, and diagnosed years 2003-2007. Controls: non-blood relatives of cases, did not live with cases and fits age/residence	2003-2009	806 cases, 585 controls	Leukemia incidence	Surveys of mobile phone use. Subjects asked about make and model of phone, whether they were regular users (6mos or longer), average length of calls, proportion of calls that were hands-free	No	No association between regular phone use and developing leukemia. Low strength study - Possible selection bias from method used to select controls (relatives) and no mention of how cases/controls were matched, interviewer bias (non-blinded) and recall bias for surveys. Sampling bias also possible due to population-based design (unclear how control selection method is population-based).
Cell Phones and Parotid Cancer Trends in England **(2011)**	de Vocht (111)	No funding	Descriptive incidence study	Incident cases in UK 1986-2008 (all individuals)	1986-2008	List rates only for selected years	Parotid Cancer incidence	No exposure assessment, comparison of rates before and after phones came into widespread use	No	Trends in England started before widespread cell phone use, are more gradual, and differ in magnitude by sex, which does not point to cell phone use as the main driver of these trends. Weak study – descriptive and no exposure assessment. Do not recommend inclusion in review.
Inferring the 1985–2014 impact of mobile phone use on selected brain cancer subtypes using Bayesian structural time series and synthetic controls **(2016)**	de Vocht (17)	No funding	Ecological	Annual 1985–2014 incidence of malignant glioma, glioblastoma multiforme, and malignant neoplasms of the temporal and parietal lobes in England (all individuals)	1985-2014	List rates only for selected years	Glioma, glioblastoma multiforme, and malignant neoplasms of the temporal and parietal	Number of cellular mobile phone subscriptions (UN data)	Yes	Increased risk of developing malignant neoplasms of temporal lobe. Medium strength study - has advanced methodology but suffers from ecological fallacy and less informative/effective exposure assessment. **(35% risk increase [95% CI: 9%-59%])**

							lobes - incidence			
Analyses of temporal and spatial patterns of glioblastoma multiforme and other brain cancer subtypes in relation to mobile phones using synthetic counterfactuals **(2019)**	de Vocht (18)	No funding	Ecological	Annual 1985–2005 incidence of brain cancer subtypes for England (all individuals)	1985-2005	14,503 malignant cases	Glioblastoma incidence	National number of cellular mobile phone subscriptions (UN data)	Yes	Increases in excess of the counterfactuals for GBM were found in the temporal and frontal lobes. Low to medium strength study - large sample size and advanced methods but suffers from ecological fallacy, poor exposure assessment, and highly uncertain estimates. **(Temporal: 38% increase [95% CI: -7% to 78%]; Frontal: 36% increase [95% CI: -8%-77%]; Cerebellum: 59% increase [95% CI: 0%-120%])**
Mobile Phone Use and Incidence of Glioma in the Nordic Countries 1979-2008. **(2012)**	Deltour *et al.* (112)	Government	Simulation study	Men and women aged 20-79 in Nordic counties diagnosed with glioma	1979-2008	35,250 glioma cases	Glioma incidence	Self-reports from sample of general population in Interphone study. Data on "regular" use, proportion of heavy users, and estimation of lag/induction period	No	No clear trend change in glioma incidence rates was observed. Medium strength study - Simulation studies have poor ability to point toward causality, but large sample size, effective exposure assessment, and accounting for induction period. Recall bias is possible due to self-reports and interviewer bias (non-blinded).
Time Trends in Brain Tumor Incidence Rates in Denmark, Finland, Norway, and Sweden, 1974 – 2003. **(2009)**	Deltour *et al.* (113)	Government and private	Incidence study (descriptive)	Men and women aged 20 – 79 years diagnosed with brain tumors in Nordic countries	1974 – 2003	59,984 diagnosed with brain tumors	Brain cancer incidence	No exposure assessment	No	No change in incidence trends from 1998 to 2003, the time when possible associations between mobile phone use and cancer risk would be informative about an induction period of 5 – 10 years. Weak study – descriptive design. Do not recommend for inclusion in review.
Use of mobile phones and risk of brain tumours: update	Frei *et al.* (25)	Government	Prospective cohort	All Danes aged ≥30 and born in Denmark after 1925,	1990-2008	358,403 phone subscription holders accrued 3.8 million person	Brain cancer incidence	Mobile phone subscriptions	No	No increased risks of tumours of the central nervous system, providing little evidence for a causal

of Danish cohort study. **(2011)**				subdivided into subscribers and non-subscribers of mobile phones before 1995.		years and 10,729 CNS tumors				association. Medium to high quality evidence based on cohort study design and sample size. Major shortfall is exposure assessment – mobile phone subscriptions is not detailed enough.
Adverse health indicators correlating with sparsely populated areas in Sweden. **(2007)**	Hallberg (114)	Author works for Ericsson	Ecological	Swedish incidence rates of all cases of prostate cancer and leukemia, among a variety of other health indicators	1997-2003	Sample size not stated – rates only	Prostate cancer and leukemia incidence	Estimated average output power over Swedish counties from mobile phones and base stations based on coverage maps (year of measure not described)	Yes	Density of base stations and higher average output=higher incidence. Low strength study - very weakly explained and designed study with no adjustment for obvious confounders and extensive use of simple linear models; many assumptions made in exposure assessment and poor explanation of how temporality/ induction period fits in. Possibly should be included in review but note serious caveats. **(Correlation statistics only – no way to calculate risk increase)**
The incidence rate and mortality of malignant brain tumors after 10 years of intensive cell phone use in Taiwan. **(2013)**	Hsu *et al*. (115)	No funding	Ecological	All cases of brain cancer in Taiwan 2000-2009	2000-2009	Sample size not state – rates only	Brain cancer incidence and mortality	Total cell phone users in Taiwan by year	No	No correlation between cell phone use and brain cancer. Weak study – basic exposure assessment, no adjustment for confounding, and suffers from ecological fallacy. Possibly should be included in review but note serious caveats.
Brain cancer incidence trends in relation to cellular telephone use in the United States. **(2010)**	Inskip *et al*. (14)	Government	Descriptive incidence study	White patients diagnosed with brain cancer 1977-2006 from SEER	1977-2006	38,788 cases of brain cancer	Brain cancer incidence	No exposure assessment, comparison of rates before and after phones came into widespread use	No	No evidence of relationship between cell phones and brain cancer. Weak study – descriptive design and no exposure assessment. Do not recommend inclusion in review.
Acoustic neuroma risk in relation to mobile telephone use: Results of the INTERPHONE	INTERPHONE group (52)	Government and private	Population-based Case-control	Cases: all patients with a schwannoma of the acoustic nerve diagnosed	2000-2004	1105 cases and 2145 controls	Acoustic neuroma incidence	Face-to-face interviews. Questions about all ionizing and	Yes	Elevated odds ratios observed at the highest level of cumulative call time, but no increase in risk of acoustic neuroma with ever regular use of a mobile phone or

international case–control study**. (2011)**				in study region in 2000-2004. Controls: 2 for each case from population-based sampling frame. Both individual and frequency matching used depending on site. Matched for age, sex, region, and ethnicity (only in Israel)				non-ionizing radiation exposure (this is as much detail given)		for users who began regular use 10 years or more before date of diagnosis. Medium to strong study – larger sample size, effective exposure assessment but authors note selection bias, non-response bias, and recall bias as concerns. Sampling bias also possible due to population-based design along with interviewer bias due to non-blinded interviews. Proxies were used for some interviews as well. Also, did not complete sensitivity analysis to check for overmatching due to individual matching design. **(179% odds increase [95% CI: 51%-416%] for those w/ ≥ 1640 hours of use)**
Mobile phones and malignant melanoma of the eye **(2002)**	Johansen *et al*. (22)	Government and NGO	Ecological	All cases of ocular melanoma in Denmark 1943-1996	1943-1996	111 total cases of ocular melanoma	Ocular melanoma incidence	Annual numbers of mobile telephone subscribers	No	No association between mobile phones and ocular melanoma. Weak study based only on incidence trends, small sample size, and rough exposure assessment over a long period where cell phones were not even around yet. Do not recommend for inclusion in review.
Electromagnetic fields and health effects—epidemiologic studies of cancer, diseases of the central nervous system and arrhythmiarelated heart disease **(2004)**	Johansen (116)	No funding	Retrospective cohort	Danish cohort of mobile phone subscribers	1982-1995	723,421 mobile phone subscribers and 2876 cases of cancer	All cancers of any mobile phone subscribers	Telephone plan subscribers. Data on duration of phone use, latency, system used (NMT, GSM or both) and age at first subscription were collected.	No	No increased risk observed for the cancers considered a priori to be possibly associated with the radiofrequency fields emitted by mobile phones, which were brain tumors, including acoustic neuroma, salivary gland tumors, and leukemia. Strong study due to sample size and because of exposure assessment: analyzed by duration of phone use, latency, system used (NMT, GSM or both) and age at first subscription. Authors note

										possible selection bias, misclassification of exposure and outcome, and confounding.
Trends in incidence of primary brain cancer in New Zealand, 1995 to 2010 **(2015)**	Kim *et al*. (117)	No funding	Descriptiv e incidence study	Brain malignancies in New Zealand from 1995 to 2010 (population-based)	1995-2010	4,212 cases of brain cancer	Brain cancers incidence	No exposure assessment	No	No consistent increase in incidence rates of primary brain cancers. Weak study due to descriptive nature and no exposure assessment. Do not recommend for inclusion in review.
Use of mobile phones in Norway and risk of intracranial tumours **(2007)**	Klaeboe *et al*. (54)	Governme nt and private	Population -based Case-control	16-69 year-olds diagnosed with gliomas, meningiomas or acoustic neuromas in 2001-2002 in Southern Norway. Controls randomly sampled from Norwegian Central Population Register (frequency-matched for age, sex, region)	2001-2002	Cases: 289 glioma, 207 meningioma, 45 acoustic neuroma from larger cohort. Controls: 518 controls	Glioma, meningio ma, Acoustic neuroma incidence	Face-to-face interviews. Data on number of years of exposure, number of years since regular use began, and cumulative time of mobile phone use.	No	No increased risk of gliomas, meningiomas, or acoustic neuromas. Low to medium strength study: non-response bias in cases and controls, differential misclassification of exposure, and recall bias. Sampling bias also possible due to population-based design along with interviewer bias due to non-blinded interviews.
Mobile phone use and risk of glioma in 5 North European countries **(2007)**	Lahkola *et al*. (55)	Governme nt and private	Population -based Case-control	Glioma patients (residents of study countries 20-69 years in Nordic, 18-59 in England). Frequency-matched (age, sex, region) controls from national population registers.	2000-2004	Cases: 1,521 glioma patients Controls: 3,301	Glioma incidence	Face-to-face interviews in all countries except Finland (paper survey). Data on regular use of mobile phones (at least once a week for at least 6 months), start and end dates of use, phone types, and	Yes, slightly in long term use	No increased risk of glioma from mobile phone use – though possible risk among longest-term exposure and most exposed portion of brain. Strong study (sample size and adjustment for confounders) but authors note recall bias likely affecting their estimates, selection bias from lost controls. Sampling bias also possible due to population-based design along with interviewer bias due to non-blinded interviews. **(39% increased odds in long-term high exposure brains [95% CI: 1% to 92%])**

								frequency of use.		
Mobile phone use and glioma risk: comparison of epidemiological study results with incidence trends in the United States **(2012)**	Little *et al*. (16)	Government	Ecological	24,813 non-Hispanic white people diagnosed with glioma at age 18 years or older	1992-2008	24,813	Glioma incidence	Mobile phone subscriptions per year in the US in 1985-2010	No	U.S. incidence rates are not high enough to indicate effect of mobile phones. Low to medium strength study – large sample size, but suffers from ecological fallacy and less detailed/effective exposure assessment. Recommended for inclusion in review, but with caveats noted.
Probabilistic Multiple-Bias Modeling Applied to the Canadian Data From the Interphone Study of Mobile Phone Use and Risk of Glioma, Meningioma, Acoustic Neuroma, and Parotid Gland Tumors **(2017)**	Momoli *et al*. (47)	Government and private	Population-based case-control	Canadians 30–59 years of age who live in Canadian INTERPHONE study regions and diagnosed w/ glioma, meningioma, acoustic neuroma, or malignant and benign parotid glandtumors. Frequency-matched (age and region) controls from provincial registry	2001-2004	Cases: 405 Controls: 516	Glioma, meningioma, acoustic neuroma, parotid gland incident tumors	In-person face-to-face interviews. Questions asked about patterns of use (daily amount and "regular" use), network operators, use of hands-free devices, and use in urban and rural areas	No	Little evidence of an increase in the risk of meningioma, acoustic neuroma, or parotid gland tumors in relation to mobile phone use. Strong study - Re-analysis of INTERPHONE study results with correction for selection, recall bias, but not sampling bias. Interviewer bias is possible due to non-blinded interviews.
Mobile Telephones and Rates of Brain Cancer **(2006)**	Muscat *et al*. (118)	Private – funded directly by telecom association	Descriptive incidence study	U.S. men and women aged 6-20 years with gangliogliomas and similar tumor types	1973-2002	List only rates over 1973-2002 period	Neuronal brain cancer incidence	No exposure assessment	No	Risk of neuronal brain cancer is not related to mobile phones. Weak study– descriptive and no exposure assessment. Do not recommend for inclusion in review.
Mobile phone use and risk of acoustic neuroma: results of the Interphone case–control study in five North European countries **(2005)**	Schoemaker *et al*. (48)	Government, NGO, and private	Population-based case control	Individuals diagnosed w/ acoustic neuroma between 1999 and 2004 at ages 20–69 years in the Nordic countries, 18–59 in	1999-2004	Cases: 678 cases of acoustic neuroma. Controls: 3553 frequency (age-, sex-, and region-) matched controls of randomly-sampled	Acoustic neuroma incidence	Face-to-face and phone interviews. Start and end date of use, the average amount of time of use and number	Yes, long-term use	No substantial risk of acoustic neuroma in the first decade after starting mobile phone use, but increased risk after longer term use or longer lag period. Strong study – large sample size, very thorough matching procedure, and effective exposure assessment.

				Southeast England, and 18–69 in the Northern UK, and live in study region		population from population registers		of calls.		Possible recall biases, other cancer-specific information biases related to tumor laterality, possible sampling bias due population-based case control design along with interviewer bias due to non-blinded interviews. **(80% increased odds [95% CI: 10%-310%] among high exposure group)**
Cellular Phones, Cordless Phones, and the Risks of Glioma and Meningioma (Interphone Study Group, Germany) **(2005)**	Schuz *et al*. (49)	Government and private	Population-based case control	366 glioma cases, 381 meningioma cases in Germany regions of Bielefeld, Heidelberg, Mainz, and Mannheim, Germany in those aged 30-69. Frequency (sex-, age-, and region-) matched controls from national registry	2000-2003	Cases: 366 glioma cases, 381 meningioma cases in Germany Controls: 1,494	Glioma and meningioma incidence	Face-to-face interviews. Data on "regular" use, make/model, number of calls received/made, start and end date of use.	No	Cordless phone use was not related to either glioma risk or meningioma risk. Non-significant association between long-term cell phone use and glioma. Medium strength study. Selection and recall bias likely in this study – high refusal rate among controls, especially among low SES + sampling bias due to population-based case-control design along with interviewer bias due to non-blinded interviews.
Radiofrequency Electromagnetic Fields Emitted from Base Stations of DECT Cordless Phones and the Risk of Glioma and Meningioma (Interphone Study Group, Germany) **(2006)**	Schuz *et al*. (50)	Government and private	Population-based case control	366 glioma cases, 381 meningioma cases in Germany regions of Bielefeld, Heidelberg, Mainz, and Mannheim, Germany in those aged 30-69. Frequency (sex-, age-, and region-) matched controls from national registry	2000-2003	Cases: 366 glioma cases, 381 meningioma cases in Germany Controls: 1,494	Glioma and meningioma incidence	Face-to-face interviews. Data on "regular" use of DECT, make/model, number of calls received/made, start and end date of use.	No	No increased risk of glioma/meningioma from DECT base stations. Medium strength study – selection and recall bias - high refusal rate among controls, especially among low SES. Also, few subjects had exposure to DECT base stations – reducing strength of evidence, plus sampling bias is possible due to study design. Interviewer bias due to non-blinded interviews also possible

Long-Term Mobile Phone Use and the Risk of Vestibular Schwannoma: A Danish Nationwide Cohort Study **(2011)**	Schuz *et al*. (23)	Governme nt and NGO	Nationwid e retrospect ive cohort	All private cellular telephone subscribers in Denmark 1992-1995	1995-2006	2.9 million Danish mobile phone subscribers	Vestibular schwanno ma incidence	Mobile phone subscription – no mobile phone use characterizati on (how much exposure per person)	No	No evidence that mobile phone use is related to the risk of vestibular schwannoma. Medium to strong study despite large sample size – no characterization/categorization of mobile phone use, and schwannoma has particularly long induction period, so may be underestimate of risk.
Time trends (1998–2007) in brain cancer incidence rates in relation to mobile phone use in England **(2011)**	de Vocht *et al*. (119)	No funding	Descriptiv e incidence study	All brain cancers in England 1998-2007	1998-2007	Lists rates only	Brain cancer incidence	No exposure assessment	No	Mobile phones have not resulted in increased risk of brain cancer. Weak study – descriptive incidence design and no exposure assessment. Do not receommend for inclusion in review.
				STUDIES VIA REFERENCE AFTER THIS LINE						
Brain Tumors and Salivary Gland Cancers Among Cellular Telephone Users **(2002)**	Auvinen *et al*. (120)	Governme nt and private	Population -based case control	All salivary gland and brain cancer patients diagnosed in Finland in 1996 and age/sex matched (does not list individual vs. frequency) controls from national registry (5 controls to every 1 case)	1996	Cases: 398 brain tumor and 34 salivary gland tumor cases Controls: 4705 controls	Salivary gland and brain cancer incidence	Mobile phone subscriptions – duration of subscription up to study timeframe and type (analog vs digital)	Yes	Cellular phone use not associated with brain tumors or salivary gland cancers overall, but weak association between gliomas and analog and cellular phones. Medium strength study based on sample size, control selection, and control for confounders. Authors note exposure assessment as limitation, but better than ecological studies. Also sampling bias is possible due to pop-based cohort design Does not list matching method in methodology. **(50% odds increase [95% CI: 0%-140%] of glioma among cell phone users and 110% odd increase [95% CI: 30%-240%] of glioma among analog phone users)**
Mobile phone use and brain tumors in children and	Aydin *et al*. (5)	Governme nt	Case-control	All children and adolescents aged 7-19 years who	2004-2008	Cases: 352 patients	Brain cancer incidence	Face-to-face and telephone	No	Mobile phone users had difference in brain tumor risk compared with nonusers, risk

adolescents: a multicenter case-control study **(2011)**				were diagnosed with a brain tumor between 2004 and 2008 in Denmark, Sweden, Norway, and Switzerland. 2 age-, sex-, region-matched (does not list frequency vs individual) controls selected per case from national registries		diagnosed w/ brain tumors Controls: 646 controls from national population registries of participating countries		interviews with children and parents. Data on regular use, time since first use of mobile phones (years), cumulative duration of subscriptions (years), cumulative duration of use (hours), and cumulative number of calls.		did not increase with the duration of mobile phone use, nor was risk higher in the areas of the brain that came into closest proximity to a hand-held mobile phone. Medium strength study based on exposure assessment and confounder control. Sample size not sufficient to detect small risk increases, recall bias a particular problem among children, and sampling bias. Interviewer bias due to non-blinded interviews also possible.
Risk of brain tumours in relation to estimated RF dose from mobile phones: results from five Interphone countries **(2011)**	Cardis *et al*. (51)	Government and private	Population-based case control	Patients with brain tumors from the Australian, Canadian, French, Israeli and New Zealand components of the Interphone Study (30-59 years with brain glioma or meningioma) and age-,sex-, region-, and tumor laterality-matched (does not mention frequency vs. individual) controls from population registries	2000-2004	Cases: 553 glioma and 676 meningioma cases and Controls: 1762 glioma and 1911 meningioma controls	Glioma and meningioma	Highly detailed interviews, with amount of use, conditions, model types and operators. Used unique algorithm to estimate actual dose of radiation for each case and control	Yes	Increased risk of glioma in long-term mobile phone users with high RF exposure and much smaller increases in meningioma risk. Medium to strong strength study due to sample size and detailed exposure assessment. Limitations are same as other interphone studies – selection bias due to lower response among controls, recall bias, and sampling bias. Also, no mention of sensitivity analysis of new algorithm – this should have been done to show results are not spurious. **(91% increased odds [95% CI: 5%-247%] with highest quintile of increasing exposure time and dose)**

Meningioma patients diagnosed 2007–2009 and the association with use of mobile and cordless phones: a case–control study **(2013)**	Carlberg *et al.* (36)	NGO and private	Population -based Case-control	All meningiomas in Sweden among those 18-75 years old during 2007-2009. Age- and region-matched controls from national population register (does not list frequency vs. individual matched)	2007-2009	Cases: 709 meningioma cases Controls: 1368 controls	Meningioma incidence	Self-administered questionnaire w/ telephone support. Poor explanation of data collected – cumulative call time and total years of use at least	No	No conclusive evidence of increased risk. Medium strength study – control for confounders, high response rate, and accounting for induction period. However, controls were not sex-matched and unexposed group not sufficient to ascertain statistically certain results along with possible sampling bias. Interviewer bias and recall bias are also possible.
Cellular telephones and risk for brain tumors: a population-based, incident case-control study **(2005)**	Christensen *et al.* (53)	Government and private	Population -based Case-control	All incident cases of glioma and meningioma diagnosed in Denmark between September 1, 2000, and August 31, 2002 aged 20-69 and population-based frequency (age- and sex-) matched controls.	2000-2002	Cases: 252 persons with glioma and 175 persons with meningioma Controls: 822 controls	Glioma and meningioma incidence	Face-to-face interviews. Data on regular users (use at least once a week for 6 months or more) and how many different cellular telephones used regularly. Start and stop dates of use were recorded.	No	No association between mobile phones and glioma or meningioma. Medium strength study – control for confounders and effective exposure assessment. Possible bias due low participation rate, recall bias, and sampling bias. Interviewer bias due to non-blinded interviews also possible.
Cellular telephone use and risk of acoustic neuroma **(2004)**	Christensen *et al.* (121)	Government and NGO	Population -based Case-control	All Danish cases of acoustic neuroma aged 20–69 years from 2000-2002. Two individually-matched (age and sex) controls for each case from national population registry.	2000-2002	Cases: 106 cases of acoustic neuroma Controls: 212 controls	Acoustic neuroma incidence	Face-to-face interviews. Data on regular users (use at least once a week for 6 months or more) and how many different cellular telephones used regularly.	No	No association between cell phone use and acoustic neuroma. Medium to strong study – control for cofounders, effective exposure assessment, and correction for biases seen in other studies (case loss due to death, interviewer bias, retrospective case ascertainment). Possible recall bias and sampling bias possible present along with interviewer bias due to non-blinded interviews. Individual matching

								Start and stop dates of use were recorded.		could have resulted in overmatching.
Cellular telephone use and time trends for brain, head and neck tumours **(2003)**	Cook *et al*. (122)	Government	Descriptive incidence study	Brain, head, and neck cancers of those aged 20 to 69 years in New Zealand from 1986-1998	1986-1998	Only rates listed	Brain, head, and neck tumor incidence	No exposure assessment	No	No increase in tumors since introduction cell phones. Weak study – study design provides nearly no evidence due to lack of exposure assessment. Do not recommend for inclusion in review.
Mobile phone use and brain tumours in the CERENAT case-control study **(2014)**	Coureau *et al.* (123)	Government and NGO	Population-based Case-control	All those 16 years and older diagnosed with glioma/meningioma in Gironde, Calvados, Manche, and Hérault regions of France from 2004-2006. 2 individually (age-, sex-, and region-) matched controls per case randomly selected from voter rolls 2005-2008	2004-2006	Cases: 253 glioma, 194 meningioma cases Controls: 892 controls	Glioma and meningioma incidence	Face-to-face interviews. Data on regular use, phone make/model, beginning and end dates for the use of the phone, average number and duration of calls made and received per month during each use period; shared or individual use; occupational or personal use and hands-free kit use.	Yes	No association when comparing users to non-users, but association for highest cumulative users. Medium strength study – control for confounders and effective exposure assessment. Authors note they found recall bias and selection bias is possible. Ascertainment of controls via voter rolls may not 1) be representative of the population – not compulsory in France or 2) match years of case diagnosis, and sampling bias is likely. Interviewer bias due to non-blinded interviews also possible. Overmatching due to individual matching design is possible. **(189% odds increase [95% CI: 41%-493%] of glioma and 157% odds increase [95% CI: 2%-544%] of meningioma in lifelong cumulative exposure)**
Mobile phone base stations and early childhood cancers: case-control study **(2010)**	Elliott *et al*. (6)	Government and private	Case-control	All registered cases of cancer in children aged 0-4 in Great Britain in 1999-2001 of the brain, CNS, leukemia, non-Hodgkin's	1999-2001	Cases: 1397 cases of cancer Controls: 5588 controls	Brain, CNS, leukemia, non-Hodgkin's lymphoma, and combined	Modeled power density from mobile phone base stations based on location – used	No	No association between risk of early childhood cancers and estimates of the mother's exposure to mobile phone base stations during pregnancy. Medium to strong study – large sample size,

				lymphoma, and combined all cancer. 4 individually (sex-, and age-) matched controls per case from UK national registry			all cancers from mother's exposure during pregnancy	fieldwork to create models that take into account rural vs. urban		highly effective exposure assessment, reduced selection bias in comparison to other case-controls. Limitations: assumption of birth address as location of pregnancy exposures, poor control for radiofrequency confounders e.g. mother's cell phone use. Overmatching due to individual matching design is possible.
Brain tumour risk in relation to mobile telephone use: results of the INTERPHONE international case-control study. **(2010)**	INTERPHONE Group (62)	Government and private	Population-based case-control	All cases of glioma and menigioma among those 30-59 years in 13 countries from 2000-2004. Frequency/individually (Age-, sex-, and region-) matched controls in 12 countries. Also matched for ethnicity in Israel.	2000-2004	Cases: 2708 glioma and 2409 meningioma cases Controls: 2971 glioma controls and 2662 meningioma controls	Glioma and meningioma	Face-to-face and printed interviews. Data on regular users (use at least once a week for 6 months or more) and how many different cellular telephones used regularly. Start and stop dates of use were also recorded along with cumulative hours of use.	Yes	No increase of risk of glioma and meningioma across most exposure categories and meningioma global model. Highest exposure (greater than or equal 1640 cumulative hours) showed increase in risk in glioma. Strong study – large sample size, effective exposure assessment, and multi-country study. Limitations are same as other interphone studies – selection bias due to lower response among controls, recall bias, and sampling bias due to study design. Interviewer bias due to non-blinded interviews also possible. Proxy interviews completed for dead subjects. Overmatching due to individual matching design is possible. **(Greater than or equal to 1640 cumulative hours: 40% odds increase [95% CI: 3%-89%])**
Cellular and cordless telephones and the risk for brain tumours **(2002)**	Hardell *et al.* (29)	Government and private	Population-based case-control	All alive 20-80 year-olds diagnosed with brain tumors in 4 regions in Sweden between 1997 and 2000. Frequency (Sex-, age-, and region-) matched controls	1997-2000	Cases: 1429 cases of brain cancer Control: 1470 controls	Brain cancers incidence	Written questionnaire + supplementary telephone interviews for certain cases/controls. Data on type of	Yes	No association for digital or cordless phones. Increased risk from analog cell phones (450 MHz) – highest association was acoustic neuroma. Increased risk of tumors on side of head where cell phone was used. Medium to strong study – large sample size, effective exposure assessment, and longer latency

				from population register.				phone, years of use, make/model, mean number/ length of daily calls, cumulative use in hours.		period than others. Some evidence of recall, sampling, and interviewer bias and no mention of confounding control. **(Analog phones: 30% odds increase [95% CI: 2%-60%]; analog phones 10+ years induction: 80% odds increase [95% CI: 10%-190%])**
Use of cellular telephones and the risk for brain tumours: A case-control study **(1999)**	Hardell *et al.* (28)	Government, NGO, and private	Population-based case-control	All alive 20-80 year-olds diagnosed with brain tumors in 2 regions of Sweden 1994-1996. Frequency (Age-, sex-, region-) matched controls from national registry.	1994-1996	Cases: 209 cases of brain tumors Controls: 425 controls	Brain cancers incidence	Written questionnaire + supplementary telephone interviews for certain cases/controls. Data on type of phone, years of use, make/model, mean number/ length of daily calls, cumulative use in hours.	No	No evidence of increased risk. Medium strength study – medium-sized sample, effective exposure assessment, and accounting for tumor induction period. However, recall, sampling, and interviewer bias are possible. Results may not be generalizable outside of these Swedish regions (including US).
Pooled analysis of two case-control studies on the use of cellular and cordless telephones and the risk of benign brain tumours diagnosed during 1997-2003 **(2006)**	Hardell *et al.* (32)	Government, NGO, and private	Population-based case-control	All alive 20-80 year-olds diagnosed with brain tumors in 2 regions of Sweden 1997-2003. Frequency (Age-, sex-, region-)matched controls from national registry.	1997-2003	Cases: 1254 cases Controls: 2162 controls	Benign brain tumor incidence	Written questionnaire + supplementary telephone interviews for certain cases/controls. Data on type of phone, years of use, make/model, mean number/ length of daily calls,	Yes	Increased risk from cordless, analog, and digital cell phones – specifically meningioma and acoustic neuroma in more specific analyses. Medium to strong study – large sample size, effective exposure assessment, accounting for tumor induction period, and confounding control. Possible recall, interviewer, and sampling bias, wide confidence interval for higher latency period results, and authors note no dose-response for certain outcomes (meningioma), which reduces case for causality. Results may

								cumulative use in hours.		not be generalizable outside of these Swedish regions (including US). **(Acoustic neuroma-analog: 190% odds increase [95% CI: 100%-330%]; acoustic neuroma-digital: 50% odds increase [95% CI: 10%-110%]; acoustic neuroma-cordless: 50% odds increase [95% CI: 4%-100%]; acoustic neuroma-analog >15 year latency: 280% odds increase [95% CI: 4%-900%])**
Pooled analysis of two case–control studies on use of cellular and cordless telephones and the risk for malignant brain tumours diagnosed in 1997–2003 **(2006)**	Hardell *et al.* (33)	Government, NGO, and private	Population-based case-control	All alive 20-80 year-olds diagnosed with brain tumors in 2 regions of Sweden 1997-2003. Frequency (Age-, sex-, region-)matched controls from national registry.	1997-2003	Cases: 905 cases Controls: 2162 controls	Malignant brain tumor incidence	Written questionnaire + supplementary telephone interviews for certain cases/controls. Data on type of phone, years of use, make/model, mean number/ length of daily calls, cumulative use in hours.	Yes	Increased risk from cordless, analog, and digital cell phones for combined malignant brain tumors among highest cumulative use category (2000hrs) – >10 year latency risk in astrocytoma as well. Medium to strong study – large sample, effective exposure assessment, accounting for tumor induction period, and confounding control. Possible recall, interviewer, and sampling bias, very wide confidence interval for many results. Results may not be generalizable outside of these Swedish regions (including US). **(Cumulative 2000+hrs)** **(All brain cancer-analog: 490% odds increase [95% CI: 150%-1300%]; All brain cancer-digital: 270% odds increase [95% CI: 70%-670%]; All brain cancer-cordless: 130% odds increase [95% CI: 50%-260%];** **(Astrocytoma >10 year latency)** **(Analog: 280% odds increase [95% CI: 4%-900%]; digital:**

										280% odd increase [95% CI: 80%-710%]; cordless: 120% odds increase [95% CI: 30%-290%]))
Pooled analysis of case-control studies on malignant brain tumours and the use of mobile and cordless phones including living and deceased subjects **(2011)**	Hardell *et al.* (35)	NGO and private	Population-based case-control	All dead and alive 20-80 year-olds diagnosed with brain tumors in 4 regions of Sweden 1997-2003. Frequency (Age-, sex-, vital status-, and region-)matched controls from national registry. Dead controls from those that had died of malignant diseases and other diseases.	1997-2003	Cases: 1251 cases Controls: 2438 controls	Malignant brain tumors incidence	Written questionnaire + supplementary telephone interviews for certain cases/controls (proxy for dead cases/controls). Data on type of phone, years of use, make/model, mean number/ length of daily calls, cumulative use in hours.	Yes	Risk of astrocytoma higher among highest latency group among mobile and cordless phone users. Low to medium strength study – large sample, accounting for induction period/dose, and control for confounding. Recall and sampling bias are possible. Strength of study significantly hindered by pooling of prospective and retrospective (deaths) case-control studies. Use of dead cases and controls is a noted methodological issue in epi – controlling for confounders is more difficult (alcohol/tobacco specifically for cancer). Study of dead cases/controls also had had exposure assessment via proxy. Results may not be generalizable outside of these Swedish regions (including US). **(Astrocytoma glioma >10 year latency)** **(mobile phone: 170% odds increase [95% CI: 90%-270% increase]; cordless: 80% odds increase [95% CI: 20%-190%])**
Case-Control Study on Cellular and Cordless Telephones and the Risk for Acoustic Neuroma or Meningioma in Patients Diagnosed 2000–2003 **(2005)**	Hardell *et al.* (30)	NGO and private	Population-based case-control	All alive 20-80 year-olds diagnosed with acoustic neuroma or meningioma in 2 regions of Sweden 2000-2003. Frequency (Age-, sex-, and region-)matched	2000-2003	Cases: 413 cases Controls: 692 controls	Acoustic neuroma and meningioma incidence	Written questionnaire + supplementary telephone interviews for certain cases/controls. Data on type of phone, years	Yes	Increased risk of both acoustic neuroma and meningioma from analog, digital, and cordless phones with increased risk from longer latency in acoustic neuroma. Medium strength study – medium sample size, effective exposure assessment, and accounting for induction period/dose. Suffers from biases such as: recall, interviewer, and

				controls from national registry.				of use, make/model, mean number/ length of daily calls, cumulative use in hours.		sampling. Results may not be generalizable outside of these Swedish regions (including US). **(Meningioma-analog 10 year latency: 110% increased odds [95% CI: 10%-330%])** **(Acoustic neuroma-analog: 320% increased odds [95% CI: 80%-900%]; >15 year latency: 740% increased odds [95% CI: 60%-4400%; acoustic neuroma-digital: 100% odds increase [95% CI: 5%-280%])**
Case–control study of the association between the use of cellular and cordless telephones and malignant brain tumors diagnosed during 2000–2003 **(2006)**	Hardell *et al.* (31)	NGO and private	Population -based case-control	All alive 20-80 year-olds diagnosed with malignant brain tumors in 2 regions of Sweden 2000-2003. Frequency (Age-) matched controls from national registry.	2000-2003	Cases: 317 cases Controls: 692 controls	Malignant brain tumor incidence	Written questionnaire + supplementary telephone interviews for certain cases/controls. Data on type of phone, years of use, make/model, mean number/ length of daily calls, cumulative use in hours.	Yes	Analog, digital, and cordless phones all increased risk of malignant brain cancer, with higher risk with longer latency period. Medium strength study – medium sized sample, effective exposure assessment, and characterization of induction period/dose. Suffers from several biases: recall, interviewer, and sampling bias. Results may not be generalizable outside of Swedish regions (including US). **(Analog: 160% increased odds [95% CI: 50%-330%]; Analog >10 yr latency: 250% increased odds [95% CI: 100%-540%]; Digital: 90% increased odds [95% CI: 30%-170%]; Digital >10 yr latency: 260% increased odds [95% CI: 70%-650%]; Cordless: 110% increased odds [95% CI: 40%-200%]; Cordless >10 yr latency: 190% increased odds [95% CI: 60%-420%]))**
Mobile Phone Use and the Risk for Malignant Brain Tumors: A Case-	Hardell *et al.* (34)	NGO and private	Population -based case control	All dead 20-80 year-olds diagnosed with brain tumors in 4	1997-2003	Cases: 346 (75%) cases Controls: 343 cancer controls	Malignant brain tumor incidence	Written questionnaire + supplementar	Yes	Longest latency period and highest use categories were associated with increased risk of malignant brain cancer. Low to

Control Study on Deceased Cases and Controls **(2010)**				regions of Sweden 2000-2003. Frequency (Age-, region-, year of death-, sex-) matched controls from national death registry. Dead controls from those that had died of malignant diseases and other diseases.		and 276 controls with other diseases		y telephone interviews for certain cases/controls. Data on type of phone, years of use, make/model, mean number/ length of daily calls, cumulative use in hours.		medium strength study. Recall, interviewer, and sampling bias are possible. Strength of study significantly hindered by retrospective case-control design. Use of dead cases and controls is a noted methodological issue in epi – controlling for confounders is more difficult (alcohol/tobacco specifically for cancer). Study of dead cases/controls also had had exposure assessment via proxy. Results may not be generalizable outside of these Swedish regions (including US). **(Mobile phone use >10 year latency: 140% odds increase [95% CI: 40%-310%]; mobile phone use >2000hrs: 240% odds increase [95% CI: 60%-610%])**
Mobile phone use and location of glioma: A case–case analysis **(2009)**	Hartikka *et al.* (124)	Government, NGO, and private	Case-case analysis	20-60 year-olds diagnosed with glioma from neurosurgery clinics of Helsinki and Tampere university hospitals in Finland between November 2000 and October 2002. The study sample represents a subset of the Finnish Interphone study.	2000-2002	99 cases of glioma	Glioma incidence	Face-to-face interviews with calculation of distance from tumor and cell phone location. Data on start and end of use, average amount of phone use, cumulative call time, side of head phone I used.	Yes	Only significant odds ratios found for contralateral use. Low strength study – No controls and low sample size but more extensive exposure assessment than other studies and confounder control. Selection bias seems likely – authors note 31 cases originally selected for study were not included in final analysis due to poor health; was already low sample size. Recall and interviewer bias are also possible. Include study in review but note caveats. **(Adjusted Contralateral vs. never/non-regular: 393% odds increase [95% CI: 13%-2000%])**
Mobile phone use and risk of glioma in adults: case-	Hepworth *et al.* (56)	Government and private	Population-based Case-control	Cases aged 18 to 69 years diagnosed with a	2000-2004	Cases: 966 cases Controls: 1716 controls	Glioma incidence	Computer-assisted face-to-face interviews.	No	No increased risk of glioma in short/medium term exposure. Medium to strong study – large sample size, effective exposure

control study **(2006)**				glioma from 1 December 2000 to 29 February 2004 from 5 areas in the UK. Frequency (age, sex, geography) controls from general practitioner database via random algorithm.				Data on network operator, start and stop year, and the number and duration of calls made and received.		assessment. Likely sampling bias due to control ascertainment from general practice list – not representative of total population in UK regions. Interviewer and recall bias - 69 glioma cases were deceased so proxy interviews were done.
Cellular-Telephone Use and Brain Tumors **(2001)**	Inskip *et al.* (21)	No funding	Case-control	Those 18 years and older with glioma, meningioma, or acoustic neuroma at 4 hospitals in Phoenix, Boston, and Pittsburgh between 1994 and 1998, could understand English/Spanish, and resided within 50 miles of hospital. Age-, sex-, race-, and proximity-matched (frequency vs individual not listed) controls were patients who were admitted to the same hospitals for a variety of nonmalignant conditions	1994-1998	Cases: 782 cases Controls: 799 controls	Glioma, meningioma, and acoustic neuroma	Computer-assisted face-to-face interviews. Data on regular use, years of regular use, make/model, duration and number of calls.	No	No association between mobile phone use and brain cancer. Medium strength study – medium to large sample size, effective exposure assessment, and confounder control. Possible interviewer bias due to non-blinding. Some cases were deceased – proxy interviews were conducted, introducing recall bias.
Cellular Telephones and Cancer—a Nationwide	Johansen *et al.* (22)	NGO and private	Retrospective cohort	All cellular telephone subscribers in Denmark 1982-1995	1982-1996	522,914 noncorporate subscribers were linked to the files of the Central	Incidence of all cancers available in Danish	Basic – simply duration of cell phone subscription.	No	No association between length of cell phone use and any cancers. Medium strength study – very large cohort design, long enough follow-up for most

Cohort Study in Denmark **(2001)**						Population Register	Cancer Registry			cancers, recall and observational bias highly unlikely, and all cancers included as endpoints, but poor exposure assessment and exposure classification (how can we be sure the subscriber is the one using the phone?).
Association between number of cell phone contracts and brain tumor incidence in nineteen U.S. States **(2011)**	Lehrer *et al*. (125)	No funding	Ecological	Brain tumor incidence 2000–2004 and population from 19 U.S. states: Az, Co, Ct, De, Id, Ma, Me, Mn, Mt, NC, ND, NM, NY, RI, SD, Tx, Ut, Va, WV and 2007 Cell phone subscriber data from the Governing State and Local Sourcebook	2000-2004, 2007	No listing of sample size – just incidence rates	Brain tumor incidence	Basic – number of cell phone subscribers by state	Yes	Significant correlation between number of cell phone subscriptions and brain tumors in nineteen US states (r = 0.950, P<0.001). Very poor study – confounder control is one redeeming quality. Exposure assessment ineffective, suffers from ecological fallacy, cell phone subscriber data years do not match with brain tumor incidence years, only used data from 19 states.
Mobile Phone Use and the Risk of Acoustic Neuroma **(2004)**	Lonn *et al*. (57)	Governme nt and private	Population -based case control	All persons age 20 to 69 years who were residents of 3 geographical areas covered by the regional Cancer Registries in Stockholm, Goteborg, and Lund. Frequency (age, sex, region) matched controls from regional population registries	1992-2002	Cases: 148 cases Controls: 604 controls	Acoustic neuroma incidence	Computer-assisted in per son interview. Data on regular users, date started/ stopped using, operator, number and duration of calls.	No	No increase in short-term risk but Increased risk of acoustic neuroma associated with mobile phone use of at least 10 years' duration (non-significant). Low to medium strength study – low sample size, but effective exposure assessment and confounder control. Sampling bias (pop-based case-control design), recall bias, selection bias (low participation rate among controls), and interviewer bias are possible. Two cases had exposures filled out via proxy. Results may not be generalizable outside of these Swedish regions (including US).
Long-Term Mobile Phone Use and	Lonn *et al*. (58)	Governme nt and private	Population -based	All glioma/ meningioma cases aged 20–69	2000-2002	Cases: 371 glioma, 273 meningioma	Glioma, meningio	Face-to-face interviews. Data on	No	No association for any amount of phone use or length of use. Low to medium strength study –

Brain Tumor Risk **(2005)**			case-control	years in the geographic areas covered by the regional cancer registries in Umea, Stockholm, Goteborg, and Lund, Sweden from 2000-2002. Non-matched controls from population registry		Controls: 674 controls	ma incidence	regular use, cumulative phone use, number of calls, years of regular use.		medium sample size, effective exposure assessment, and confounder control. Recall bias, sampling bias (pop-based case-control design), no accounting for induction period, interviewer bias (non-blinded), non-matched controls and selection bias (lower participation rate among controls). Results may not be generalizable outside of these Swedish regions (including US).
Adult and childhood leukemia near a high-power radio station in Rome, Italy **(2002)**	Michelozzi *et al.* (11)	No funding	Incidence study	All those in Rome, Italy living within 10km of the Vatican Radio station, with 5 distance bands for comparison	1987-1998 (adults) 1987-1999 (children)	Total: 49,656 residents in study area. 40 cases of adult leukemia and 8 cases of childhood leukemia	Leukemia incidence and mortality	No exposure assessment, but radio station emits 527 KHz-21,850 KHz frequency	Yes	Risk of childhood leukemia was higher than expected for the distance up to 6 km from the radio station and there was a significant decline in risk with increasing distance both for male mortality (p = 0.03) and for childhood leukemia. Low strength study – large sample size, but no exposure assessment, no analysis comparison groups, and no control for confounders, low number of cases, and low statistical power. **(up to 6Km from station for children: SIR of 2.2 [95% CI: 1.0-4.1]**
Handheld cellular telephones and risk of acoustic neuroma **(2002)**	Muscat *et al.* (126)	Government and private	Case-control	Cases were 18 years of age or older with histologically confirmed acoustic neuroma at New York University Medical Center and New York Presbyterian Medical Center 1997-1999. 86 frequency (age-,	1997-1999	Cases: 90 patients Controls: 86 controls	Acoustic neuroma incidence	In-person questionnaire. Data on the number of years of use, minutes/ hours used per month, year of first use, manufacturer, and average monthly bill.	No	No association between cell phones and acoustic neuroma. Low strength – confounder control and effective exposure assessment, but low sample size, interviewer bias (non-blinded interviews), no accounting for induction period, and recall bias. Results may not be generalizable because controls were hospitalized patients.

				sex-, race-, and hospital-) matched in-patient controls with a variety of nonmalignant conditions						
Handheld Cellular Telephone Use and Risk of Brain Cancer **(2000)**	Muscat *et al.* (20)	Government and private	Case-control	All 18-80 year olds in 5 US medical institutions (NYC, Providence, Boston) with primary brain cancer. Frequency (age-, sex-,race-, month of admission-) matched controls of non-malignant in-patients (3 centers) and non-brain cancer malignancies [not leukemia or lymphoma (2 centers)	1994-1998	Cases: 469 brain cancer patients Controls: 422 controls	Brain cancer incidence	In-person questionnaire. Data on the number of years of use, minutes/ hours used per month, year of first use, manufacturer, and average monthly bill.	No	No association between cell phones and brain cancer. Medium strength study – confounder control, effective exposure assessment, and medium sample size. Interviewer bias, no accounting for induction period, recall bias, and selection bias (both use of controls with other cancers and higher participation rate among controls than cases). Results may not be generalizable because controls were hospitalized patients.
Cellular phone use and risk of benign and malignant parotid gland tumors--a nationwide case-control study **(2008)**	Sadetzki *et al.* (59)	Government, private, and NGO	Population-based case control	All those 18 years and older in Israel with parotid gland tumors 2001-2003. Individual (gender-, interview date-, age-, continent of birth-) matched via algorithm from national population registry	2001-2003	Cases: 402 benign and 58 malignant incident cases of parotid gland tumors. Controls: 1266 controls	Parotid tumor incidence	In-person interview. Data on ‘‘regular users’’, make/model, dates of starting and stopping use, number of calls made or received, average duration of calls, and side of head.	Yes	Elevated risk of parotid gland tumors for highest call time and number of calls and finding of dose-response relationship. Medium strength study – large sample size, confounder control, and effective exposure assessment. Recall bias, sampling bias (pop-based case control design), interviewer bias, no accounting for induction period, and selection bias (lower participation rate among controls) Also, did not complete sensitivity analysis to check for overmatching due to individual matching design. Patients were all Jewish and study was conducted in Israel –

										may not be generalizable to other populations. **(Cumulative calls: 58% odds increase [95% CI: 11%-124%]; call time: 49% odds increase [95% CI: 5%-113%])**
Risk of pituitary tumors in cellular phone users: a case-control study **(2009)**	Schoemaker *et al*. (60)	Government, NGO, and private	Population-based case control	All 18-59 year old in Southeast England diagnosed with pituitary cancer 2000-2005. Frequency matched controls on the sex, age, and health-authority distribution of the total group of cases via population registry.	2000-2005	Cases: 291 cases Controls: 630 controls	Pituitary cancer incidence	Face-to-face interviews (2 controls interviewed over phones). Data on make/model, regular use, start and end date, average number of calls per day, average amount of use.	No	No association between cell phone use and pituitary tumors. Medium strength study – medium sample size, confounder control, and effective exposure assessment. Recall bias, sampling bias (pop-based case-control design), interviewer bias (non-blinded interviews), low participation rate overall, no accounting for induction period, and lower among controls (selection bias). Results may not be generalizable outside study area.
Use of wireless phones and the risk of salivary gland tumours: a case–control study **(2012)**	Soderqvist *et al.* (38)	Government and NGO	Population-based Case-control	Patients with salivary gland tumors in 9 Swedish counties 2000-2003. Controls age-, county-, sex-matched from national registry (individual vs. frequency method not listed)	2000-2003	Cases: 69 cases Controls: 262 controls	Salivary gland tumors	Questionnaire. Data about current and previous use of wireless phones (e.g. cumulative number of hours, time since first use, the ear mostly used), including mobile phones as well as cordless phones.	No	No increased risk of salivary gland tumors from wireless phones. Low strength study – small sample size, confounder control, unclear exposure assessment (poorly explained). Recall bias, sampling bias (pop-based case-control design), possible interviewer bias (does not list whether face-to-face or not. Results may not be generalizable outside study area.
Mobile phone use and acoustic neuroma risk in Japan **(2006)**	Takebayashi *et al*. (61)	Government	Population-based case control	Hospitalised acoustic neuroma cases aged 30–69 years from 30 Tokyo	2000-2004	Cases: 101 acoustic neuroma cases Controls: 339 controls	Acoustic neuroma incidence	Computer-assisted in-person interviews. Data on	No	No association, even among long time users of mobile phones and high call times. Low to medium strength study – low sample size, confounder control,

				neurosurgery departments 2000-2004. Individually matched controls (age, sex, residency) from random digit dialing of population.				regular users, make/models , start and stop dates, the average duration and frequency of calls		effective exposure assessment. Recall bias, sampling bias (pop-based case-control design), and interviewer bias possible. Results may not be generalizable outside of study area. Overmatching due to individual matching design is possible.
Cancer Incidence near Radio and Television Transmitters in Great Britain I. Sutton Coldfield Transmitter **(1997)**	Dolk *et al*. (12)	Government	Retrospective cohort	Adult and child cancer incidence data geocoded to address at diagnosis were examined from 1974 to 1986 within 10km of a high power radio/ TV transmitter in Birmingham, UK. National "expected" cancer rates as comparison group.	1974-1986	703 cancer cases in 1974-1986	All common cancers and leukemia incidence	None – simple distance from 100 kHz to 300 GHz and 30 MHz to 1 GHz high power transmitter	Yes	No increased risk of cancers among children – 83% [22%=174%] increase in leukemia risk in adults that live within 2km of base station. Low strength study in context of RFR-cancer relationship – medium sample size, cohort design, some control for confounding, but some of the exposure frequencies are outside of what children would experience in a school environment, no mention of correcting for cancer induction period, authors note their O/E ratio estimates are biased, exposure assessment is not individualized and generally non-existent, distance/dose-response is not consistent, and analyses not corrected for other RFR exposure.
Cancer Incidence near Radio and Television Transmitters in Great Britain II. All High Power Transmitters **(1997)**	Dolk *et al*. (13)	Government	Retrospective cohort	Adult and child cancer incidence data geocoded to address at diagnosis were examined from 1974 to 1986 within 10km of 20 high power radio/ TV transmitters throughout England, Ireland,	1974-1986	3,305 adult leukemia cases, 8,307 bladder cancer cases, and 1,540 skin melanoma cases.	Leukemia, bladder cancer, and skin melanoma incidence	None – simple distance from transmitters with at least 500 Kw frequency	Yes	No increased risk of leukemia, bladder cancer, or skin melanoma among children - very weak increase in risk of adult leukemia of those within 10Km of transmitters – 3%[0%-7%]. Medium strength study – large sample size, some confounding control, but some of exposure frequencies outside of what children would experience in a school environment, no correction for

				and Scotland.. National "expected" cancer rates as comparison group.						cancer induction period, authors note their O/E ratio estimates are biased, exposure assessment is not individualized and generally non-existent, distance/dose-response is not consistent, and analyses not corrected for other RFR exposure. Authors note their 2 1997 studies taken together show little evidence of an effect
Childhood leukemia in relation to radio frequency electromagnetic fields in the vicinity of TV and radio broadcast transmitters **(2008)**	Merzenich *et al.* (10)	Government	Population-based case control	West German municipalities near high-power radio and TV broadcast towers, including 16 AM and 8 FM transmitters w/ at least 200Kw frequency. Cases aged 0-14 from cancer registry. Individual (age, sex, transmitter area) matched controls from population registry	1984-2003	1,959 cases and 5,848 controls.	Childhood leukemia incidence	Individual exposure to RFR 1 year before diagnosis estimated with modeling via location of residence and field strength of transmitter	No	No elevated odds of leukemia among population of children living near high power radio/ TV transmitters. Medium strength study – large sample size, large geographic coverage, population-based design, but possible sampling bias, no confounder control – key limitation, individual matching could introduce overmatching issues, and exposure assessment is estimated crudely.
A population-based case-control study of radiofrequency exposure in relation to childhood neoplasm **(2012)**	Li *et al.* (8)	Government	Population-based case-control	Cases were Taiwanese children 15 years and younger with any neoplasm from 2003-2007. Matched (age) controls were selected from insurance rolls representing all Taiwanese children without neoplasms. Seems to be individual matching.	2003-2007	2,606 cases and 78,180 controls	All neoplasms	Exposure was quantified by using location of mobile phone base stations and location of each subject and years of residence at that location	Yes	Weak association between higher average power density of RFR and all neoplasm incidence, but not separately for leukemia or brain cancer. Medium strength study – large sample size, population-based design, large geographic coverage, and confounder control, but sampling bias is possible, crude classification of exposure, poor control of non-transmitter RFR confounding, and authors note some neoplasms may be misclassified.

Radio-frequency radiation exposure from AM radio transmitters and childhood leukemia and brain cancer **(2007)**	Ha *et al.* (7)	Government	Case-control	South Korean children under 15 diagnosed with leukemia or brain cancer between 1993-1999 from 14 hospitals. Individually matched (age, sex, diagnosis year) controls from children with respiratory diseases in same 14 hospitals.	1993-1999	1,928 leukemia patients, 956 brain cancer patients and 3,082 controls	Childhood leukemia and brain cancer	Exposure quantified via validated model using location of 31 transmitters and 49 antennas in South Korea with at least 20Kw frequency and residence of cases and controls. Separation into quartiles of exposure.	Yes	Association between close residence to AM transmitters (2Km) and childhood leukemia (some are much lower than frequencies in schools) + association between overall transmitter/ TV freq and lymphoctic leukemia and some dose-response. Medium strength study – large sample size (enough for moderate statistical power), some confounding control, validated geography-based exposure assessment, but poor control for individual RFR exposures = misclassification bias, frequencies of exposures do not directly match that of U.S. schools, and non-linear dose-response. **(Close residence (2Km) vs. 20Km for all leukemias: 115% [0%-3.67%] odds increase; lymphocytic leukemia: 39% [4%-86%] odds increase; 2nd & 3rd quartile of exposure: 59% [19%-111%] odds increase)**
Investigation of increased incidence in childhood leukemia near radio towers in Hawaii: preliminary observations **(1994)**	Maskarinec *et al.* (9)	None	Case-control	Case defined as a child under 15 yr of age who was diagnosed with acute leukemia between 1979 and 1990 and had resided in census tracts 96, 97, or 98 in Hawaii before diagnosis. Matched (age, sex) controls from patient file of local health center.	1979-1990	12 cases of leukemia and 48 controls	Childhood leukemia incidence	Unblinded telephone interviews of parents for covariates, including x-ray exposure. No direct quantification of RFR exposure – simply all cases within 2.6 miles of radio towers.	Yes	The cluster of 12 cases produced results that showed excess leukemia cases in the area surrounding radio towers. However, the case-control study had non-significant results. Low strength study – poor control for confounding (specifically SES, other RFR, ionizing radiation beyond x-rays), significant issues with exposure misclassification, small sample size (too small for effect found to be considered stable), and selection bias noted as possibility in case-control.

										(SIR: 2.09 [1.08-3.65])
Mobile phone use and the risk of skin cancer: a nationwide cohort study in Denmark **(2013)**	Poulsen *et al.* (24)	Government and private	Nationwide prospective cohort study	All cases of skin cancers diagnosed in Denmark from 1987-1995 from the Danish Cancer Registry linked to private mobile phone subscriptions. Followed until 2007	1987-2007	355,701 private mobile phone subscribers in Denmark	Skin cancer incidence	Mobile phone subscriptions for individuals. Measured both existence and length of mobile phone subscriptions	No	No relationship found between mobile phone subscriptions and skin cancer incidence. Medium strength study – large sample, but poor controls for confounding, serious problems with exposure classification, as subscriptions is not effective to quantify total exposure to RFR.

notable differences in power output between the CDMA standard (widely implemented in US) and the GSM standard.[1]
1. Kelsh, M.A; Shum, M.; Sheppard, A.R.; Mcneely, M.; Kuster, N.; Lau, E.; Weidling, R.; Fordyce, T.; Kuhn, S.; Sulcer, C. (2011). "Measured radiofrequency exposure during various mobile-phone use scenarios". *Journal of Exposure Science and Environmental Epidemiology*. **21**: 343–354. doi:10.1038/jes.2010.12.

CDMA: https://en.wikipedia.org/wiki/Code-division_multiple_access
GSM: https://en.wikipedia.org/wiki/GSM
Comparison: https://en.wikipedia.org/wiki/Comparison_of_mobile_phone_standards

Something else that should be noted about brain cancer studies in the mid-1990s: "Another essential problem is related to the long induction periods and latencies of tumors in the head and neck region. Mobile phone use that was insignificant before the mid-1990s could not be studied with respect to its influence during induction period because, in almost all users, malignant transformation has likely occurred long before exposure to mobile phones commenced."

Table 2: Cancer studies: review articles

Study Name **(Year)**	Authors	Funding Source	Study Type	# of Epidemiology Studies Reviewed	Endpoint Examined	Issues in studies + Types of Bias Identified	Conclusions by Review Authors + Opinion of Reviewer	If meta-analysis, overall statistical effect
Mobile phone radiation and the risk of cancer; a review **(2008)**	Abdus-Salam *et al*. (127)	No funding	Non-systematic Review	Unclear	All cancers	Authors note that exposure assessment is an issue, especially because the biological mechanism of action is weakly understood.	No significant increase in risk of cancer among mobile phone users. Non-systematic review and does not identify possible biases effectively.	N/A
Epidemiological risk assessment of mobile phones and cancer: where can we improve? **(2006)**	Auvinen *et al*. (128)	Government and NGO	Non-systematic Review	15	All cancers	Major uncertainties in exposure assessment, unknown biological mechanism, and lack of acceptable comparison group (everyone is exposed to mobile phone RF and similar frequencies). Authors note that detailed exposure history is required vs asking 'have you used a cell phone?'. All 15 studies reviewed (all epi studies up to late 2005) are noted as having fairly crude exposure assessment. Also, phone make/model not noted enough – different phones have different frequencies and standards (i.e. GSM/CDMA). Recall bias is major issue in most of released studies. Other information bias related to likelihood of reporting phone use.	No conclusion provided by authors. Non-systematic review, but deeply covers biases and strengths/weaknesses of published studies.	N/A
Electromagnetic Fields and Cancer: The Cost of Doing Nothing **(2010)**	Carpenter (129)	No funding	Non-systematic Review	3	Glioma and acoustic neuroma	None	Author notes they believe RF is possible human carcinogen and does not consider all possible studies in review. Lack of identification of weaknesses of studies.	N/A
Human disease resulting from exposure to electromagnetic fields **(2013)**	Carpenter (130)	No funding	Non-systematic Review	~10 related specifically to cancer	All cancer	None	Author notes they believe RF is possible human carcinogen and does not consider all possible studies in review. Lack of identification of weaknesses of studies.	N/A

Cell phones and glioma risk: a review of the evidence **(2012)**	Corle *et al*. (131)	Government	Non-systematic Review	~12-15 (inexact due to listing of multiple Interphone studies	Glioma	Authors note issues of recall bias in case-controls, unclear biological mechanism, and wide-ranging inconsistent results in case-controls. Use of cordless phones not considered in Interphone studies, which could have hindered exposure assessment. Very difficult to compare and pool case-controls due to differing designs and tumor latency periods.	There is no definitive answer due to limitations in study design. Authors note cohort studies are needed. Effective review of methodological problems.	N/A
Recent Advances in Research on Radiofrequency Fields and Health: 2004–2007 **(2009)**	Habash *et al*. (132)	No funding	Systematic Review	21	Acoustic neuroma, glioma, meningioma, and tumors of the parotid gland.	Authors note issues with recall bias in case-control participants and short follow-up periods. Generally note issues in exposure assessment.	Unclear, no evidence of increases in benign head and neck tumors, but long-term use may result in brain cancers. More research needed. Highly quality review overall, but not focused specifically on cancer.	N/A
Using the Hill viewpoints from 1965 for evaluating strengths of evidence of the risk for brain tumors associated with use of mobile and cordless phones **(2013)**	Hardell *et al*. (133)	NGO	Review of Causation	13	Brain tumors	None – this work mostly argues in favor of a causal relationship between phones and brain cancers by analyzing Bradford Hill's criteria	Authors argue that RFR/ glioma and acoustic neuroma relationship is causal based on Hill criteria. They note strength, consistency, specificity, temporality, and biologic gradient as evidence. At least 2 of these causal subjects of evidence – consistency and biologic gradient are not true when considering all available studies.	N/A
Radio frequency electromagnetic fields: Cancer, mutagenesis, and genotoxicity **(2003)**	Heynick *et al*. (134)	Government	Non-systematic review	100+	All cancers	Most consistent issue presented throughout is a lack of focus on statistical power – some effects found are not as statistically significant as authors seem to profess. Much larger sample sizes are also noted as a need.	Authors noted that weight of evidence indicates no RFR cancer effect in both occupational settings and with mobile phone use.	N/A
Mobile phones and health: A literature overview **(2005)**	Karger *et al*. (135)	None	Review of reviews & expert panels	6 (epi reviews) + 4 occupational studies + 9 epi cancer studies	All cancers	Authors note that detailed data on individual exposures are lacking and some of the studies are biased – no causal implications should be drawn. Noted that one of the key findings indicating association from Hardell (2000) has	No association between mobile phone radiation and cancer in epidemiology studies.	N/A

						been identified as possibly due to random chance and over-adjustment/ overfitting of models. Some studies criticized for not checking for recall bias and exposure misclassification.		
Epidemiological Evidence for a Health Risk from Mobile Phone Base Stations **(2010)**	Khurana *et al*. (136)	None	Systematic review	10 total but 3 specifically for cancer	Generalized cancer incidence	In 2 of the cancer studies, the latency period is too short to make any conclusion on the effect of RFR base stations on cancer incidence.	Authors note increased cancer incidence within 500 meters of mobile phone base stations. It is not clear how they arrive at this conclusion based on their assessment of short latency periods.	N/A
Cell phones and tumor: still in no man's land **(2009)**	Kohli *et al*. (137)	None	Systematic review (but does not list systematic methods)	42	All cancers	Multiple issues noted in existing research: few studies assessed risk of cell phone use >10 years, reliance on self-report data/ retrospective interviews, exposure to RFR varies with different phone models, use of hands-free devices, whether calls were made from rural or urban, virtually impossible to eliminate exposure to RFR from other sources for studying the isolated effects of cell phones. Note that future studies should not be done using analog phones because they emit RFR in bursts instead of continuous like GSM (what cell phones use currently)	The association between RFR and cancer is inconclusive. This review digs less deeply into bias and misclassification of exposure that is rampant in the literature. Other reviews look much more at the methodology of studies.	N/A
Recent Advances in Research on Radiofrequency Fields and Health: 2001–2003 **(2007)**	Krewski *et al*. (138)	None	Non-systematic review	14 (epidemiology cancer studies), 4 review studies	All cancers	Author notes limited duration of mobile phone use by many target populations, the lack of rigorous exposure measures, and the possibility of recall bias and response error.	Author does not make final determination of views on relationship, as the review covers many outcomes. Based on what's presented, it seems like they view the study results as inconclusive.	N/A
The Controversy about a Possible Relationship between Mobile Phone Use and Cancer **(2009)**	Kundi *et al*. (139)	None	Meta-analysis (focus on brain cancer)	25 brain tumor studies	Brain tumors	Major issues noted include not taking into account the long induction period of head/ neck tumors, issues in exposure measurement and classification, and selection of which cancer outcomes to study so far has been arbitrary instead of attempting to identify which types of tissue may be susceptible to RFR. Recall bias, misclassification bias, and selection bias noted as particular problems.	Conclusion of author: "overall evidence speaks in favor of an increased risk, but its magnitude cannot be assessed at present because of insufficient information on long-term use." One of the more in-depth	**Combined OR for Glioma:** **1.5 (1.2-1.8); no other endpoints are statistically significant**

							reviews completed to date.	
Are Mobile Phones Harmful? **(2000)**	Blettner and Berg (140)	None	Non-systematic review	3 (epidemiologic cancer studies)	All cancers	Authors simply note inconsistent results, but no comments on methodology.	Based on limited evidence, authors note that the evidence was inconclusive as of the year 2000.	N/A
Cancer epidemiology update, following the 2011 IARC evaluation of radiofrequency electromagnetic fields (Monograph 102) **(2018)**	Miller *et al*. (141)	Government	Non-systematic review	~25	All cancers	Authors note misclassification bias, recall bias, and selection bias as rampant throughout the literature.	Does not represent all relevant studies or highlight method deficits in presented studies. For example, review provides extensive comments on some studies but not others. Also, excludes the large Rothman *et al*. cohort study showing no effect.	N/A
Review on health effects related to mobile phones. Part II: results and conclusions **(2011)**	Moussa (142)	None	Systematic review	~13 cancer studies	All cancers	Authors agree with review by Kundi, where no evidence-based exposure metrics exist for RFR, leading to unreliable risk estimates. Selection bias, recall bias, and misclassification bias are a problem in the literature.	Author's view: "the body of literature indicating no increased risk of cancer in conjunction with cell phone use is larger and more diverse than the results of existing studies indicating an increased risk of cancer."	N/A
Mobile Phone Radiation: Physiological & Pathophysiologcal Considerations **(2015)**	Nageswari (67)	None	Non-systematic review	14 cancer studies	All cancers	Some issues noted in getting unexposed controls, follow up of the cohorts, actual dose measurement for exposure assessment in case-control studies, inaccuracy, recall bias and selective non response in recall of phone use by mobile phone users, long induction times, long latencies (the effects we observe now are of analogue phones that are no longer used). Also, rarity of observed malignancies, variable ways of using the phone by the user (e.g., left or right ear, headsets/speaker/blue tooth).	No final view about cancer is presented.	N/A
Review of Published Literature between 2008 and 2018 of Relevance to	U.S. Food and Drug Administration (44)	Government	Systematic review	69 epidemiology cancer studies	Focus on brain tumors, acoustic neuroma,	Review notes limitations in measuring RFR exposure, strong misclassification biases, poor evidence based on U.S. studies (different RFR standards), no overall risk increase in cancer	Authors conclude that existing evidence is insufficient to suggest that use of cell phones can is independent factor	One of the best reviews completed. Examination of nearly all

Radiofrequency Radiation and Cancer **(2020)**					vestibular schwannoma, parotid gland, skin cancers, leukemia,	incidence + evidence of subgroup effects, selection bias in some studies.	influencing incidence of intracranial and some other tumors in the general population. Any existing risk is extremely low compared to both the natural incidence of the disease and known controllable risk factors."	relevant studies.
Epidemiology of Gliomas **(2015)**	Ostrom *et al*. (143)	None	Non-systematic review	7 for mobile phone exposure	Glioma	No specific biases or study issues noted.	"The scientific evidence used to produce the 2011 IARC report, as well as the scientific evidence reported since its publication does not support a significant association between use of cellular phones and risk of glioma."	Few studies reviewed in this review; largely rely on IARC monograph.
Electromagnetic fields (EMF): Do they play a role in children's environmental health? **(2007)**	Otto *et al.* (144)	None	Non-systematic review	2 for high frequency RFR (radio, TV, etc. frequency) & mobile phone studies	All cancers, specifically note leukemia and brain tumors	No specific biases or study issues noted.	General opinion of the authors is that the evidence is inconclusive. Very little examination of the evidence.	N/A
Systematic review of wireless phone use and brain cancer and other head tumors **(2012)**	Repacholi *et al*. (45)	None	Systematic review and meta-analysis	55 epidemiology studies	Brain and head tumors	Recall bias, selection bias, and misclassification bias noted as possibilities. Noted that no validation studies have been completed in the Hardell group and authors postulate that systematic error is possible.	Authors find that none of the Hill criteria support a causal relationship between wireless phone use and brain cancers or other tumors in the areas of the head that most absorb the RF energy from wireless phones." Insufficient data to make determination of risks for children and those with 10+ years of exposure. Well-sourced review.	**Glioma, meningioma, acoustic neuroma: No association in meta-analysis ORs**
Cancer risks related to low-level RF/MW exposures, including cell phones **(2013)**	Szmigielski (145)	None	Non-systematic review	~15 epidemiology studies	All cancers	Authors notes that many studies have invalid assessment of the RFR exposure (including use of years / cell phone subscriber rolls, which are very inaccurate at estimating actual individual dose) and recall bias.	Authors find that studies do not show that mobile phones can increase considerably the risk of cancer (lack of solid	Authors did not review all available articles.

							biological mechanism + brain cancer rates not going up significantly).	
How dangerous are mobile phones, transmission masts, and electricity pylons? **(2005)**	Wood (146)	None	Non-systematic review	21 studies of mobile phones and base stations	All cancers	Issues with misclassification bias and determining individual dosage over time. Little overall discussion of methodological issues.	No consistent associations between human cancers and mobile phone/ base stations.	N/A
Epidemiological studies of radio frequency exposures and human cancer **(2003)**	Elwood (147)	None	Non-systematic review	~50 studies on target frequencies	All cancers	Poor explanation of methodological issues – mainly mentions generalized exposure classification problems.	Authors conclude that the study results fall do not support cancer causation of RFR exposures.	N/A
Cellular phone use and brain tumor: a meta-analysis **(2008)**	Kan *et al.* (148)	None	Systematic review and meta-analysis	9 studies	Brain tumors	Authors note that studies utilized for their meta-analysis have possible selection bias, information bias, confounding and misclassification of exposure, which should be considered in interpreting their M-A results. Very little explanation outside of this.	Authors conclude that there is no overall increased risk of brain tumors among cellular phone users. Potential elevated risk of brain tumors after 10+ years of cell phone use should be confirmed by future studies."	**No association in overall use. Pooled analysis for 10+ year users: OR of 1.25 [1.01-1.54]**
Cell phones and brain tumors: a review including the long-term epidemiologic data **(2009)**	Khurana *et al.* (149)	None	Systematic review and meta-analysis	11 studies	Brain tumors (10+ years of latency	Generally, poor review of the methodological problems. Recall bias and misclassification bias are mentioned, but mostly explained away as non-issues, which is not how other review authors see these.	Conclusion: " there is adequate epidemiologic evidence to suggest a link between prolonged cell phone use and the development of an ipsilateral brain tumor." Review did not include all relevant studies.	**Glioma: OR of 1.9 [1.4-2.4]** **Acoustic neuroma: OR 1.6 [1.1-2.4]**
Meta-analysis of mobile phone use and intracranial tumors **(2006)**	Lakhola *et al.* (150)	None	Systematic review and meta-analysis	12 studies	Brain and other intracranial tumors	Authors note that some of the studies released suffer from substantial random error and recall bias. Significant differences in exposure classification from study to study – likely why there is so much inconsistency.	Authors find evidence does not indicate a substantially increased risk of intracranial tumors from mobile phone use for a period of at least 5 years.	**No association in overall pooled estimates or separately for glioma, meningioma, and acoustic neuroma**

Mobile phone radiation causes brain tumors and should be classified as a probable human carcinogen (2A) **(2015)**	Morgan *et al.* (151)	None	Non-systematic review	~25 studies (mostly case-control)	Brain tumors	Poor discussion of the biases surrounding the case-control studies that form the backbone of this review. Overall, relatively poor discussion of methodology.	Authors concluded RF fields should be classified as Group 2A probable human carcinogen under the criteria used by the International Agency for Research on Cancer."	This review was not inclusive of all relevant publications.
Mobile Phone Use and Risk of Tumors: A Meta-Analysis **(2009)**	Myung *et al.* (43)	None	Systematic review and meta-analysis	23 case-control studies	All tumors	Interestingly, this meta-analysis has a measure of "methodologic quality," which is based on the Newcastle-Ottawa Scale (NOS) for case-control studies – authors arbitrarily set 7 as the score needed to be considered "high quality" – unclear why this was done. Hardell studies make up 7 of the 10 "high methodologic quality" studies. It is important to note that this scale misses some sources of bias/error – like exposure classification.	Authors find "possible evidence linking mobile phone use to an increased risk of tumors." Only consistent effect w/ 10+ years of latency. Also, one of the M-A ORs showed a protective effect. Based solely on case-control studies	**10+ years of exposure: OR of 1.18 [1.04-1.34] (13 studies)** **No overall effect in studies of malignant and benign tumors**
Review of four publications on the Danish cohort study on mobile phone subscribers and risk of brain tumors **(2012)**	Soderqvist *et al.* (152)	None	Non-systematic review	4 studies	Brain tumors	This paper serves as a methodological "challenge" to the results of the largest cohort study done on cell phones and brain tumors. Very few methodological explanations.	Conclusion: large Danish cohort study has methodological problems and concerns about funding from telecoms. Seems to not be inclusive of all relevant studies.	N/A
Children's health and RF EMF exposure. Views from a risk assessment and risk communication perspective **(2011)**	Wiedemann and Schutz (153)	Private	Non-systematic review	13 childhood cancer epidemiology studies	Leukemia and brain tumors	Authors note that many of the studies they review on childhood cancer outcomes suffer from the ecological fallacy. No methodological issues of case-controls are presented in this review.	Authors concluded that available evidence does not support association between RFR exposure and brain cancer or leukemia in children. Authors noted many studies showing a relationship between childhood leukemia and RFR are ecological, not lending much credence to an argument for causation.	N/A

Table 3. Noncancer Toxicity

Study Name	Authors	Funding Source	Study Type	Study Population	Sample Size	Endpoint Examined	Exposure Assessment	Adverse Effect	Comments	My comments
Effect of cell phone use on semen analysis in men attending infertility clinic: an observational study	Agarwal *et al.* (2008) (91)		Observational	Healthy American males (mean age, 32 years)	361	Sperm characteristics	Cell phone use	Yes	Reported cell phone use duration associated with decreased sperm count, motility, viability, morphology.	Self-reported cell phone use; No RFR measurement
Epidemiology of Health Effects of Radiofrequency Exposure	Ahlbom *et al.* (2004) (154)		Review			Reproductive outcomes	RFR exposure	No	Authors concluded that problems of exposure assessment temper any conclusions on reproductive outcomes, and no adverse effects of RFR substantiated.	
Male fertility and its association with occupational and mobile phone towers hazards: An analytic study	Al-Quzwini *et al.* (2016) (155)		Experimental	Healthy Iranian couples	200	Semen analysis	Environmental exposure to mobile phone towers	Yes	Proximity to mobile phone towers associated with poorer quality of semen and lower fertility rate	No RFR measurement. Highly subjective approach too.
The Effect of Electromagnetic Radiation due to Mobile Phone Use on Thyroid Function in Medical Students Studying in a Medical College in South India	Baby *et al.* (2017) (156)		Cross-sectional	Healthy Indian medical students (mean age, 20 years)	83	Thyroid dysfunction	RFR exposure based on SAR values of the phone model and reported duration of cell phone use	Yes	Significant relationship between estimated RFR exposure and increase in thyroid-stimulating hormone. High variability in response for a small cohort.	Many confounders unaccounted for. No RFR measurement. Estimate of RFR exposure highly uncertain.
Cellular Phone Irradiation of the Head Affects Heart Rate Variability Depending on Inspiration/Expiration Ratio	Béres *et al.* (2018) (82)	Medical Faculty of the University of Pecs, Hungary	Cross-sectional	Healthy Hungarian adults with the mean ages of 25.2 with the ranges of 21 to 32 years old	20	Heart rate asymmetry and heart rate variability	1800 MHz from GSM cellular phone	Mixed	Acute effects on autonomic nervous system	

Are Thyroid Dysfunctions Related to Stress or Microwave Exposure (900 MHz)?	Bergamaschi *et al.* (2004) (157)		Cross-sectional	Healthy Italian adults (mean, 28 years old)	2,598 employees	Thyroid dysfunction	Self-reported mobile phone use	Mixed	No effect on low TSH of mobile phone use. Indication of lower TSH levels in small group of workers with >33 hours talk/month	Many potential confounders unaccounted for.
Effects on auditory function of chronic exposure to electromagnetic fields from mobile phones	Bhagat *et al.* (2016) (70)		Cross-sectional	Healthy Indian students (mean age, 23 years)	40	Auditory system	Mobile phone use	No	No adverse effect on the auditory system	Compare dominant ear for cell phones to non-dominant ear
Changes in Tympanic Temperature During the Exposure to Electromagnetic Fields Emitted by Mobile Phone	Bortkiewicz *et al.* (2012) (158)		Experimental	Healthy Polish adults (mean age, 22 years)	10	Tympanic temperature via probe close to aural canal membrane in ear opposite one in contact with phone	60 minutes intermittent or continuous exposures to RFR generated by mobile phone (frequency 900 MHz, SAR 1.23 W/kg)	Yes	small changes in tympanic temperature monitored on different days for sham vs exposed	
Uncertainty Analysis of Mobile Phone Use and Its Effect on Cognitive Function: The Application of Monte Carlo Simulation in a Cohort of Australian Primary School Children	Brzozek *et al.* (2019) (159)	National Health and Medical Research Council, Australia	Longitudinal	Healthy Australian students; mean age, 10 years	412	Cognitive functions	Mobile phone use	No	Cognitive functions of school students not affected by mobile phone use	Used survey to estimate cell phone use. Subject to recall bias
A cross-sectional study of the association between mobile phone use and symptoms of ill health	Cho *et al.* (2016) (160)	Korean CDC collaboration	Cross-sectional	Healthy Korean adults (median age, 57 years)	532	Symptoms of ill health (general health)	Reported mobile phone use	Mixed	Mobile phone call duration not associated with stress, sleep, cognitive function, or depression. Associated with headache severity.	Study did not measure RFR exposure.
Effects of short-term radiation	Choi *et al.*	Korean government	Experimental	Healthy Korean adults	52 (26 adults and	Heart rate variability	RFR exposure at 1950 MHz	No	Short-term RFR exposure had no effect on	

emitted by WCDMA mobile phones on teenagers and adults	(2014) (80)			(mean age, 28 years) and teenagers (mean age, 15 years)	26 teenagers)	and respiratory rate			autonomic nervous system	
Intraoperative observation of changes in cochlear nerve action potentials during exposure to electromagnetic fields generated by mobile phones	Colletti *et al.* (2011) (73)		Experimental	Italian adults with definite unilateral Meniere's disease whom received medical therapy for at least 6 months (50-54 years old)	13 (7 in experimental group and 5 in control group)	Cochlear nerve	RFR exposure	Yes	RFR exposure increased latency of cochlear nerve compound action potentials during 5-minute exposure and for 5 minutes after	Exposures done during craniotomy which exposes the brain tissue. Intact skulls might prevent this observation.
Electromagnetic fields and EEG spiking rate in patients with focal epilepsy	Curcio *et al.* (2015) (161)		Experimental	Italian adults diagnosed with symptomatic focal epilepsy (ages, 21-79 years)	12	Brain electrical (EEG)	RFR exposure	No	No RFR effect on risk of seizures in symptomatic focal epilepsy	
Evaluation in humans of the effects of radiocellular telephones on the circadian patterns of melatonin secretion, a chronobiological rhythm marker	de Seze *et al.* (1999) (162)	Motorola Inc.	Experimental	Healthy French males, 20-32 years old	37	Melatonin secretion	Exposure to 900 MHz and 1800 MHz	No	Melatonin circadian profile not disrupted with RFR exposure compared to pre-exposure	
Effects of short and long term electromagnetic fields exposure on the human hippocampus	Deniz *et al.* (2017) (163)		Experimental	Healthy US female medical students aged 18 to 25 years	60	Hippocampus	Cell phones use	Mixed	Longer daily phone use risk for lack of attention/ concentration, but no effect on size of hippocampus	
An Investigation on the Effect of Extremely Low Frequency Pulsed Electromagnetic	Fang *et al.* (2016) (81)	RMIT University, Australia + Shanghai University	Experimental	Healthy Australian adults aged 20 to 38 years	22	Heart	RFR exposure	Yes	Short term exposure to RFR associated with small change in ECG RR intervals, but not in several other ndicators.	

Fields on Human ECGs										
A Prospective Cohort Study of Adolescents' Memory Performance and Individual Brain Dose of Microwave Radiation from Wireless Communication	Foerster *et al.* (2018) (77)	Swiss NSF, Euro Comm. Seventh Framework Programm – GERONIMO project	Prospective cohort	Healthy Swiss adolescents (12-17 years old; mean, 14 years)	895	Memory performance (brain)	Mobile phone use	Yes	Mobile phone use may affect figural memory in regions most exposed during mobile phone use	Very small statistically significant effects; very large difference between reported phone use and phone use records; many group comparisons not significant.
The influence of handheld mobile phones on human parotid gland secretion	Goldwein & Aframian (2010) (164)		Cross-sectional	Healthy Israeli adults (ages 19-33 years; mean, 27 years)	50	Parotid gland - saliva secretion rate and protein concentrations	Mobile phone use	Yes	Increase in mobile phone use related to elevated salivary rate and less protein secretion	
Exposure to wireless phone emissions and serum β-trace protein	Hardell *et al.* (2010) (165)	Cancer-och Allergifonden, Cancerhjalpen and Orebro University Hospital Cancer Fund	Cross-sectional	Healthy Swiss adults (18-30 years old)	62	ß-trace protein	RFR exposure of 890 MHz	No	No significant change of ß-trace protein between the exposure and the control group	
Effects of electromagnetic radiation of mobile phones on the central nervous system	Hossmann & Hermann (2003) (85)		Review	Adults		Central nervous system	RFR exposure	No	Little evidence of RFR effect on functional and structural integrity of brain. Mostly thermal effects	
Exposure to pulse-modulated radio frequency electromagnetic fields affects regional cerebral blood flow	Huber *et al.* (2005) (166)	Swiss and international research organizations	Cross-sectional	Healthy Swiss adults (mean age, 22.5 years)	12	Cerebral blood flow	RFR exposure	Yes	Association with small changes in cerebral blood flow	

Association of personal exposure to power-frequency magnetic fields with pregnancy outcomes among women seeking fertility treatment in a longitudinal cohort study.	Ingle *et al.* (2020) (89)	National Institutes of Environmental Health Sciences; Electric Power Research Institute.	Prospective cohort	Women recruited from 2012 to 2018, who underwent in vitro fertilization (IVF	119	Pregnancy outcomes	Women wore personal RFR exposure monitors for up to 3 consecutive 24-hour periods separated by several weeks.	No	Personal MF exposures not associated with fertility treatment outcomes or pregnancy outcomes.	
Mobile phone use for 5 minutes can cause significant memory impairment in humans	Kalafatakis *et al.* (2017) (108)		Cross-sectional	Healthy Greek adults and adults with mild cognitive impairments	84	Memory (brain)	Use of mobile phone for 5 minutes	Yes	Mobile phone use has negative effect on working memory	Cannot deduce anything about RFR. Reported changes could be due to distraction.
Assessment of oxidant/antioxidant status in saliva of cell phone users	Khalil *et al.* (2014) (167)	Yarmouk University	Cross-sectional	Healthy Jordan male adults (mean age, 22 years)	12	Salivary gland	Mobile phone use (1800 MHZ)	No	No relation between mobile phone use and changes in salivary oxidants/antioxidants	
Effects of radiation emitted by WCDMA mobile phones on electromagnetic hypersensitive subjects	Kwon *et al.* (2012) (83)	Korean government	Cross-sectional	Korean adults with/out self-reported EMF hypersensitivity (mean age, 30 years)	37 (17 with electromagnetic hypersensitivity and 20 without)	Central nervous system	Exposure to 1950 MHz RFR	No	No changes in nervous system (heart rate, respiration rate) in either group	
Exposure to Magnetic Field Non-Ionizing Radiation and the Risk of Miscarriage: A Prospective Cohort Study	Li *et al.* (2017) (88)	National Institute of Environmental Health Sciences	Prospective cohort	Healthy US pregnant women	913	Miscarriage risk	EMDEX Lite meter for measurement of RFR exposure	Yes	Exposure to higher RFR level associated with higher miscarriage risk	
A Prospective Study of In-utero Exposure to Magnetic Fields and the Risk of Childhood Obesity	Li *et al.* (2012) (168)	California Public Health Foundation	Prospective cohort	Pregnant women / children	733	Obesity	EMDEX Lite meter collected magnetic field measurements for 24 hours during pregnancy (40– 800 Hz	Yes	Exposure to RFR during pregnancy measured on one day associated with childhood obesity.	Association for persistent obesity, not transitory (unlikely) obesity. Income and childhood habit of eating fruits and vegetables

							every 10 seconds)			varied among exposure groups
Exposure to magnetic fields and the risk of poor sperm quality	Li *et al.* (2010) (87)		Cross-sectional	Healthy Chinese adult male (18-45 years old)	148 (76 cases, 72 controls)	Sperm	EMDEX Lite meter for measurement of RFR exposure	Yes	Higher RFR exposure associated with poorer sperm quality	
Use of mobile phone during pregnancy and the risk of spontaneous abortion	Mahmoudabadi *et al.* (2015) (169)	Tarbiat Modares University, Tehran Iran	Case-control	Healthy Irian pregnant women; ages 18-35 years	472 (226 cases and 246 controls)	Unexplained spontaneous abortion	Mobile phone use	Yes	Use of mobile phones associated with early spontaneous abortions	Very weak study design. Cannot make a conclusion for effect of cell phones.
Tinnitus and cell phones: the role of electromagnetic radiofrequency radiation	Medeiros *et al.* (2016) (71)		Review			Tinnitus	RFR exposure	Mixed	Mixed evidence for association between RFR exposure and tinnitus	
Audiologic Disturbances in Long-Term Mobile Phone Users	Panda *et al.* (2010) (72)		Cross-sectional case control	Healthy Indian adults (ages 18-45 years; mean 28 years for cases, 30 years for controls)	112	Audiology systems	Mobile phone use	No	No effect on hearing	Small sample size
Can electromagnetic fields emitted by mobile phones stimulate the vestibular organ?	Pau *et al.* (2005) (69)		Cross-sectional	Healthy German adults (mean age, 48 years)	13	Audiology systems	RFR exposure of 890 MHz	No	Small increase in temperature too small to affect inner ear or brain	Small sample size
Comparison of the effects of continuous and pulsed mobile phone like RF exposure on the human EEG	Perentos *et al.* (2007) (170)		Cross-sectional	Healthy Australians (mean age, 26 years)	12	EEG	900MHz	No	No effect on EEG of continuous or pulsed RFR	
The relationship between adolescents' well-being and their wireless phone	Redmayne *et al.* (2013) (171)	Dominion Post and Victoria University of Wellington	Cross-sectional	Healthy New Zealand students (mean age, 12 years)	373	Headache	Mobile phone use using survey	Mixed	Association between increase risk for headache and increased mobile phone use. No solid association with phone use and tinnitus.	Lower odds of waking up at night with increased wireless use. Painful thumbs

use: a cross-sectional study										from texting showed the most stability among outcomes. No trouble falling asleep with increased use.
Prenatal exposure to extremely low frequency magnetic field and its impact on fetal growth	Ren *et al.* (2019) (172)		Cross-sectional	Healthy Chinese pregnant women in 3rd trimester	128	Fetal growth	EMDEX Lite meter for measurement of RFR exposure	Yes	Higher RFR exposure levels in utero associated with decreased fetal growth in girls but not boys	Exposure representing pregnancy was only done for 24 hours. Difficult to make solid conclusions from this study.
Cognitive function and symptoms in adults and adolescents in relation to rf radiation from UMTS base stations	Riddervold *et al.* (2008) (74)		Cross-sectional	Healthy Danish adolescents (15-16 years old) and adults (25-40 years old)	80 (40 adolescents and 40 adults)	Cognitive functions (brains)	RFR exposure of 2140 MHz	No	No effect on Trail Making B test performance before and during RFR exposure	
Symptoms of ill health ascribed to electromagnetic field exposure – a questionnaire survey	Röösli *et al.* (2004) (173)	Swiss Federal Office of Public Health	Cross-sectional	Swiss adults with mean age of 51 years old	429	Ill health (body)	People asked if exposure to power lines, train and tram lines, transformers, broadcast transmitters, mobile phone base stations, and other RFR sources affected their health	Yes	People perceived that exposure affected their health.	Highly subjective. No exposure assessment. No clinical diagnosis of symptoms. No conclusions can be made about RFR exposures and health.
Symptoms and Cognitive Functions in Adolescents in Relation to Mobile	Schoeni *et al.* (2015) (174)		Cross-sectional	Healthy swiss adolescents between the ages of 12 to 17	439	Cognitive functions (brains)	Mobile phone use at night	No	Cognitive tests on memory and concentration not related to mobile phone use at night	

Phone Use during Night										
Can mobile phone emissions affect auditory functions of cochlea or brain stem?	Sievert *et al.* (2005) (68)		Cross-sectional	Healthy German adults with the mean ages of 27.8 years and the ranges of 19 to 57 years old	12	Auditory functions of cochlea and brain stem	RFR exposure of 8896 MHz	No	RFR exposure not associated with auditory brain stem reflexes and auditory functions	
Use of wireless telephones and self-reported health symptoms: a population-based study among Swedish adolescents aged 15–19 years	Söderqvist *et al.* (2008) (175)	Academia + government	Cross-sectional	Healthy Swedish adolescent between the age of 15 to 19 years	1269	General health	Mobile phone use as measure by survey	Yes	Adolescents who used mobile phones were more likely to report having health problems	Did not measure RFR. Self-reported phone use. Many potential confounders unaccounted for
Use of mobile phones and changes in cognitive function in adolescents	Thomas *et al.* (2010) (75)	Government and mobile telecommunications industry	Prospective cohort	Healthy Australian students in year 7	236	Cognitive functions – working memory, reaction time (brains)	Mobile phone use by survey	No	Authors concluded that change in cognitive function at 1 year follow-up likely due to age increase rather than cell phones use	
Evaluation of the Effect of Using Mobile Phones on Male Fertility	Wdowiak *et al.* (2007) (176)		Cross-sectional	Healthy Polish male	304 (99 controls, 157 used mobile phone for 1-2 years, 48 used mobile phone >2 years)	Sperm	Reported mobile phone use through survey	Mixed	Possible lower occurrence of sperm abnormalities in those who did not use GSM phones. Frequency of cell phone use not related to sperm concentration in semen.	
Mother's Exposure to Electromagnetic Fields before and during Pregnancy is Associated with Risk of Speech Problems in Offspring	Zarei *et al.* (2019) (177)		Cross-sectional	3 to 7 year-old Iranian children with and without speech problems	185 (110 in the case group and 75 in the control group)	Speech problem	RFR exposure before and during pregnancy and living close to cell phones towers	No	No association between speech problems and RFR exposure before and during pregnancy	

Table 4. Mental health

Study Name	Authors	Funding Source	Study Type	Study Population	Sample Size	Endpoint Examined	Exposure Assessment	Adverse Effect	Comments	My comments
Associations between problematic mobile phone use and psychological parameters in young adults	Augner *et al.* (2012) (96)		Cross-sectional	Health young adults (17-35 years old; mean, 20 years)	196	Psychological and physical health well-being	Survey on mobile phone behavior	Yes	Cell phone use positively correlated with chronic stress and depression	Social and recall bias; Use of cell phones rather than RFR exposure
A follow-up study of the association between mobile phone use and symptoms of ill health	Cho *et al.* (2017) (178)	IT R&D program of MSIP/IITP and Korea Centers for Disease Control and Prevention	Cross-sectional	Healthy South Korean adults with mean age of 57 years old	532	Psychological symptoms	Average frequency of calls per day; average duration per call using survey and mobile phone bill records	Yes	Cell phone use related to increased headache and cognitive impairment in females, but not males. No association with several other indicators of mental health. Headache indicator lower upon follow-up.	Social and recall bias; Use of cell phones rather than RFR exposure
Association between mobile phone use and depressed mood in Japanese adolescents: a cross-sectional study Effects of weak mobile phone - electromagnetic fields (GSM, UMTS) on well-being and resting EEG	Ikeda *et al.* (2014) (179)		Cross-sectional	Healthy Japanese high school students	2,698	Moods	Survey with the exposure of cell phone use (e.g., duration, intensity, frequency)	Yes	Cell phone use related to higher tension and excitement, fatigue, and depressed mood	Social and recall bias; Use of cell phones rather than RFR exposure
Effects of weak mobile phone-Electromagnetic fields (GSM, UMTS) on event related potentials	Kleinlogel *et al.* (2008) (180)		Cross-sectional	Healthy Swiss males (ages 20-35 years; mean, 27 years)	15	EEG; well-being; Visually and auditory evoked potential,	RFR exposure of 1950 MHz and 900 MHz	No	Short term exposure to RFR does not affect well-being or resting EEG. No effect on cognitive function	Small sample size and lacking generalizability

and cognitive functions						continuous performance test				
An analysis of the impact of cell phone use on depressive symptoms among Japanese elders	Minagawa *et al.* (2014) (98)	Japan Society for the Promotion of Science	Cross-sectional	Healthy Japanese older adults between the ages of 65 to 103 years old with the mean age of 76 years old	5,164	Depressive symptoms	Survey with the exposure of cell phone use (e.g., duration, intensity, frequency)	No	Cell phone use associated with fewer depressive symptoms (beneficial) in women but not men (after controlling for covariates)	Social and recall bias; Use of cell phones rather than RFR exposure
Mobile Phones and Mental Well-Being: Initial Evidence Suggesting the Importance of Staying Connected to Family in Rural, Remote Communities in Uganda	Pearson *et al.* (2017) (99)		Cross-sectional	Household in Uganda	92	Mental well-being	Survey with the exposure about cell phone ownership and use	No	Owning cell phones is related to higher mental well-being	Social and recall bias; Use of cell phones rather than RFR exposure
Association between General Health and Mobile Phone Dependency among Medical University Students: A Cross-sectional Study in Iran	Ranjbaran *et al.* (2019) (181)	Arak University of Medical Sciences	Cross-sectional	Iranian medical students with the mean ages of 22.29±3.5 years old	334	General health	Survey on mobile phone dependency and use behaviors	Yes	Anxiety and sleep disorder and social dysfunction are main predictors of mobile phone dependency	Social and recall bias; Use of cell phones rather than RFR exposure
Effects of exposure to electromagnetic fields emitted by GSM 900 and WCDMA mobile phones on cognitive function in young male subjects	Sauter *et al.* (2011) (182)		Cross-sectional	Healthy German males (18-30 years old; mean, 25 years)	30	Cognitive function included attention and working memory	Exposure to GSM 900 MHz, WCEMA/3G UMTS	No	Did not provide any evidence of RFR effect on human cognition, but author highlighted the need to control for time of day	Small sample size and lacking generalizability
Association between Excessive	Tamura *et al.*		Cross-sectional	Healthy Japanese	295	Insomnia and	Survey with the	Yes	Cell phone use of 5 hours per day	Social and recall bias; Use of cell

Use of Mobile Phone and Insomnia and Depression among Japanese Adolescents	(2017) (183)			adolescents (mean age, 16 years)		depression	exposure of cell phone use (e.g., duration, intensity, frequency)		associated with less sleep and insomnia but not depression. Phone use for social network services and online chats associated with higher risk of depression.	phones rather than RFR exposure
Perceived connections between information and communication technology use and mental symptoms among young adults - a qualitative study	Thomée *et al.* (2010) (184)		Prospective cohort	Healthy Sweden adults between the ages of 21 to 28 years old	32	Mental symptoms	Interview about computer and mobile phone use (e.g., duration, intensity, frequency)	Yes	High quantity of mobile phone and computer use associated with stress, depression, and sleep disorders	Social and recall bias; Use of cell phones rather than RFR exposure
Mobile phone use and stress, sleep disturbances, and symptoms of depression among young adults--a prospective cohort study	Thomée *et al.* (2011) (185)	Swedish Council for Working Life and Social Research	Qualitative	Healthy Sweden adults between the ages of 20 to 24 years old	4,156	Mental health outcomes	Survey on cell phone use (e.g., duration, intensity, frequency)	Yes	High frequency of mobile phone use could be risk factor for developing sleep disturbances and depression	Social and recall bias; Use of cell phones rather than RFR exposure
Associations between screen time and lower psychological well-being among children and adolescents: Evidence from a population-based study	Twenge *et al.* (2018) (94)		Cross-sectional	Healthy US children between the ages of 2 to 17 years old	40,337	Psychological well-being	Survey with exposure about screen time, including television, cell phones, computer, and tablets	Yes	Higher screen use time associated with lower psychological well-being, inability to finish tasks, more difficulty making friends, more likely to be diagnosed with depression or anxiety or needed treatment for mental/behavioral health conditions	Study can only make conclusions about effect of screen time and not exposure to RFR.
The association between smartphone use, stress, and	Vahedi *et al.* (2018) (93)		Meta-analysis	Multiple studies	21,736	Stress and anxiety	Survey of cell phone use (e.g., duration,	Yes	Small to medium association between smartphone use	Use of cell phones rather than RFR exposure

anxiety: A meta-analytic review							intensity, frequency)		and stress and anxiety	
The influence of electromagnetic fields generated by wireless connectivity systems on the occurrence of emotional disorders in women	Wdowiak *et al.* (2018) (97)		Cross-sectional	Healthy Polish Women (ages 25-35 years; mean, 31 years)	200	Depression and anxiety	Survey about exposure to GSM 900 MHz, GSM 1800 MHz, UMTS, DECT, WLAN	Yes	10-hour exposure assessment of RFR from wireless devices believed to contribute to depressive disorders. Opposite effect associated with WLAN.	Very narrow exposure window + disorders examined subject to variability in grading. Most comparison tests of exposure and health condition showed no association.
Effects of electromagnetic fields from mobile phones on depression and anxiety after titanium mesh cranioplasty among patients with traumatic brain injury	Zhu *et al.* (2016) (186)	National Basic Research Program of China; National Natural Science Foundation of Chines	Prospective cohort	Chinese patients with traumatic brain injury and titanium mesh cranioplasty (mean age, 45 years)	220	Depression and anxiety	Survey about exposure to mobile phones as proxy for RFR exposure	No	Cell phone use after cranioplasty associated with lower risk of depression and anxiety status	Recall and social bias; Lacking generalizability
Mobile Phones in the Bedroom: Trajectories of Sleep Habits and Subsequent Adolescent Psychosocial Development	Vernon *et al.* (2018) (187)		Cross-sectional	Health Austria adolescents between the ages of 13 to 16 years old	1,011	Depressed mood, sleep behavior, coping, self-esteem, externalizing behavior	Survey about nighttime phones use	Yes	Increase mobile phone used associated with increased externalizing behavior and decreased self-esteem and coping	Social and recall bias; Use of cell phones rather than RFR exposure

Table 5. Sleep

Study Name	Authors	Funding Source	Study Type	Study Population	Sample Size	Endpoint Examined	Exposure Assessment	Adverse Effect	Comments	My comments
Altering Adolescents' Pre-Bedtime Phone Use to Achieve Better Sleep Health	Bartel *et al.* (2019) (188)		Cross-sectional	Australian adolescents (14-18 years old; mean, 16 years)	63	Sleep time	Sleep diary on cell phone use	Yes	Less phone use associated with longer sleep time and better quality of sleep	Recall and social bias
A meta-analysis of the effect of media devices on sleep outcomes	Carter *et al.* (2016) (103)		Meta-analysis	Multiple studies based on children and adolescents		Sleep quantity	Media use (e.g., television, cell phones, computers, video games)	Yes	Media use before bedtime associated with poorer sleep quantity, quality, and excess daytime sleepiness	No RFR exposure assessment
Effects of EMFs emitted by mobile phones (GSM 900 and WCDMA/UMTS) on the macrostructure of sleep	Danker-Hopfe *et al.* (2011) (189)	German Mobile Telecommunication Research Programme	Cross-sectional	Healthy German males (18-30 years old; mean, 25 years)	30	Sleep quality and heart rate during sleep	Exposure to GSM 900 MHz and WCDMA – (SAR = 2 W/kg)	No	Little evidence for sleep-disturbing effect of cell phone exposure	High exposure for a prolonged period not realistic for either sleep or school environments.
An experimental study on effects of radiofrequency electromagnetic fields on sleep in healthy elderly males and females: Gender matters!	Danker-Hopfe *et al.* (2020) (190)	German Federal Office for Radiation Protection	Cross-sectional	Healthy German males and females (60-80 years old; mean, 68 years old)	60	Sleep quality and heart rate during sleep	Exposure to GSM 900 MHz, TETRA, SHAM. 0.5 hour before sleep and 7.5 hours during sleep.	Mixed	Some evidence of sleep-disturbing effects of cell phone exposure	Exposure time and SAR (2-6 W/kg) unrealistically high for sleeping and school environments.
Mobile phone use, school electromagnetic field levels and related symptoms: a cross-sectional survey among 2150 high school students in Izmir	Durusoy *et al.* (2017) (191)	German Federal Office for Radiation Protection	Cross-sectional	Healthy Turkish high school students (mean age, 16 years)	2510	Well-being after sleep	Survey on mobile phone use, presence of base station nearby, school RFR levels measured with Aaronia Spectran	No	Phone use (text talk) associated with headache and other symptoms. Limited associations between vicinity to base stations and some general symptoms. No symptoms association with school RFR levels.	Social and recall bias

							HF-4060 device.			
Bedtime mobile phone use and sleep in adults	Exelmans *et al.* (2016) (192)	Turkish National and Scientific Research Council	Cross-sectional	Healthy German adults (18-94 years old; mean age, 46 years)	844	Sleep quality, fatigue, and insomnia	Survey on bedtime mobile phone use	No	Phone use before bed associated with poorer sleep quality, more likely to experience insomnia, and increase fatigue	Social and recall bias; did not use complex survey design
Impact of Media Use on Adolescent Sleep Efficiency:	Fobian *et al.* (2016) (102)		Cross-sectional	Healthy American adolescents (ages 14-15 years; mean 15 years)	55	Sleep offset and sleep efficiency	Survey on media use, including television, computer, cell phones, and video games	Yes	Media use is associated with poorer sleep efficiency, sleep onset, and sleep offset	Social and recall bias; did not use complex survey design
Adolescent Sleep Patterns and Night-Time Technology Use: Results of the Australian Broadcasting Corporation's Big Sleep Survey	Gamble *et al.* (2014)v(193)		Cross-sectional	Healthy Australian adolescents (11-17 years old; mean age, 15 years)	1184	Sleep patterns, sleepiness, sleep disorders	Survey on electronic devices use in the bed at nighttime	Yes	Use of computers, cellphones, and TVs in bed prior to sleep associated with delayed sleep/wake patterns	Social and recall bias; did not use complex survey design
Electromagnetic fields, such as those from mobile phones, alter regional cerebral blood flow and sleep and waking EEG	Huber *et al.* (2002) (104)	Ionizing and Non-ionizing Radiation Protection Research Center	Cross-sectional	Healthy Swiss males (mean age, 22 years)	32	Sleeping-related variables	900 MHz	Yes	RFR exposure during sleep altered waking regional cerebral blood flow and pulse modulation of RFR effect waking and sleep EEG changes	
Mobile phone 'talk-mode' signal delays EEG-determined sleep onset	Hung *et al.* (2007) (105)	Swiss and international research groups	Cross-sectional	Healthy UK adults (18-28 years old; mean, 22 years)	10	Sleep latency	Exposure to GSM 900 MHz with pulsed frequency at 217 Hz via thermally insulated silent phone beside the right ear	Yes	Exposure to GSM 900 associated with delay in sleep onset	Small sample size and lack of generalizability. Highly specific conditions (exposure for 30 minutes during the day followed by opportunity to sleep for 90 minutes)

Environmental Radiofrequency Electromagnetic Fields Exposure at Home, Mobile and Cordless Phone Use, and Sleep Problems in 7-Year-Old Children	Huss *et al.* (2015) (101)	Swiss and international research groups	Cross-sectional	Healthy children in Amsterdam (6.7-8.5 years)	2361	Sleep problems	Mapping and modeling of RFR exposure from mobile phone base stations at children's home, WIFI at home, mobile phones	Mixed	Sleep onset delay, parasomnias and daytime sleepiness not associated with residential RFR from base stations. Sleep duration scores associated with RFR from base stations. Higher use mobile phones associated with less favorable sleep duration, night wakenings and parasomnias, and bedtime resistance. Cordless phone use not related to any sleeping scores.	Authors concluded that their study does not support the hypothesis that exposure to RFR is detrimental to sleep quality in 7-year old children, but potentially other factors that are related to mobile phone use.
Electromagnetic field of mobile phones affects visual event related potential in patients with narcolepsy: Mobile Phone Affects ERP in Narcolepsy	Jech *et al.* (2001) (194)		Cross-sectional	Adults with Narcolepsy in Czech Republic (mean age, 48 years)	17	Event related potentials (EPR) during sleep	RFR 900 MHz from mobile phones	No	Exposure to mobile phone might suppress sleepiness and improve cognitive performance	Small sample size and lack of generalizability
National data showed that delayed sleep in six-year-old children was associated with excessive use of electronic devices at 12 years	Kato *et al.* (2018) (195)		Longitudinal	Healthy children (mean age, 6 years)	9,607		Survey on mobile phone use, watch TV, play video games	Yes	Use of mobile phone, TV, and video games associated with delay bedtime for children	Social and recall bias; did not use complex survey design
Electronic media use and insomnia complaints in German adolescents: gender differences in use patterns	Lange *et al.* (2017) (196)	Japan Society for the Promotion of Science	Cross-sectional	Healthy Germans (ages, 11-17 years; mean, 14 years)	7533	Sleep time	Survey on media use on TV, computer/internet, video games, cell phones,	Yes	Everyday use of electronic media devices associated with insomnia	Social and recall bias; did not use complex survey design

and sleep problems							music before bed			
Investigation of Brain Potentials in Sleeping Human Exposed to the Electromagnetic Field of Mobile Phones	Lebedeva *et al.* (2001) (197)		Experimental	Healthy Russian male between the ages of 20 to 28 years	20	Insomnia complaints	Sham or RFR exposure from mobile phone	Yes	Exposure to RFR increased EEG alpha range power density during sleep in human's cerebral cortex biopotentials	Small sample size and lack of generalizability
The effect of electromagnetic fields emitted by mobile phones on human sleep	Loughran *et al.* (2005) (198)		Experimental	Healthy Australian adults (18-60 years old; mean age, 31 years)	55	Sleep stage (duration and alternation)	900 MHz from mobile phones, 217 Hz pulsed field 30 minutes before sleep	Yes	Decrease in rapid eye movement sleep latency and increased EEG spectral power in 11.5-12.25 Hz frequency during initial part of sleep	
Effects of evening exposure to electromagnetic fields emitted by 3G mobile phones on health and night sleep EEG architecture	Lowden *et al.* (2019) (199)		Experimental	Healthy Swedish adults (ages, 18-19 years)	22	Sleep stage (duration and alternation)	Sham vs 1930 – 1990 MHz for 3 hours before sleep. (SAR = 1.6 W/kg)	No	No differences in self-evaluated health symptoms, performance on the Stroop color word test during exposure or for sleep quality.	Small sample size and lack of generalizability
Stimulation of the Brain With Radiofrequency Electromagnetic Field Pulses Affects Sleep-Dependent Performance Improvement	Lustenberger *et al.* (2013) (200)		Experimental	Healthy male adults between the ages of 18 to 21 years	16	Sleepiness and sleep architecture	All-night sham vs 0.25-0.8 Hz pulsed RFR (900 MHz mobile phone)	Yes	Low frequency pulse-modulated RFR affected some EEG parameters during sleep and altered sleep-dependent performance improvement	Small sample size and lack of generalizability
Inter-individual and intra-individual variation of the effects of pulsed RF EMF exposure on the human sleep EEG: Reproducibility of RF EMF Exposure Effects	Lustenberger *et al.* (2015) (201)		Experimental	Healthy male adults (mean age, 23 years)	20	Sleep architecture	900 MHz from mobile phones	No	No difference in sleep spindle and delta-theta activity. Increases in delta-theta frequency range in several fronto-central electrodes	Small sample size and lack of generalizability

Association between screen viewing duration and sleep duration, sleep quality, and excessive daytime sleepiness among adolescents in Hong Kong	Mak *et al.* (2014) (202)		Cross-sectional	Healthy Hong Kong adolescent between the ages of 12 to 20 years old	762	Sleep duration, quality and daytime sleepiness	Survey on screen viewing	Yes	Screen viewing correlated with shorter sleep duration, greater sleep disturbances, and daytime sleepiness	Social and recall bias; did not use complex survey design
The Association between Use of Mobile Phones after Lights Out and Sleep Disturbances among Japanese Adolescents: A Nationwide Cross-Sectional Survey	Munezawa *et al.* (2011) (203)		Cross-sectional	Healthy Japanese adolescents between the ages of 13 to 18 years old	94,777	Sleep disturbances	Survey on the use of mobile phones after light out	Yes	Use of mobile phones after lights out associated with sleep disturbances	Social and recall bias
Effects of electromagnetic fields emitted from W-CDMA-like mobile phones on sleep in humans	Nakatani-Enomoto *et al.* (2013) (204)		Experimental	Healthy Japanese adults (22-39 years old; mean age, 31 years)	19	Sleep stage (duration and alternation)	900 MHz from mobile phones	No	No effect on sleep	Small sample size and lack of generalizability
Comparison of the effects of continuous and pulsed mobile phone like RF exposure on the human EEG	Perentos *et al.* (2007) (205)		Experimental	Healthy Australian adults (19-32 years old; mean, 26 years)	12	Sleep architecture	900 MHz from mobile phones	No	No effect on sleep	Small sample size and lack of generalizability
Sleeping with technology: cognitive, affective, and technology use predictors of sleep problems among college students	Rosen *et al.* (2016) (206)		Cross-sectional	Healthy US college students - mean age, 26 years	734	Sleep problems	Survey on daily smartphone use, nighttime phone location	Yes	Daily phone use and phone use at night are predictors of sleep problems	Social and recall bias; did not use complex survey design
Are you awake? Mobile phone use after lights out	Saling *et al.* (2016) (207)		Cross-sectional	Healthy Australians (18-69 years old; mean, 34 years	397	Self-report tiredness after sleep	Survey on nighttime mobile phone use	Yes	Using mobile phones after lights out associated with tiredness and sleep disturbance	Social and recall bias

Mobile phone use and stress, sleep disturbances, and symptoms of depression among young adults--a prospective cohort study	Thomée *et al.* (2011) (208)	Swedish Council for Working Life and Social Research	Prospective cohort	Healthy Sweden adults (20-24 years old)	4156	Sleep disturbances	Survey on mobile phone uses	Yes	High mobile phone use associated with sleep disturbances and symptoms of depression for men at 1-year follow up	Social and recall bias
Mobile Phones in the Bedroom: Trajectories of Sleep Habits and Subsequent Adolescent Psychosocial Development	Vernon *et al.* (2018) (187)		Cross-sectional	Healthy Austrian adolescents between the ages of 13 to 16 years old	1011	Sleep behaviors	Survey on nighttime mobile phone use	Yes	Night-time mobile phone use and associated with poor sleep behavior	Social and recall bias; did not use complex survey design
Human sleep EEG under the influence of pulsed radio frequency electromagnetic fields.	Wagner *et al.* (2000) (209)	Technologiezentrum of Deutsche Telekom Ag	Experimental	Health German males (19-36 years; mean age, 24 years)	20	Sleep architecture	900 MHz from mobile phones. Power flux density of 50 W/m(2)	No	No significant effect on sleep compared to non-exposed	Small sample size and lack of generalizability

Table 3. Noncancer Toxicity

Study Name	Authors	Funding Source	Study Type	Study Population	Sample Size	Endpoint Examined	Exposure Assessment	Adverse Effect	Comments	My comments
Effect of cell phone use on semen analysis in men attending infertility clinic: an observational study	Agarwal *et al.* (2008)		Observational	Healthy American males (mean age, 32 years)	361	Sperm characteristics	Cell phone use	Yes	Reported cell phone use duration associated with decreased sperm count, motility, viability, morphology.	Self-reported cell phone use; No RFR measurement
Epidemiology of Health Effects of Radiofrequency Exposure	Ahlbom *et al.* (2004)		Review			Reproductive outcomes	RFR exposure	No	Authors concluded that problems of exposure assessment temper any conclusions on reproductive outcomes, and no adverse effects of RFR substantiated.	

Male fertility and its association with occupational and mobile phone towers hazards: An analytic study	Al-Quzwini *et al*. (2016)		Experimental	Healthy Iranian couples	200	Semen analysis	Environmental exposure to mobile phone towers	Yes	Proximity to mobile phone towers associated with poorer quality of semen and lower fertility rate	No RFR measurement. Highly subjective approach too.
The Effect of Electromagnetic Radiation due to Mobile Phone Use on Thyroid Function in Medical Students Studying in a Medical College in South India	Baby *et al*. (2017)		Cross-sectional	Healthy Indian medical students (mean age, 20 years)	83	Thyroid dysfunction	RFR exposure based on SAR values of the phone model and reported duration of cell phone use	Yes	Significant relationship between estimated RFR exposure and increase in thyroid-stimulating hormone. High variability in response for a small cohort.	Many confounders unaccounted for. No RFR measurement. Estimate of RFR exposure highly uncertain.
Cellular Phone Irradiation of the Head Affects Heart Rate Variability Depending on Inspiration/Expiration Ratio	Béres *et al*. (2018)	Medical Faculty of the University of Pecs, Hungary	Cross-sectional	Healthy Hungarian adults with the mean ages of 25.2 with the ranges of 21 to 32 years old	20	Heart rate asymmetry and heart rate variability	1800 MHz from GSM cellular phone	Mixed	Acute effects on autonomic nervous system	
Are Thyroid Dysfunctions Related to Stress or Microwave Exposure (900 MHz)?	Bergamaschi *et al*. (2004)		Cross-sectional	Healthy Italian adults (mean, 28 years old)	2,598 employees	Thyroid dysfunction	Self-reported mobile phone use	Mixed	No effect on low TSH of mobile phone use. Indication of lower TSH levels in small group of workers with >33 hours talk/month	Many potential confounders unaccounted for.
Effects on auditory function of chronic exposure to electromagnetic fields from mobile phones	Bhagat *et al*. (2016)		Cross-sectional	Healthy Indian students (mean age, 23 years)	40	Auditory system	Mobile phone use	No	No adverse effect on the auditory system	Compare dominant ear for cell phones to non-dominant ear
Changes in Tympanic Temperature During the Exposure to Electromagnetic Fields Emitted by Mobile Phone	Bortkiewicz *et al*. (2012)		Experimental	Healthy Polish adults (mean age, 22 years)	10	Tympanic temperature via probe close to aural canal membrane in ear	60 minutes intermittent or continuous exposures to RFR generated by mobile phone (frequency	Yes	small changes in tympanic temperature monitored on different days for sham vs exposed	

						opposite one in contact with phone	900 MHz, SAR 1.23 W/kg)			
Uncertainty Analysis of Mobile Phone Use and Its Effect on Cognitive Function: The Application of Monte Carlo Simulation in a Cohort of Australian Primary School Children	Brzozek *et al*. (2019)	National Health and Medical Research Council, Australia	Longitudinal	Healthy Australian students; mean age, 10 years	412	Cognitive functions	Mobile phone use	No	Cognitive functions of school students not affected by mobile phone use	Used survey to estimate cell phone use. Subject to recall bias
A cross-sectional study of the association between mobile phone use and symptoms of ill health	Cho *et al*. (2016)	Korean CDC collaboration	Cross-sectional	Healthy Korean adults (median age, 57 years)	532	Symptoms of ill health (general health)	Reported mobile phone use	Mixed	Mobile phone call duration not associated with stress, sleep, cognitive function, or depression. Associated with headache severity.	Study did not measure RFR exposure.
Effects of short-term radiation emitted by WCDMA mobile phones on teenagers and adults	Choi *et al*. (2014)	Korean government	Experimental	Healthy Korean adults (mean age, 28 years) and teenagers (mean age, 15 years)	52 (26 adults and 26 teenagers)	Heart rate variability and respiratory rate	RFR exposure at 1950 MHz	No	Short-term RFR exposure had no effect on autonomic nervous system	
Intraoperative observation of changes in cochlear nerve action potentials during exposure to electromagnetic fields generated by mobile phones	Colletti *et al*. (2011)		Experimental	Italian adults with definite unilateral Meniere's disease whom received medical therapy for at least 6 months (50-54 years old)	13 (7 in experimental group and 5 in control group)	Cochlear nerve	RFR exposure	Yes	RFR exposure increased latency of cochlear nerve compound action potentials during 5-minute exposure and for 5 minutes after	Exposures done during craniotomy which exposes the brain tissue. Intact skulls might prevent this observation.
Electromagnetic fields and EEG spiking rate in	Curcio *et al*. (2015)		Experimental	Italian adults diagnosed with	12	Brain electrical (EEG)	RFR exposure	No	No RFR effect on risk of seizures in symptomatic focal epilepsy	

patients with focal epilepsy				symptomatic focal epilepsy (ages, 21-79 years)						
Evaluation in humans of the effects of radiocellular telephones on the circadian patterns of melatonin secretion, a chronobiological rhythm marker	de Seze *et al.* (1999)	Motorola Inc.	Experim ental	Healthy French males, 20-32 years old	37	Melatonin secretion	Exposure to 900 MHz and 1800 MHz	No	Melatonin circadian profile not disrupted with RFR exposure compared to pre-exposure	
Effects of short and long term electromagnetic fields exposure on the human hippocampus	Deniz *et al.* (2017)		Experim ental	Healthy US female medical students aged 18 to 25 years	60	Hippocam pus	Cell phones use	Mixed	Longer daily phone use risk for lack of attention/ concentration, but no effect on size of hippocampus	
An Investigation on the Effect of Extremely Low Frequency Pulsed Electromagnetic Fields on Human ECGs	Fang *et al.* (2016)	RMIT University, Australia + Shanghai University	Experim ental	Healthy Australian adults aged 20 to 38 years	22	Heart	RFR exposure	Yes	Short term exposure to RFR associated with small change in ECG RR intervals, but not in several other ndicators.	
A Prospective Cohort Study of Adolescents' Memory Performance and Individual Brain Dose of Microwave Radiation from Wireless Communication	Foerster *et al.* (2018)	Swiss NSF, Euro Comm. Seventh Framework Programm – GERONIMO project	Prospec tive cohort	Healthy Swiss adolescents (12-17 years old; mean, 14 years)	895	Memory performa nce (brain)	Mobile phone use	Yes	Mobile phone use may affect figural memory in regions most exposed during mobile phone use	Very small statistically significant effects; very large difference between reported phone use and phone use records; many group comparisons not significant.
The influence of handheld mobile phones on human parotid gland secretion	Goldwei n & Aframian (2010)		Cross-section al	Healthy Israeli adults (ages 19-33 years; mean, 27 years)	50	Parotid gland - saliva secretion rate and	Mobile phone use	Yes	Increase in mobile phone use related to elevated salivary rate and less protein secretion	

						protein concentrations				
Exposure to wireless phone emissions and serum β-trace protein	Hardell *et al.* (2010)	Cancer-och Allergifonden, Cancerhjalpen and Orebro University Hospital Cancer Fund	Cross-sectional	Healthy Swiss adults (18-30 years old)	62	ß-trace protein	RFR exposure of 890 MHz	No	No significant change of ß-trace protein between the exposure and the control group	
Effects of electromagnetic radiation of mobile phones on the central nervous system	Hossmann & Hermann (2003)		Review	Adults		Central nervous system	RFR exposure	No	Little evidence of RFR effect on functional and structural integrity of brain. Mostly thermal effects	
Exposure to pulse-modulated radio frequency electromagnetic fields affects regional cerebral blood flow	Huber *et al.* (2005)	Swiss and international research organizations	Cross-sectional	Healthy Swiss adults (mean age, 22.5 years)	12	Cerebral blood flow	RFR exposure	Yes	Association with small changes in cerebral blood flow	
Association of personal exposure to power-frequency magnetic fields with pregnancy outcomes among women seeking fertility treatment in a longitudinal cohort study.	Ingle *et al.* (2020)	National Institutes of Environmental Health Sciences; Electric Power Research Institute.	Prospective cohort	Women recruited from 2012 to 2018, who underwent in vitro fertilization (IVF	119	Pregnancy outcomes	Women wore personal RFR exposure monitors for up to 3 consecutive 24-hour periods separated by several weeks.	No	Personal MF exposures not associated with fertility treatment outcomes or pregnancy outcomes.	
Mobile phone use for 5 minutes can cause significant memory impairment in humans	Kalafatakis *et al.* (2017)		Cross-sectional	Healthy Greek adults and adults with mild cognitive impairments	84	Memory (brain)	Use of mobile phone for 5 minutes	Yes	Mobile phone use has negative effect on working memory	Cannot deduce anything about RFR. Reported changes could be due to distraction.
Assessment of oxidant/antioxidant status in saliva of cell phone users	Khalil *et al.* (2014)	Yarmouk University	Cross-sectional	Healthy Jordan male adults (mean age, 22 years)	12	Salivary gland	Mobile phone use (1800 MHZ)	No	No relation between mobile phone use and changes in salivary oxidants/antioxidants	

Effects of radiation emitted by WCDMA mobile phones on electromagnetic hypersensitive subjects	Kwon *et al*. (2012)	Korean government	Cross-sectional	Korean adults with/out self-reported EMF hypersensitivity (mean age, 30 years)	37 (17 with electromagnetic hypersensitivity and 20 without)	Central nervous system	Exposure to 1950 MHz RFR	No	No changes in nervous system (heart rate, respiration rate) in either group	
Exposure to Magnetic Field Non-Ionizing Radiation and the Risk of Miscarriage: A Prospective Cohort Study	Li *et al*. (2017)	National Institute of Environmental Health Sciences	Prospective cohort	Healthy US pregnant women	913	Miscarriage risk	EMDEX Lite meter for measurement of RFR exposure	Yes	Exposure to higher RFR level associated with higher miscarriage risk	
A Prospective Study of In-utero Exposure to Magnetic Fields and the Risk of Childhood Obesity	Li *et al*. (2012)	California Public Health Foundation	Prospective cohort	Pregnant women / children	733	Obesity	EMDEX Lite meter collected magnetic field measurements for 24 hours during pregnancy (40– 800 Hz every 10 seconds)	Yes	Exposure to RFR during pregnancy measured on one day associated with childhood obesity.	Association for persistent obesity, not transitory (unlikely) obesity. Income and childhood habit of eating fruits and vegetables varied among exposure groups
Exposure to magnetic fields and the risk of poor sperm quality	Li *et al*. (2010)		Cross-sectional	Healthy Chinese adult male (18-45 years old)	148 (76 cases, 72 controls)	Sperm	EMDEX Lite meter for measurement of RFR exposure	Yes	Higher RFR exposure associated with poorer sperm quality	
Use of mobile phone during pregnancy and the risk of spontaneous abortion	Mahmoudabadi *et al*. (2015)	Tarbiat Modares University, Tehran Iran	Case-control	Healthy Irian pregnant women; ages 18-35 years	472 (226 cases and 246 controls)	Unexplained spontaneous abortion	Mobile phone use	Yes	Use of mobile phones associated with early spontaneous abortions	Very weak study design. Cannot make a conclusion for effect of cell phones.
Tinnitus and cell phones: the role of electromagnetic radiofrequency radiation	Medeiros *et al*. (2016)		Review			Tinnitus	RFR exposure	Mixed	Mixed evidence for association between RFR exposure and tinnitus	

Audiologic Disturbances in Long-Term Mobile Phone Users	Panda *et al*. (2010)		Cross-sectional case control	Healthy Indian adults (ages 18-45 years; mean 28 years for cases, 30 years for controls)	112	Audiology systems	Mobile phone use	No	No effect on hearing	Small sample size
Can electromagnetic fields emitted by mobile phones stimulate the vestibular organ?	Pau *et al*. (2005)		Cross-sectional	Healthy German adults (mean age, 48 years)	13	Audiology systems	RFR exposure of 890 MHz	No	Small increase in temperature too small to affect inner ear or brain	Small sample size
Comparison of the effects of continuous and pulsed mobile phone like RF exposure on the human EEG	Perentos *et al*. (2007)		Cross-sectional	Healthy Australians (mean age, 26 years)	12	EEG	900MHz	No	No effect on EEG of continuous or pulsed RFR	
The relationship between adolescents' well-being and their wireless phone use: a cross-sectional study	Redmayne *et al*. (2013)	Dominion Post and Victoria University of Wellington	Cross-sectional	Healthy New Zealand students (mean age, 12 years)	373	Headache	Mobile phone use using survey	Mixed	Association between increase risk for headache and increased mobile phone use. No solid association with phone use and tinnitus.	Lower odds of waking up at night with increased wireless use. Painful thumbs from texting showed the most stability among outcomes. No trouble falling asleep with increased use.
Prenatal exposure to extremely low frequency magnetic field and its impact on fetal growth	Ren *et al*. (2019)		Cross-sectional	Healthy Chinese pregnant women in 3rd trimester	128	Fetal growth	EMDEX Lite meter for measurement of RFR exposure	Yes	Higher RFR exposure levels in utero associated with decreased fetal growth in girls but not boys	Exposure representing pregnancy was only done for 24 hours. Difficult to make solid conclusions from this study.

Cognitive function and symptoms in adults and adolescents in relation to rf radiation from UMTS base stations	Riddervold *et al.* (2008)		Cross-sectional	Healthy Danish adolescents (15-16 years old) and adults (25-40 years old)	80 (40 adolescents and 40 adults)	Cognitive functions (brains)	RFR exposure of 2140 MHz	No	No effect on Trail Making B test performance before and during RFR exposure	
Symptoms of ill health ascribed to electromagnetic field exposure – a questionnaire survey	Röösli *et al.* (2004)	Swiss Federal Office of Public Health	Cross-sectional	Swiss adults with mean age of 51 years old	429	Ill health (body)	People asked if exposure to power lines, train and tram lines, transformers, broadcast transmitters, mobile phone base stations, and other RFR sources affected their health	Yes	People perceived that exposure affected their health.	Highly subjective. No exposure assessment. No clinical diagnosis of symptoms. No conclusions can be made about RFR exposures and health.
Symptoms and Cognitive Functions in Adolescents in Relation to Mobile Phone Use during Night	Schoeni *et al.* (2015)		Cross-sectional	Healthy swiss adolescents between the ages of 12 to 17	439	Cognitive functions (brains)	Mobile phone use at night	No	Cognitive tests on memory and concentration not related to mobile phone use at night	
Can mobile phone emissions affect auditory functions of cochlea or brain stem?	Sievert *et al.* (2005)		Cross-sectional	Healthy German adults with the mean ages of 27.8 years and the ranges of 19 to 57 years old	12	Auditory functions of cochlea and brain stem	RFR exposure of 8896 MHz	No	RFR exposure not associated with auditory brain stem reflexes and auditory functions	
Use of wireless telephones and self-reported health symptoms: a population-based study among Swedish	Söderqvist *et al.* (2008)	Academia + government	Cross-sectional	Healthy Swedish adolescent between the age of 15 to 19 years	1269	General health	Mobile phone use as measure by survey	Yes	Adolescents who used mobile phones were more likely to report having health problems	Did not measure RFR. Self-reported phone use. Many potential confounders unaccounted for

adolescents aged 15–19 years										
Use of mobile phones and changes in cognitive function in adolescents	Thomas *et al.* (2010)	Government and mobile telecommunications industry	Prospective cohort	Healthy Australian students in year 7	236	Cognitive functions – working memory, reaction time (brains)	Mobile phone use by survey	No	Authors concluded that change in cognitive function at 1 year follow-up likely due to age increase rather than cell phones use	
Evaluation of the Effect of Using Mobile Phones on Male Fertility	Wdowiak *et al.* (2007)		Cross-sectional	Healthy Polish male	304 (99 controls, 157 used mobile phone for 1-2 years, 48 used mobile phone >2 years)	Sperm	Reported mobile phone use through survey	Mixed	Possible lower occurrence of sperm abnormalities in those who did not use GSM phones. Frequency of cell phone use not related to sperm concentration in semen.	
Mother's Exposure to Electromagnetic Fields before and during Pregnancy is Associated with Risk of Speech Problems in Offspring	Zarei *et al.* (2019)		Cross-sectional	3 to 7 year-old Iranian children with and without speech problems	185 (110 in the case group and 75 in the control group)	Speech problem	RFR exposure before and during pregnancy and living close to cell phones towers	No	No association between speech problems and RFR exposure before and during pregnancy	

Table 4. Mental health

Study Name	Authors	Funding Source	Study Type	Study Population	Sample Size	Endpoint Examined	Exposure Assessment	Adverse Effect	Comments	My comments
Associations between problematic mobile phone use and psychological parameters in young adults	Augner *et al.* (2012)		Cross-sectional	Health young adults (17-35 years old; mean, 20 years)	196	Psychological and physical health well-being	Survey on mobile phone behavior	Yes	Cell phone use positively correlated with chronic stress and depression	Social and recall bias; Use of cell phones rather than RFR exposure
A follow-up study of the association between mobile phone use and symptoms of ill health	Cho *et al.* (2017)	IT R&D program of MSIP/IITP and Korea Centers for Disease Control	Cross-sectional	Healthy South Korean adults with mean age of 57 years old	532	Psychological symptoms	Average frequency of calls per day; average duration per call using survey and mobile	Yes	Cell phone use related to increased headache and cognitive impairment in females, but not males. No association with	Social and recall bias; Use of cell phones rather than RFR exposure

		and Prevention					phone bill records		several other indicators of mental health. Headache indicator lower upon follow-up.	
Association between mobile phone use and depressed mood in Japanese adolescents: a cross-sectional study Effects of weak mobile phone - electromagnetic fields (GSM, UMTS) on well-being and resting EEG	Ikeda *et al*. (2014)		Cross-sectional	Healthy Japanese high school students	2,698	Moods	Survey with the exposure of cell phone use (e.g., duration, intensity, frequency)	Yes	Cell phone use related to higher tension and excitement, fatigue, and depressed mood	Social and recall bias; Use of cell phones rather than RFR exposure
Effects of weak mobile phone-Electromagnetic fields (GSM, UMTS) on event related potentials and cognitive functions	Kleinlogel *et al.* (2008)		Cross-sectional	Healthy Swiss males (ages 20-35 years; mean, 27 years)	15	EEG; well-being; Visually and auditory evoked potential, continuous performance test	RFR exposure of 1950 MHz and 900 MHz	No	Short term exposure to RFR does not affect well-being or resting EEG. No effect on cognitive function	Small sample size and lacking generalizability
An analysis of the impact of cell phone use on depressive symptoms among Japanese elders	Minagawa *et al.* (2014)	Japan Society for the Promotion of Science	Cross-sectional	Healthy Japanese older adults between the ages of 65 to 103 years old with the mean age of 76 years old	5,164	Depressive symptoms	Survey with the exposure of cell phone use (e.g., duration, intensity, frequency)	No	Cell phone use associated with fewer depressive symptoms (beneficial) in women but not men (after controlling for covariates)	Social and recall bias; Use of cell phones rather than RFR exposure
Mobile Phones and Mental Well-Being: Initial Evidence Suggesting the Importance of	Pearson *et al*. (2017)		Cross-sectional	Household in Uganda	92	Mental well-being	Survey with the exposure about cell phone	No	Owning cell phones is related to higher mental well-being	Social and recall bias; Use of cell phones rather than RFR exposure

Staying Connected to Family in Rural, Remote Communities in Uganda							ownership and use			
Association between General Health and Mobile Phone Dependency among Medical University Students: A Cross-sectional Study in Iran	Ranjbaran *et al.* (2019)	Arak University of Medical Sciences	Cross-sectional	Iranian medical students with the mean ages of 22.29±3.5 years old	334	General health	Survey on mobile phone dependency and use behaviors	Yes	Anxiety and sleep disorder and social dysfunction are main predictors of mobile phone dependency	Social and recall bias; Use of cell phones rather than RFR exposure
Effects of exposure to electromagnetic fields emitted by GSM 900 and WCDMA mobile phones on cognitive function in young male subjects	Sauter *et al.* (2011)		Cross-sectional	Healthy German males (18-30 years old; mean, 25 years)	30	Cognitive function included attention and working memory	Exposure to GSM 900 MHz, WCEMA/3G UMTS	No	Did not provide any evidence of RFR effect on human cognition, but author highlighted the need to control for time of day	Small sample size and lacking generalizability
Association between Excessive Use of Mobile Phone and Insomnia and Depression among Japanese Adolescents	Tamura *et al.* (2017)		Cross-sectional	Healthy Japanese adolescents (mean age, 16 years)	295	Insomnia and depression	Survey with the exposure of cell phone use (e.g., duration, intensity, frequency)	Yes	Cell phone use of 5 hours per day associated with less sleep and insomnia but not depression. Phone use for social network services and online chats associated with higher risk of depression.	Social and recall bias; Use of cell phones rather than RFR exposure
Perceived connections between information and communication technology use and mental symptoms among young adults - a qualitative study	Thomée *et al.* (2010)		Prospective cohort	Healthy Sweden adults between the ages of 21 to 28 years old	32	Mental symptoms	Interview about computer and mobile phone use (e.g., duration, intensity, frequency)	Yes	High quantity of mobile phone and computer use associated with stress, depression, and sleep disorders	Social and recall bias; Use of cell phones rather than RFR exposure

Mobile phone use and stress, sleep disturbances, and symptoms of depression among young adults--a prospective cohort study	Thomée *et al*. (2011)	Swedish Council for Working Life and Social Research	Qualitative	Healthy Sweden adults between the ages of 20 to 24 years old	4,156	Mental health outcomes	Survey on cell phone use (e.g., duration, intensity, frequency)	Yes	High frequency of mobile phone use could be risk factor for developing sleep disturbances and depression	Social and recall bias; Use of cell phones rather than RFR exposure
Associations between screen time and lower psychological well-being among children and adolescents: Evidence from a population-based study	Twenge *et al*. (2018)		Cross-sectional	Healthy US children between the ages of 2 to 17 years old	40,337	Psychological well-being	Survey with exposure about screen time, including television, cell phones, computer, and tablets	Yes	Higher screen use time associated with lower psychological well-being, inability to finish tasks, more difficulty making friends, more likely to be diagnosed with depression or anxiety or needed treatment for mental/behavioral health conditions	Study can only make conclusions about effect of screen time and not exposure to RFR.
The association between smartphone use, stress, and anxiety: A meta-analytic review	Vahedi *et al*. (2018)		Meta-analysis	Multiple studies	21,736	Stress and anxiety	Survey of cell phone use (e.g., duration, intensity, frequency)	Yes	Small to medium association between smartphone use and stress and anxiety	Use of cell phones rather than RFR exposure
The influence of electromagnetic fields generated by wireless connectivity systems on the occurrence of emotional disorders in women	Wdowiak *et al*. (2018)		Cross-sectional	Healthy Polish Women (ages 25-35 years; mean, 31 years)	200	Depression and anxiety	Survey about exposure to GSM 900 MHz, GSM 1800 MHz, UMTS, DECT, WLAN	Yes	10-hour exposure assessment of RFR from wireless devices believed to contribute to depressive disorders. Opposite effect associated with WLAN.	Very narrow exposure window + disorders examined subject to variability in grading. Most comparison tests of exposure and health condition showed no association.
Effects of electromagnetic fields from mobile phones on depression and anxiety after titanium mesh cranioplasty	Zhu *et al*. (2016)	National Basic Research Program of China; National Natural Science	Prospective cohort	Chinese patients with traumatic brain injury and titanium mesh cranioplasty	220	Depression and anxiety	Survey about exposure to mobile phones as proxy for RFR exposure	No	Cell phone use after cranioplasty associated with lower risk of depression and anxiety status	Recall and social bias; Lacking generalizability

among patients with traumatic brain injury		Foundation of Chines		(mean age, 45 years)						
Mobile Phones in the Bedroom: Trajectories of Sleep Habits and Subsequent Adolescent Psychosocial Development	Vernon *et al*. (2018)		Cross-sectional	Health Austria adolescents between the ages of 13 to 16 years old	1,011	Depressed mood, sleep behavior, coping, self-esteem, externalizing behavior	Survey about nighttime phones use	Yes	Increase mobile phone used associated with increased externalizing behavior and decreased self-esteem and coping	Social and recall bias; Use of cell phones rather than RFR exposure

Table 5. Sleep

Study Name	Authors	Funding Source	Study Type	Study Population	Sample Size	Endpoint Examined	Exposure Assessment	Adverse Effect	Comments	My comments
Altering Adolescents' Pre-Bedtime Phone Use to Achieve Better Sleep Health	Bartel *et al*. (2019)		Cross-sectional	Australian adolescents (14-18 years old; mean, 16 years)	63	Sleep time	Sleep diary on cell phone use	Yes	Less phone use associated with longer sleep time and better quality of sleep	Recall and social bias
A meta-analysis of the effect of media devices on sleep outcomes	Carter *et al*. (2016)		Meta-analysis	Multiple studies based on children and adolescents		Sleep quantity	Media use (e.g., television, cell phones, computers, video games)	Yes	Media use before bedtime associated with poorer sleep quantity, quality, and excess daytime sleepiness	No RFR exposure assessment
Effects of EMFs emitted by mobile phones (GSM 900 and WCDMA/UMTS)	Danker-Hopfe *et al*. (2011)	German Mobile Telecommunication Research	Cross-sectional	Healthy German males (18-30 years old;	30	Sleep quality and heart rate	Exposure to GSM 900 MHz and WCDMA –	No	Little evidence for sleep-disturbing effect of cell phone exposure	High exposure for a prolonged period not realistic for either sleep or

on the macrostructure of sleep		Programm e		mean, 25 years)		during sleep	(SAR = 2 W/kg)			school environments.
An experimental study on effects of radiofrequency electromagnetic fields on sleep in healthy elderly males and females: Gender matters!	Danker-Hopfe *et al*. (2020)	German Federal Office for Radiation Protection	Cross-sectional	Healthy German males and females (60-80 years old; mean, 68 years old)	60	Sleep quality and heart rate during sleep	Exposure to GSM 900 MHz, TETRA, SHAM. 0.5 hour before sleep and 7.5 hours during sleep.	Mixed	Some evidence of sleep-disturbing effects of cell phone exposure	Exposure time and SAR (2-6 W/kg) unrealistically high for sleeping and school environments.
Mobile phone use, school electromagnetic field levels and related symptoms: a cross-sectional survey among 2150 high school students in Izmir	Durusoy *et al*. (2017)	German Federal Office for Radiation Protection	Cross-sectional	Healthy Turkish high school students (mean age, 16 years)	2510	Well-being after sleep	Survey on mobile phone use, presence of base station nearby, school RFR levels measured with Aaronia Spectran HF-4060 device.	No	Phone use (text talk) associated with headache and other symptoms. Limited associations between vicinity to base stations and some general symptoms. No symptoms association with school RFR levels.	Social and recall bias
Bedtime mobile phone use and sleep in adults	Exelman s *et al*. (2016)	Turkish National and Scientific Research Council	Cross-sectional	Healthy German adults (18-94 years old; mean age, 46 years)	844	Sleep quality, fatigue, and insomnia	Survey on bedtime mobile phone use	No	Phone use before bed associated with poorer sleep quality, more likely to experience insomnia, and increase fatigue	Social and recall bias; did not use complex survey design
Impact of Media Use on Adolescent Sleep Efficiency:	Fobian *et al*. (2016)		Cross-sectional	Healthy American adolescents (ages 14-15 years; mean 15 years)	55	Sleep offset and sleep efficiency	Survey on media use, including television, computer, cell phones, and video games	Yes	Media use is associated with poorer sleep efficiency, sleep onset, and sleep offset	Social and recall bias; did not use complex survey design
Adolescent Sleep Patterns and Night-Time Technology Use: Results of the Australian Broadcasting	Gamble *et al*. (2014)		Cross-sectional	Healthy Australian adolescents (11-17 years old; mean age, 15 years)	1184	Sleep patterns, sleepiness , sleep disorders	Survey on electronic devices use in the bed at nighttime	Yes	Use of computers, cellphones, and TVs in bed prior to sleep associated with delayed sleep/wake patterns	Social and recall bias; did not use complex survey design

Corporation's Big Sleep Survey										
Electromagnetic fields, such as those from mobile phones, alter regional cerebral blood flow and sleep and waking EEG	Huber *et al*. (2002)	Ionizing and Non-ionizing Radiation Protection Research Center	Cross-sectional	Healthy Swiss males (mean age, 22 years)	32	Sleeping-related variables	900 MHz	Yes	RFR exposure during sleep altered waking regional cerebral blood flow and pulse modulation of RFR effect waking and sleep EEG changes	
Mobile phone 'talk-mode' signal delays EEG-determined sleep onset	Hung *et al*. (2007)	Swiss and international research groups	Cross-sectional	Healthy UK adults (18-28 years old; mean, 22 years)	10	Sleep latency	Exposure to GSM 900 MHz with pulsed frequency at 217 Hz via thermally insulated silent phone beside the right ear	Yes	Exposure to GSM 900 associated with delay in sleep onset	Small sample size and lack of generalizability. Highly specific conditions (exposure for 30 minutes during the day followed by opportunity to sleep for 90 minutes)
Environmental Radiofrequency Electromagnetic Fields Exposure at Home, Mobile and Cordless Phone Use, and Sleep Problems in 7-Year-Old Children	Huss *et al*. (2015)	Swiss and international research groups	Cross-sectional	Healthy children in Amsterdam (6.7-8.5 years)	2361	Sleep problems	Mapping and modeling of RFR exposure from mobile phone base stations at children's home, WIFI at home, mobile phones	Mixed	Sleep onset delay, parasomnias and daytime sleepiness not associated with residential RFR from base stations. Sleep duration scores associated with RFR from base stations. Higher use mobile phones associated with less favorable sleep duration, night wakenings and parasomnias, and bedtime resistance. Cordless phone use not related to any sleeping scores.	Authors concluded that their study does not support the hypothesis that exposure to RFR is detrimental to sleep quality in 7-year old children, but potentially other factors that are related to mobile phone use.
Electromagnetic field of mobile phones affects visual event related potential	Jech *et al*. (2001)		Cross-sectional	Adults with Narcolepsy in Czech Republic	17	Event related potentials (EPR)	RFR 900 MHz from mobile phones	No	Exposure to mobile phone might suppress sleepiness and improve	Small sample size and lack of generalizability

in patients with narcolepsy: Mobile Phone Affects ERP in Narcolepsy				(mean age, 48 years)		during sleep			cognitive performance	
National data showed that delayed sleep in six-year-old children was associated with excessive use of electronic devices at 12 years	Kato *et al*. (2018)		Longitudinal	Healthy children (mean age, 6 years)	9,607		Survey on mobile phone use, watch TV, play video games	Yes	Use of mobile phone, TV, and video games associated with delay bedtime for children	Social and recall bias; did not use complex survey design
Electronic media use and insomnia complaints in German adolescents: gender differences in use patterns and sleep problems	Lange *et al*. (2017)	Japan Society for the Promotion of Science	Cross-sectional	Healthy Germans (ages, 11-17 years; mean, 14 years)	7533	Sleep time	Survey on media use on TV, computer/internet, video games, cell phones, music before bed	Yes	Everyday use of electronic media devices associated with insomnia	Social and recall bias; did not use complex survey design
Investigation of Brain Potentials in Sleeping Human Exposed to the Electromagnetic Field of Mobile Phones	Lebedeva *et al.* (2001)		Experimental	Healthy Russian male between the ages of 20 to 28 years	20	Insomnia complaints	Sham or RFR exposure from mobile phone	Yes	Exposure to RFR increased EEG alpha range power density during sleep in human's cerebral cortex biopotentials	Small sample size and lack of generalizability
The effect of electromagnetic fields emitted by mobile phones on human sleep	Loughran *et al.* (2005)		Experimental	Healthy Australian adults (18-60 years old; mean age, 31 years)	55	Sleep stage (duration and alternation)	900 MHz from mobile phones, 217 Hz pulsed field 30 minutes before sleep	Yes	Decrease in rapid eye movement sleep latency and increased EEG spectral power in 11.5-12.25 Hz frequency during initial part of sleep	
Effects of evening exposure to electromagnetic fields emitted by 3G mobile phones on health and night sleep EEG architecture	Lowden *et al.* (2019)		Experimental	Healthy Swedish adults (ages, 18-19 years)	22	Sleep stage (duration and alternation)	Sham vs 1930 – 1990 MHz for 3 hours before sleep. (SAR = 1.6 W/kg)	No	No differences in self-evaluated health symptoms, performance on the Stroop color word test during exposure or for sleep quality.	Small sample size and lack of generalizability

Stimulation of the Brain With Radiofrequency Electromagnetic Field Pulses Affects Sleep-Dependent Performance Improvement	Lustenberger *et al*. (2013)		Experimental	Healthy male adults between the ages of 18 to 21 years	16	Sleepiness and sleep architecture	All-night sham vs 0.25-0.8 Hz pulsed RFR (900 MHz mobile phone)	Yes	Low frequency pulse-modulated RFR affected some EEG parameters during sleep and altered sleep-dependent performance improvement	Small sample size and lack of generalizability
Inter-individual and intra-individual variation of the effects of pulsed RF EMF exposure on the human sleep EEG: Reproducibility of RF EMF Exposure Effects	Lustenberger *et al*. (2015)		Experimental	Healthy male adults (mean age, 23 years)	20	Sleep architecture	900 MHz from mobile phones	No	No difference in sleep spindle and delta-theta activity. Increases in delta-theta frequency range in several fronto-central electrodes	Small sample size and lack of generalizability
Association between screen viewing duration and sleep duration, sleep quality, and excessive daytime sleepiness among adolescents in Hong Kong	Mak *et al*. (2014)		Cross-sectional	Healthy Hong Kong adolescent between the ages of 12 to 20 years old	762	Sleep duration, quality and daytime sleepiness	Survey on screen viewing	Yes	Screen viewing correlated with shorter sleep duration, greater sleep disturbances, and daytime sleepiness	Social and recall bias; did not use complex survey design
The Association between Use of Mobile Phones after Lights Out and Sleep Disturbances among Japanese Adolescents: A Nationwide Cross-Sectional Survey	Munezawa *et al*. (2011)		Cross-sectional	Healthy Japanese adolescents between the ages of 13 to 18 years old	94,777	Sleep disturbances	Survey on the use of mobile phones after light out	Yes	Use of mobile phones after lights out associated with sleep disturbances	Social and recall bias
Effects of electromagnetic fields emitted from W-CDMA-like mobile phones on sleep in humans	Nakatani-Enomoto *et al*. (2013)		Experimental	Healthy Japanese adults (22-39 years old; mean age, 31 years)	19	Sleep stage (duration and alternation)	900 MHz from mobile phones	No	No effect on sleep	Small sample size and lack of generalizability

Comparison of the effects of continuous and pulsed mobile phone like RF exposure on the human EEG	Perentos *et al*. (2007)		Experimental	Healthy Australian adults (19-32 years old; mean, 26 years)	12	Sleep architecture	900 MHz from mobile phones	No	No effect on sleep	Small sample size and lack of generalizability
Sleeping with technology: cognitive, affective, and technology use predictors of sleep problems among college students	Rosen *et al*. (2016)		Cross-sectional	Healthy US college students - mean age, 26 years	734	Sleep problems	Survey on daily smartphone use, nighttime phone location	Yes	Daily phone use and phone use at night are predictors of sleep problems	Social and recall bias; did not use complex survey design
Are you awake? Mobile phone use after lights out	Saling *et al*. (2016)		Cross-sectional	Healthy Australians (18-69 years old; mean, 34 years	397	Self-report tiredness after sleep	Survey on nighttime mobile phone use	Yes	Using mobile phones after lights out associated with tiredness and sleep disturbance	Social and recall bias
Mobile phone use and stress, sleep disturbances, and symptoms of depression among young adults--a prospective cohort study	Thomée *et al.* (2011)	Swedish Council for Working Life and Social Research	Prospective cohort	Healthy Sweden adults (20-24 years old)	4156	Sleep disturbances	Survey on mobile phone uses	Yes	High mobile phone use associated with sleep disturbances and symptoms of depression for men at 1-year follow up	Social and recall bias
Mobile Phones in the Bedroom: Trajectories of Sleep Habits and Subsequent Adolescent Psychosocial Development	Vernon *et al.* (2018)		Cross-sectional	Healthy Austrian adolescents between the ages of 13 to 16 years old	1011	Sleep behaviors	Survey on nighttime mobile phone use	Yes	Night-time mobile phone use and associated with poor sleep behavior	Social and recall bias; did not use complex survey design
Human sleep EEG under the influence of pulsed radio frequency electromagnetic fields.	Wagner *et al*. (2000)	Technologiezentrum of Deutsche Telekom Ag	Experimental	Health German males (19-36 years; mean age, 24 years)	20	Sleep architecture	900 MHz from mobile phones. Power flux density of 50 W/m(2)	No	No significant effect on sleep compared to non-exposed	Small sample size and lack of generalizability