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.

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 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.

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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. And the exact attributes associated with the use of these devices need to be explored further in longitudinal (long term follow-up) studies, in-depth health assessments, double blind studies, and RFR exposure assessments.

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Background

Senate Bill 283 (SB 283) directs the Oregon Health Authority (OHA) to r~~1) rR~~eview peer-reviewed, independently funded scientific studies of the health effects of exposure to microwave radiation, particularly ~~exposure that results~~ 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~~; and 2)~~ r~~R~~eport the results ~~of the review~~ of this review to an interim committee of the Legislative Assembly related to education by~~not later than~~ 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)

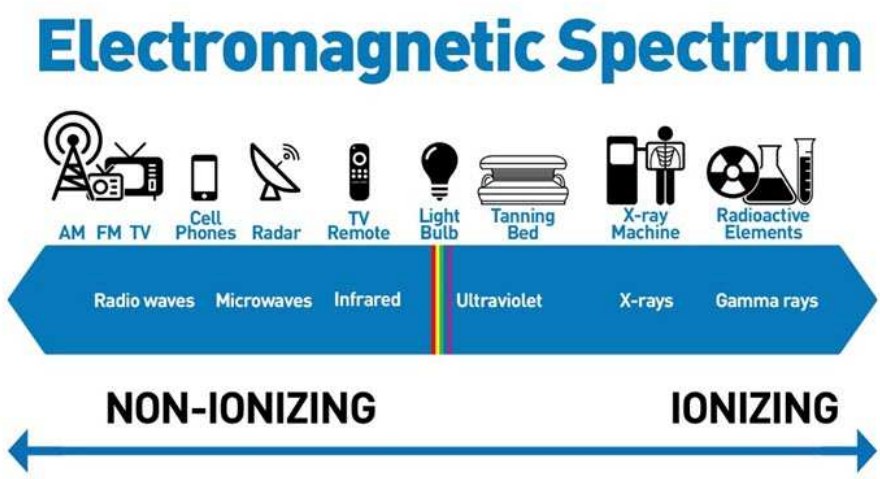
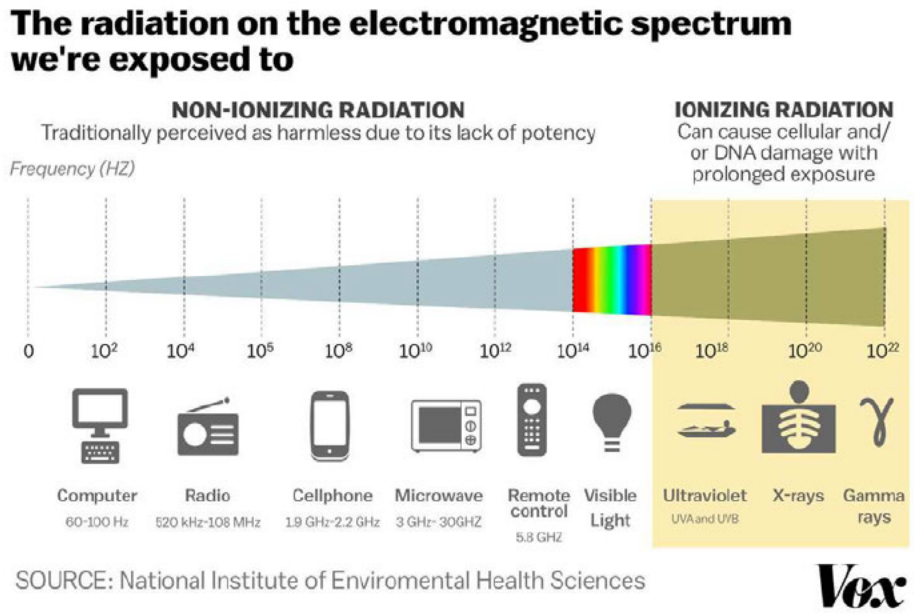


Figure 1: Electromagnetic Spectrum



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 and to send telephone and television communications. One of the common consumer use of microwave energy is in microwave ovens. Microwaves excite molecules causing them to vibrate which in turn heats food and water. 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.

Commented [HAK1]: not cell phones or wifi?

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. E~~E~~stablishing causal relationships between exposures and ~~cancer~~health outcomes relies on effective epidemiolog~~y~~ical study designs. A major epidemiolog~~y~~ical 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 epidemiologi~~ca~~cal study subtype is experimental studies, which include randomized controlled trials (RCTs), non-randomized trials, and other types. Observational studies are most common for ~~examination of cancer~~nonclinical health settings~~ outcomes in human populations, as experimental studies are typically unethical~~

~~or not feasible for study of cancer progression sequences~~. 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)~~is a benchmark that is commonly referenced for determination of causation.~~ 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~~is another factor that influences the ability to determine causation. For example, the strong positive statistical association between smoking and lung cancer is extremely consistent in the literature, providing robust evidence of a causal relationship.~~ 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 ~~cancer~~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 [BRB3]: 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

~~In order to begin a literature review of the scientific evidence of an association between cancers and exposure to radiofrequency radiation (RFR) commonly found in school environments, a search strategy was first formulated. The goal of the search was to identify all evidence from studies on human exposure to RFR commonly found in school environments from published peer-reviewed scientific articles which had cancer endpoints, were published in English, and involved the broad set of search terms below. For the purposes of this literature search, exposure to "RFR commonly found in school environments" was identified as RFR exposures in the frequency range of mobile phones and Wi-Fi, or approximately between 1.6 and 30 gigahertz. This frequency range includes both ultra-high and super-high radio frequencies, which is also the range that the majority of current fifth generation (5G) networks utilize.[1] Studies without specific reference to the frequency range of exposures were reviewed on a case-by-case basis to identify if the exposure constituted an RFR exposure that would likely to be present in schools. The date range used for the RFR exposure/cancer studies was January 1st, 1993 to April 24th, 2020. This date range was utilized in order to target the timeframe between rollout of 2G networks in the United States (1993) and present day. Two scientific article databases, PubMed and IEEE Xplore, were selected as the search databases for this review based on the ability of these databases to capture all relevant articles. The pool of initial cancer studies on school-related exposure to RFR was identified using the following terms on~~ 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 initial~~ search found 176 papers ~~for consideration~~. Use of the "humans" species filter ~~on PubMed~~ reduced the number of papers to~~scope of the search to~~ 137 ~~papers~~. ~~The parameters after the 'NOT' term also removed many unrelated papers outside of the scope of the review.~~ Many ~~of the~~ 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~~school-related human~~ RFR exposures and cancer or were outside ~~of~~ the scope of this review. Further a~~A~~bstract~~s of the 105 remaining studies were then~~ review~~ed, result~~ed~~ing in removal of ~~47~~59 more studies. Articles not included after abstract filtering included those that did not contain exposures within the relevant RFR range~~on the~~

~~targeted radiofrequency band of the electromagnetic spectrum~~, those that were not completed for human populations, and those that were not original research or review articles. We reviewed the ~~After completion of these procedures, 58 studies remained. After review of the full text of the 58 articles, 12 more studies were removed based on a lack of targeting of the relevant frequency band, leaving 46 studies for review. R~~references of the remaining~~all~~ 46 studies ~~were also reviewed in order~~ to capture research papers that we~~re~~ missed in our~~the above~~ initial search. This ~~terms, result~~ed~~ing~~ in ~~48~~ 49 more studies for a total ~~added for consideration. Overall,~~ 97 cancer studies that we~~re~~ reviewed.

IEEE Xplore search terms ~~In similar fashion to the search strategy for PubMed research articles, search terms were also formulated to identify RFR exposure/cancer studies in the IEEE Xplore database with goals to capture any studies that were more technical than those available on PubMed. Again, the date range for the search was January 1st, 1993 to April 24th, 2020 for articles published in English. The pool of initial cancer studies was identified using the following search terms on IEEE Xplore:~~

((((((("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 initial~~ search found 159 papers ~~for review~~. 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~~results~~ was reduced to 50 papers ~~possibly relevant to the review~~. ~~After r~~Review of the titles of the studies removed~~,~~ 13 studies of~~were removed due to~~ unrelated subject matter. After title filtering, we reviewed the abstracts of all remaining 37 studies and found no articles that ~~were reviewed, resulting in removal of 32 more studies that~~ were within~~outside of~~ the scope of this review, either due to the lack of~~. Finally, full-text articles of the remaining 5 studies were reviewed and it was determined that all of the studies did not have~~ cancer endpoints under direct study or to a focus limited~~were focused on technical aspects related only~~ to exposure assessment. Therefore, we did not include ~~Due to this circumstance, no~~ cancer studies from IEEE ~~were included~~ in this review.

~~Occupational Studies~~

~~Following a similar strategy to the search for cancer studies, the scientific evidence of an association between all adverse health outcomes and occupational RFR exposures with frequencies that overlap with frequencies of RFR commonly found in school environments. The goal of this search was to identify all evidence from studies on human occupational exposure to RFR within the range of school-related frequencies from published peer-reviewed scientific articles which studied adverse health outcomes, were published in English, and involved the broad set of search terms below. These studies were included in the literature review search strategy to examine how high levels of exposure to school-related radiofrequencies may be associated with adverse health outcomes. The date range used for the occupational RFR exposure studies was January 1st, 1993 to April 24th, 2020. The same two scientific article databases, PubMed and IEEE Xplore, were selected as the search databases for the occupational study review. The pool of initial occupational studies was identified using the following terms on PubMed:~~

~~"Radio Waves/adverse effects"[MeSH] OR "Electromagnetic Fields/adverse effects"[MeSH] OR "wi-fi"[ALL FIELDS] OR "wifi"[ALL FIELDS] OR "wlan"[ALL FIELDS] OR ("mobile"[ALL FIELDS] AND "phones"[ALL FIELDS) OR ("cell"[ALL FIELDS] AND "phones"[ALL FIELDS]) OR "cell towers"[ALL FIELDS] AND ("occupational health"[MeSH] OR ("occupational"[ALL FIELDS] AND "health"[ALL FIELDS]) OR "occupational exposure?"[MeSH] or ("occupational"[ALL FIELDS] AND "exposure"[ALL FIELDS])) AND "1993/01/01"[Date - Publication] : "3000"[Date - Publication]) AND English[lang] NOT("behavior change"[ALL FIELDS] OR "hearing loss"[ALL FIELDS] OR "adolescent"[ALL FIELDS] OR "child" [ALL FIELDS] OR "smoking"[ALL FIELDS] OR "pollution"[ALL FIELDS] OR "rehabilitation"[ALL FIELDS] OR "mass media"[ALL FIELDS] OR "motor vehicles"[ALL FIELDS] OR "history"[ALL FIELDS] OR "rats"[MeSH] OR "infections"[ALL FIELDS] OR "infection control"[ALL FIELDS] OR "Comment"[Publication Type] OR "cell line"[ALL FIELDS] OR "psychology"[ALL FIELDS] OR "telemedicine"[ALL FIELDS] OR "qualitative research"[MeSH] OR "delivery of health care"[MeSH] OR "electromagnetic phenomena/instrumentation"[MeSH] OR "user-computer interface"[MeSH] OR "air pollutants/toxicity"[MeSH] OR "metals"[NM] OR ("in vitro"[ALL FIELDS] AND "human"[ALL FIELDS] AND "cells"[ALL FIELDS]) OR "computer simulation"[MeSH] OR ("accidents"[ALL FIELDS] AND "driving"[ALL FIELDS]) OR "Letter"[Publication Type] OR "Editorial"[Publication Type] OR "News"[Publication Type] OR "Guideline"[Publication Type])~~

The initial search found 395 papers for review. Use of the "humans" species filter on PubMed reduced the scope of the search to 365 papers. Like the cancer study search, the parameters after the 'NOT' term also removed many unrelated papers outside of the scope of the review, including those related to occupational exposure assessment, those not in appropriate mediums (such as newspapers), and those using human cell lines. Titles of all 365 papers were then reviewed, 35 more were removed due to unrelated content matter. Next, the abstracts of all 330 remaining studies were, resulting in removal of 135 studies, largely due to a lack of targeting of RFR frequencies commonly found in schools (1.6-30 GHz). Finally, the full-text articles of the remaining 195 articles were examined, resulting in further removal of 144 studies. Most of the removed full-text articles did not target RFR frequencies commonly found in schools. For example, there were many studies focusing on power frequencies, frequencies associated with magnetic resonance imaging, frequencies associated with welding occupations, and others. The majority of the remaining 51 occupational studies focused on occupations with radio, microwave, radar, and other similar exposures, which overlap with RFR frequencies commonly found in schools.

Like the cancer studies, search terms were also formulated to identify adverse health outcome/occupational RFR exposure studies in the IEEE Xplore database with goals to capture any studies that were more technical than those available on PubMed. Again, the date range for the search was January 1st, 1993 to April 24th, 2020 for articles published in English. The pool of initial occupational studies was identified using the following search terms on IEEE Xplore:

(((((((("All Metadata":wifi) OR "All Metadata":wi-fi) OR "All Metadata":wlan) OR "Mesh_Terms":mobile phones) OR "All Metadata":mobile phones) OR "All Metadata":cell phones) AND "Index Terms":occupational health) OR "All Metadata":occupational health)

The initial search found 2,095 papers for review. After using filters to only include journal articles, magazine articles, articles published in English, articles in the date range, and articles filed under the "occupational health" publication topic, the number of results was reduced to 88 papers possibly relevant to the review. After review of the titles of the studies, 58 studies were removed due to subject matter not directly related to the review topic. After title filtering, abstracts of all 30 studies were reviewed, resulting in removal of 21 more studies that were outside of the scope of this review. Finally, full-text articles of the remaining 9 studies were reviewed and it was determined that all of the studies did not have adverse health outcomes under direct study or were focused on technical aspects related only to exposure assessment. Due to this circumstance, no occupational studies from IEEE were included 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.

Commented [HAK4]: What does this refer to? Is it a google search or studies cited in papers?

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

~~Establishing causal relationships between exposures and cancer outcomes relies on effective epidemiological study designs. A major epidemiological 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 epidemiological study subtype is experimental studies, which include randomized controlled trials (RCTs), non-randomized trials, and other types. Observational studies are most common for examination of cancer outcomes in human populations, as experimental studies are typically unethical or not feasible for study of cancer progression sequences. 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 causal evidence.~~

~~Causal inference in epidemiology is not an exact science and there is no single definition of what constitutes a causal exposu e-outcome relationship. Beyond study design, a va iety of othe contextual facto s can be utilized to examine causal relationships. A dose–esponse g adient, whe e inc easing exposu e dose esults in inc eased isk of adve se health outcomes;~~

Commented [5]: Is there an intro sec ion? Discussing basic science around wifi radiation. Discussing basic epi and study types. What is needed to infer a casual relationship?

Commented [HAK6R5]: Agreed. Hillary will take care of the RFR physics and background though

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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

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~~is a benchmark that is commonly referenced for determination of causation. Consistency in study results is another factor that influences the ability to determine causation. For example, the strong positive statistical association between smoking and lung cancer is extremely consistent in the literature, providing robust evidence of a causal relationship. 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 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 a 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. ~~Therefore, mechanistic evidence of a relationship between RFR and cancer is currently lacking.~~ In the following sections, we reviewed studies examining relationships between super-high and ultra-high RFR exposure and cancer endpoints ~~are reviewed~~.

Commented [9]: is this the landmark paper that suggested this mechanism? I would cite either the landmark paper, a consensus statement, or something from a professional or governmental agency

Commented [BRB10R9]: There are not really –the FDA's review does not even list anything about possible mechanisms, the FCC's RFR fact sheet does not list a mechanism: https://www.fcc.gov/engineering-technology/electromagnetic-compatibility-division/radio-frequency-safety/faq/rf-safety and a 2017 fact sheet by a Canadian environmental health agency says the mechanism is unknown: https://ncceh.ca/environmental-health-in-canada/health-agency-projects/radiofrequency-radiation. Maybe we could simply say the mechanism is still under investigation or unclear?

Commented [11]: is there a good reference to indicate that this is the only viable and accepted mechanism?

Childhood Cancer Studies

Like other health endpoints in subsequent ~~other~~ sections of this report, there is a limited number of ~~are fewer~~ epidemiologi~~cal~~ly studies that directly examined the health ~~carcinogenic~~ effects of RFR exposure on children. Based on our search terms and the search time frame, there are 9 studies that ~~epidemiologically~~ 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 2,606 cancer cases in children 15 years and under from Taiwan's national health insurance database and 78,180 controls from a national population registry, individually matched by age. Exposure was quantified by using location of mobile phone base stations, participant residence location, and years of residence at that location. The study found a 13% increase in odds of overall cancer (but not separately for leukemia or brain cancer) among children in higher average RFR power density areas, although adjusting the highest tertile (highest quarter) of exposure for covariates rendered it statistically insignificant.

Another large case-control study completed by Elliott *et al.* (2010) in Britain for the period 1999-2001 found no association between exposure to mobile phone base station exposure and early childhood cancers such as brain, central nervous system (CNS), non-Hodgkin's lymphoma, and all combined cancers.[6] 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 brain tumor risk increase with duration of mobile phone use or 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 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.

~~Of the 6 studies where RFR exposures were higher than what would be expected in schools, one~~Another case-control study ~~completed~~ by Ha ~~et al~~*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 ~~were recruited from~~in children under 15 years diagnosed between 1993 and 1999 in 14 South Korea~~n~~ 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, ~~A descriptive incidence study by Michelozzi et al. (2002) completed near a high-power radio station in Rome, Italy found that risk of childhood leukemia was higher than expected for distances up to 6 kilometers from the radio transmitters.[11] The study population included 49,656 residents, which was all adults and children living within 10 kilometers of the Vatican Radio station for the years 1987 to 1999. No exposure assessment was completed for the study, relying instead on childhood leukemia mortality and incidence rates of Rome overall as the comparison group. The standardized incidence ratio of leukemia for children living up to 6 kilometers from the radio station transmitters was 2.2, or over twice as high as the incidence rate for Rome overall. The researchers also found that there was a dose-response relationship in terms of risk of childhood leukemia with decreasing distance from the transmitter. The lack of an exposure assessment in this study reduces the ability to interpret the results, as no individual child RFR exposures were recorded. This results in misclassification bias and unmeasured confounding in the associations.~~

~~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, there was a large case-control study completed by Merzenich et al. (2008) in Germany between 1984 and 2003 examining childhood leukemia near high-power AM and FM radio transmitters and television broadcast towers.[10] 1,959 cases of childhood leukemia in children 14 years and under were ascertained from a German national childhood cancer registry, while 5,848 controls were 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.~~

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.

~~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] 2,606 cancer cases in children 15 years and under were ascertained from Taiwan's national health insurance database, while 78,180 controls were ascertained from a national population registry and individually matched by age. Exposure was quantified by using location of mobile phone base stations, participant residence location, and years of residence at that location. The study found a 13% increase in odds of overall cancer among children in higher average RFR power density areas, but not separately for leukemia or brain cancer.~~

Overall,

~~Another large case-control study completed by Elliott et al. (2010) in Britain for the periodbetween 1999 and 2001 found no association between exposure toexamining the effects of mobile phone base station exposure and early childhood cancers such as on brain, central nervous system (CNS), non-Hodgkin's lymphoma, and all combined cancers in children found no association.[6] 1,397 cancer cases in children 4 years and under were ascertained from the British cancer registry, while 5,588 controls were ascertained from the British national birth registry and 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.~~

~~Because only~~ 9 studies examined the relationship between RFR exposures and childhood cancer endpoints with mixed results.~~, it is difficult to arrive at a definitive conclusion.~~ These ~~results for the existing~~ studies had~~should also be considered in light of a major overarching~~ several methodological limitation that included~~:~~ poor assessment of and control for individualized RFR exposures and confounding from other RFR sources. ~~.~~For example, m~~M~~odeled 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 ~~all of~~ the ~~important~~ 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~~is lack of~~ studies and methodological problems ~~clarity~~ are~~is~~ further compounded by the fact that ~~the results~~findings have been inconsistent ~~from study to~~among stud~~y~~ies 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 ~~are reviewed~~.

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.[54] 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.[55] 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.[56] 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.[57,58] 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.[59] 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.[60] 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[61] 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. 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.[62] 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.[63] 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. The authors included all cases of skin cancers diagnosed in Denmark and having cell phone subscriptions starting between 1987 and 1995. 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.[64] 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.[65] 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 (Benson *et al*., 2014)[66].

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.

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 ~~has~~ published 15 epidemiologi~~cal~~ly papers directly related to the present review that examined~~, where they analyzed~~ relationships between analog, cordless, and mobile phones and types of brain, head, and neck tumors [14–26] Fourteen~~14 Most~~ of the ~~15~~ papers report~~ed~~ results from case-control studies and twelve~~12 of the 15 papers~~ 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 ~~to one another~~ and therefore~~, so they~~ share the same methodological strengths and weaknesses. A major strength of the Hardell group~~'s~~ case-control studies is the use of blinding for exposure interviews, which is somewhat rare among case-control studies on this subject.[27] Noted weaknesses of the Hardell group case-control studies ~~have~~ include~~d~~ pooling of case-control results, recall bias, participation bias, reporting bias, sampling bias, and selection bias.[28] Five of the 15~~2~~ 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.[18,19,21,25,29] We reviewed a ~~A~~ selection of studies by this ~~e Hardell~~ research group ~~are reviewed~~ below.

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First:
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):1833-1845

Second (#29 below):
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):1036-1044.

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.[15] The study included 1,429 brain cancer cases ~~were ascertained~~ 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.[17] The study included 317 malignant brain cancer cases ~~were ascertained~~ from 2 Swedish regional cancer registries encompassing all individuals 20 to 80 years diagnosed with brain tumors and~~, while~~ 692 controls ~~were ascertained~~ 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.[22] The study included 390 meningioma cases ~~were ascertained~~ from 6 Swedish cancer registries encompassing all individuals aged 18 years to 75 years diagnosed with meningiomas and~~, while~~ 1,368 controls ~~were ascertained~~ from the national population registry~~, and~~ 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~~, indicating a weak dose-response relationship~~.

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. ~~Other researchers~~A few studies on long-term phone exposure studies from the INTERPHONE group (discussed below) and other researchers have ~~have~~ replicated these results, but the association is not unanimous and it remains unclear whether ~~this is due to~~there is a true positive effect or bias and unmeasured confounding.~~ T~~Still, t~~he Hardell group's overall consistently positive and statistically significant associations are not consistent with~~an anomaly among~~ the broader case-control literature on mobile phones and cancer endpoints. This becomes clearer when considering meta-analysis study results that~~, which~~ showed no statistically significant increase in brain or head/neck cancer risk from use of wireless phones.[30] 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.[28,30] 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~~*et al.*, meaning that the extent and direction of bias is impossible to know.[30] A recent~~2020~~ 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.[22,25,26,28,29] 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~~s~~ 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,[31] which is the time frame when the majority of these case-control studies were completed.

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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 focus~~concentrate~~d on cancer in ~~younger~~ people age~~s~~d 30 years to 59 years living~~and~~ in~~among~~ urban settings~~individuals~~, 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 14 papers, with six~~6~~ finding positive statistically significant associations

between mobile phones and cancer endpoints.[32–46] Like the Hardell group case-controls, INTERPHONE case-control studies have several~~a litany of~~ 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~~a~~ review a selection of ~~important~~ INTERPHONE studies~~case-controls are reviewed~~.

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.[47] 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~~, while in Israel, controls were also matched by ethnicity~~. All controls were ascertained from population-based databases~~, such as national population 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 (~~greater than or equal~~ 1,640 cumulative hours or more) category showed an increase in glioma risk ~~in glioma~~. The other large INTERPHONE case-control study (2011) followed a~~very~~ similar methodology to the 2010 study and~~, but instead~~ examined the risk of acoustic neuroma as a result of mobile phone use in 1,105 cases and 2,145 controls.[37] The study found increased ~~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 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.[33] It included 678 cases of acoustic neuroma ~~were~~ ascertained from medical centers in the respective countries and 3553 controls ~~were ascertained~~ 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.[36] The study included 553 glioma and 676 meningioma cases ~~were~~ ascertained from neurological and ontological centers in each country and~~, while~~ 1,762 glioma controls and 1911 meningioma controls ~~were ascertained~~ from locally-appropriate population-based sampling frames. Exposure was quantified with highly detailed

interviews that collected data on ~~usage~~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 ~~non-~~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.[32] The study included~~4~~ 405 cases ~~were ascertained~~ from hospitals in participating Canadian provinces and 516 controls ~~were ascertained~~ 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~~, so results may be more reliable~~.

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.[33,36,37,47] 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~~.~~[48–50] including that for ~~Also, a dose-response relationship exists for the causal association between~~ ionizing radiation and cancer~~,~~[51] ~~so the same would be expected for non-ionizing radiation from mobile phones~~. Some INTERPHONE studies ~~have~~ also found that mobile phones provided a "protective" effect on cancer, which indicates significant and multifactorial bias~~, undermining the validity of INTERPHONE results~~.[28] 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 ~~extensive~~ 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,[52] and 4) poor evidence of a dose-response relationship.

~~**Other Studies**~~

~~Descriptive, ecological, case-control, and cohort studies have also been completed by other researchers for study of the relationship between RFR exposure and cancer endpoints. In terms of the hierarchy of epidemiological evidence, descriptive and ecological studies are generally viewed as lower quality evidence than case-controls, while cohort studies are viewed as higher quality evidence,[53] although quality varies from study to study. Below is a collection of important studies not completed by the Hardell or INTERPHONE groups.~~

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A 2010 descriptive study by Inskip et al. examined brain cancer incidence trends in the United States as they related to widespread phone use over time.[54] The study included 38,788 cases of brain cancers among white patients diagnosed between 1977 and 2006. Because the study was descriptive, 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 note in their discussion section 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 usage and brain cancer. However, a small but causal increase cannot be ruled out based on their study design. A similar 2016 descriptive study by Chapman et al. examined overall brain cancer incidence trends and phone usage in Australia.[55] 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 any rise in brain cancer incidence in any age group that could be attributed to mobile phones usage. Incidence studies do not take into account individual mobile phone exposures, so deriving causal evidence is more difficult.

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Two ecological studies by de Vocht et al. (2016 & 2019) examined the associations between brain cancers in England and mobile phone subscriptions.[57,58] The 2016 study assessed the relationship between annual mobile phone subscriptions 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 increases. The 2019 study assessed the relationship between annual mobile phone subscriptions and annual 1985-2005 incidence of glioblastoma (14,503 cases). The study found non-significant risk increases of between 35% and 59% for temporal and frontal lobe tumors and tumors of the cerebellum. Both of the de Vocht studies use 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.[59] 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 2000 U.S. case-control study by Muscat et al. examined the risk of brain cancer as a result of cell phone use.[60] The study

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included 469 cases were ascertained from individuals 18 years to 80 years diagnosed with primary brain cancer in 5 medical institutions in New York City, Providence, and Boston between 1994 and 1998 and, while 422 controls were ascertained from non-malignantin-patients without cancer and non-brain cancer malignant in patients 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. A 2001 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.[61] in 782 cases were ascertained from individuals 18 years and older diagnosed in 4 hospitals in Phoenix, Boston, and Pittsburgh between 1994 and 1998 and, while 799 controls were ascertained from patients admitted to the same hospitals for non-malignant conditions and frequency-matched by age, sex, race, and hospital proximity. 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. These results are in general agreement with most of the INTERPHONE studies, but less so with the Hardell group studies.

Both retrospective and prospective cohort studies have been completed to examine the risk of cancer from mobile phone use. A 2004 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.[62] 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 crude and based only on 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.

A 2011 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.[63] 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 usage of mobile phones wais related to risk of vestibular schwannoma. 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 Danes 30 years and older born in Denmark after 1925.[64] From these records, Danish 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 found no increased risk of CNS cancer from mobile phone exposure. A 2013 prospective study by Benson et al. examined the risk of intracranial CNS tumors as a result of mobile phone use.[65] 791,710 middle-aged U.K. women were recruited for the study between 1996 and 2001 via a National Health Service

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Commented [20]: there are some huge studies in here that are arguably stronger than some of those given separate headings above. It would make sense to lead with these and not list them under "other studies". Why do Interphone and Hardell studies get their special sec ions? Are they better conducted?

Commented [BRB21R20]: I briefly responded to this above – mostly due to the volume of studies by interphone and Hardell. In my opinion, these retrospective cohorts are also not that great due to their terrible exposure assessments despite the huge sample sizes. Benson *et al*. is the only one possibly worthy of having its own section. It seemed more intuitive to set it up this way for a narrative format, as opposed to what I did previously where I set up the sections based on study types.

~~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 incidentce CNS tumors were observed. The study found no difference in risk of CNS tumors between never and ever users of mobile phones but found an 146% increased risk of acoustic neuroma in long-term mobile phone users and a dose-response relationship for acoustic neuroma in terms of duration of use. No increased risk of glioma or meningioma was found for long-term users. Generally, cohort studies are considered the highest quality epidemiological 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. The findings of this study agree with a number of the INTERPHONE and Hardell group studies, where long-term exposure to mobile phones is associated with increased risk of CNS cancer. The Benson et al. study also found a dose-response relationship, which is a finding that is largely missing from the case-control studiesliterature outside.~~

Summary of Cancer Endpoints

Overall, there is ~~currently~~ insufficient evidence to indicate a causal relationship between mobile phone exposures and any cancer endpoint. Most~~The large majority of~~ studies that we reviewed found no association between ultra-high and super-high RFR exposures and cancer endpoints. Alt~~T~~hough an association ~~there is some agreement among studies of an association~~ between long-term mobile phone use and various brain cancers was found in some studies, ~~including in the high-quality Danish prospective cohort study by Benson et al.,~~ more studies found no association between long-term use and cancers. Further, many~~most~~ of the studies ~~with positive associations~~ have~~ve~~ ~~an extensive list of~~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 ~~problems~~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 ~~many~~ 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 ~~Further, results~~~~Results~~ ~~from the Benson et al. and case-control~~epidemiology studies with positive associations ~~y~~ are not enough ~~evidence alone~~ 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, ~~.~~ ~~T~~ the lack of a dose-response relationship in most studies, and the overall inconsistent results ~~further indicate that a causal relationship between RFR and cancer is unlikely to exist. Going forward, researchers should consider completi~~However, as the global population continues to be exposed to RFR from various sources, m~~n~~gore high quality prospective cohort studies are needed to ~~confirm to further examine the true~~inform the weight of evidence for any ~~the carcinogenic~~ effects of long-term RFR~~mobile ph~~ exposure~~one use~~ 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.

Toxicity

~~Radiofrequency Radiation Exposures on Body System~~

~~Radiofrequency radiation (RFR) is non-ionizing radiation that is often emitted from electronic devices such as cell phones, computers, tablets, and television. Many electronic devices utilizing wireless technology will emit RFR. Due to the advancement of technology and the reliance on electronic devices in human lives, humans are exposure to RFR daily. The effect of RFR had been examined among literature.~~
~~Exposure to RFR could lead to negative effect on the human body. Many literature had examined the effect of RFR on various human body system. Harms to any part of the human body could lead to negative impact on everyday functions and disabilities. In the following sections, studies examining the relationship between RFR exposure and the human body will be discussed categorized by different human body systems and functions, such as auditory functions, cognitive functions, cardiorespiratory systems, central nervous system, children development, miscarriage, and reproductive system.~~

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~~*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 ~~(aged 29 to 58 years; mean, 47.5 years) participants in the study~~. Participants~~They~~ were exposed to RFR from a simulated GSM signal (889.6 MHz/2.2 W) at both ears at different times. ~~two mobile phones (one on each ear) with simulated pulsed GSM signal with assigned frequency of f = 889.6 MHz along with pulse modulation with repetition frequency fp = 217 Hz, period of Tframe 4.61 ms, and pulse width of Tp = 576 µs.~~ 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)~~study found that the inner layer of the ear tissues (ear canal) have less than 0.1°C of temperature increased.~~ ~~but it does change the body temperature (Bortkiewicz et al., 2012).~~ ~~The results found that temperature only raised when the tissue layers were next to the radiation source, where deeper layer of tissues were unaffected.~~

~~In the cross-sectional study by Sievert et al. (2005) examined whether mobile phone emission of RFR could affect cochlear or auditory brain stem functions. 12 healthy individuals (mean age, 28.7 years; range, 19 to 57 years) with normal hearing, auditory brain stem reflex participated in the study. All participants were exposure to RFR from two mobile phone, one on each ear, with GSM Signal with frequency of 8896 MHz. Participants were exposure RFR via two different styles of RFR exposure, pulsed and continuous filed. Before each new session of RFR exposure, there was a pause of three minutes. The results found that there were no changes to absolute and interpeak latency from each wave of measure. Absolute latencies can be influenced by peripheral hearing loss and the interpeak latencies are measured of central neural conduction time. The results suggested that no influence of RFR, neither with pulsed nor with continuous mode of application, could be observed. The study conclude that short-term range of RFR from mobile phone will affect auditory function. However, any long-term effects were not determine in the study.~~ 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. 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) (Colletti *et al*., 2011) which might correspond to a direct thermal effect due to the exposed brain tissue.

Brain/cognitive function

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In a cross-sectional study, ~~by~~ Riddervold ~~et al~~*et al*. (2008) found~~ind the~~ that exposure to RFR d~~oes~~id not affect cognitive function. The purpose of the study was to assess the effect of RFR from ~~UMTS~~3G ~~-~~telecommunications base~~d~~ station on symptoms and cognitive function in adults and adolescents. ~~40 of 15 to 16 years old adolescents and 40 adults between ages of 25 to 40 years old participated in the study. Each participants was exposed to a combination of four possible exposure types; sham, CW at 2140 MHz, a signal at 2140 MHz modulated s UMTS and UMTS at 2140 MHZ.~~ The cognitive ~~test of the~~ function test, Trail Making B ~~(TMB) test~~, ~~a test~~ where participants had to draw lines alternating between numbers and letters in consecutive order, w~~as~~~~ere~~ administ~~rat~~ered after the exposure to RFR. ~~To determine the effect of RFR exposure on cognitive function, an ANOVA model including study day, exposure, group (adult/adolescents) as fixed effect and participants (persons) as a random factor.~~ The authors~~results~~ found ~~that there were~~ no effect of RFR on ~~significant in scores on the TMB~~ test ~~between the sham group and the RFR exposure group for adults and adolescents when analyzed separately by age group~~performance. ~~The study results did not support the hypothesis of UMTS radiation reduces general performance in the TMB test.~~

Thomas ~~et al~~*et al*. (2010) conducted a survey to investigate mobile phone use behaviors over a period of 1 year in a cohort ~~regarding the usage of mobile phones as a proxy for exposure for RFR among~~of 238 adolescents living in Australia. The authors also assessed ~~. Data from the Australian Mobile Radiofrequency Phone Exposed Users' Study (MoRPHEUS), which consisted of year 7 students during 2005/2006 period with a 1-year follow-up. The study focus on the data form the 1-year follow-up and determine how the usage of mobile phones changed after 1 year along with cognitive performance. Questionnaires were used to determine participants' mobile phone usage behaviors and~~ cognitive function ~~were assessed~~ 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. ~~Data of 238 participants were included in the analysis. Among the participants, there were increased in proportion of mobile phone owners from baseline to follow-up and the total number of self-reported voice calls per week and the number of text messages increase from baseline as well. The results of the cognitive test found that performance in the Stroop Color-Word test improved with an overall decrease in response time between baseline and follow-up. From the analysis of regression on number of voice calls and number of text massagers adjusting for age at baseline, sex, ethnicity, height difference between baseline and follow-up, time period, and socioeconomic status, association were found between difference in numbers of voice calls and working memory response time. Additional analysis based on increase in exposure (e.g., mobile phone, RFR) and decrease or no change in exposure found that those with an increase in exposure had a greater~~

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~~reduction in response time. Further, no association were found between mobile phone usages behavior and the Stroop Word Test.~~ The authors suggested that while change in cognitive functions were observed, the change could be due to statistical regression to the mean ~~scores of exposure~~ and not to ~~be the~~ effects of mobile phone exposure. ~~It is important to note that this study used survey to measure mobile phone behaviors and used as proxy for RFR exposure. Therefore, caution should be taken when examining the relationship with RFR and cognitive function.~~

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).

Foerster *et al*. (2018) found associations between cell phone use and effects on figural memory in Swiss adolescent schoolchildren. However, the statistically significant effects were small, there were very large difference 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. 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

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.

~~Heart (ECG)~~

Fang ~~et al~~*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 ~~between the ages of 20 to 38 years old with 16 males and 6 females participated in the study~~. ~~Using the ELF-PEMF generation system, p~~Participants were exposed to RFR with 16 Hz operating frequency ~~. Participants were exposed to RFR~~ for 10 minutes followed by a ~~, after which a~~ 30 ~~-~~second ~~s~~ ECG

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recording ~~of ECG signal was taken. The mean RMS value of all participants of the ECG after exposure was increased by .0025 volts and the mean of the change rate was 3.72%. The results of paired-t test found significant different between before and after exposure to FRF on the RMS values. From the ECG signals, it was find the exposure to RFR did not significantly affect the electrical activity or cardiac tissues where the heartbeat originated. However, there were small changes found in the RR interval that could contribute to the variation in the heart rate.~~ The authors reported a small change in ~~study find that exposure to RFR only affect the~~the RR interval ~~in~~of the ECG but not in other intervals ~~(e.g., QT interval)~~. 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. ~~This demonstrated the exposure to RFR can affect the properties of ECG signals in the heart which could affect the function of the heart.~~

Béres ~~et al~~*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). ~~effect of RFR exposure~~ on HRV ~~human, especially on the heart. The purpose of the study was to examine the influence of the acute effects of pulsed microwave irradiation from a commercial cellular phone on~~and heart rate asymmetry ~~and heart rate variability.~~ in 20 healthy participants ~~(14 females and 6 males) with the mean age of 25.2 years old (range: 21 to 32 years old) participants in the study~~. ~~A Nokia 6230i mobile phone was used for RFR exposure at 1800 MHz GSM network (217 Hz pulse rate; 577 µs pulse width).~~ The mobile phone was attached to the participants' right ear and 5 consecutive 6-minute ~~360 seconds long~~ ECG ~~stages~~ strips were record for each volunteer randomly at various stages of the study. ~~RFR exposure from the mobile phone took place randomly either during the second and third, or during the fourth and fifth stages. ECG were used to measure heart rate asymmetry and heart rate variability.~~ There were no consistent significant effects of exposure on ~~change in heart rate~~ HRV and there were no effects on heart asymmetry ~~found between RFR exposure and the sham exposure. However, the time-domain analysis found RFR exposure affect heart rate variability. It was found that the mean RR interval changed significantly after exposure to RFR, which increased heart rate variability among the participants~~. ~~The results of the analysis found the exposure to RFR could affect the autonomic nervous system and the heart function.~~ 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. ~~Further studies are need to determine the relationship between these variables.~~

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.

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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. ~~For the brain, some studies suggested the EMF exposure affect cognitive function, such as memory~~

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.

Reproductive ~~*related*~~ ***health endpoints*** ~~*function*~~

Li ~~et al~~*et al.* (2010) examined the effect of RFR exposure on sperm quality in a ~~. The~~ population-based case control study ~~aim to determine the relationship between sperm quality and exposure to RFR~~of ~~–~~148 participants ~~participated in the study with 7~~(76 ~~cases~~ with~~(~~ abnormal semen~~)~~ and 72 ~~control~~with ~~(~~normal semen)~~ participants~~. Participants ~~of the study~~ wore an EMDEX-LITE meter for 24 hours to measure~~s~~ the exposure to RFR~~RFR~~. ~~Odd ratio with its 95% confidence interval as used to measure the association between RFR exposure and poor sperm quality using logistic regression.~~ The authors adjusted for d~~D~~emographic factors such as age, education, occupation, marital status, income, body mass index, smoker, alcohol consumption, steam bath use, living environment, and sexual activity ~~were used as covariates in the analysis~~. ~~Spearman rank order correlations analysis was conducted to examine the correlations between increasing RFR exposure and the different semen parameters measured on a continuous scale.~~ The authors reported ~~results found that compare to participants with lower RFR exposure, those with higher RFR exposure had~~ a two-fold increased risk of abnormal sperm motility and morphology ~~(OR = 2.0, 95% CI [1.0, 3.9])~~ in the 90th percentile exposed versus low exposed groups. In addition, they reported ~~. The results of the Spearman rank order correlations found~~ an inverse relationship between RFR exposure and semen quality indicators~~parameters~~ (~~i.e~~*e.g.*~~,~~ volume, pH, density, vitality, morphology, and motility). ~~The results of this study demonstrated adverse effect on sperm quality.~~

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

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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.

~~In the review by Houston et la. (2016) investigating the effect of RFR exposure on the male reproductive system. The review focus on the RFR exposure with the frequencies of 900/1800 MHz. Total of 27 studies were included in the review. Out of the included studies, 21 studies indicated that there are negative effect of RFR on male reproductive organ and sperm function. It was found that exposure to RFR could decrease sperm motility, elevated reactive oxygen species, and DNA damage in sperm. The review suggested that exposure to RFR induce mitochondrial dysfunction which lead to the elevated reactive oxygen species during sperm production.~~ 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 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.

~~Summary of RFR Exposures on Sleep~~

~~It is evident that exposure to RFR could affect the human body. Current literature had demonstrated the effects of RFR on human body, especially hearing, brain/cognitive function, heart, and reproductive system. In this review, among the 55 studies found to examined the relationship between RFR and the various parts of the human body, some suggested exposure to RFR have negative effect on the human body, while some suggested RFR does not have an~~

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impact on our body. Among these included studies, the effect of RFR is systems/organs specific. It might have effect on some part of the body while it does not affect other part of the body. Continuous researches are needed to determine the effect of RFR on the human body. Many of the included studies are cross-sectional studies, which limited our understanding of the long term effect of RFR on the human body. Further, some of the included studies sin this review used proxy measure of RFR, such as mobile/cell phones usages and laptop usage. Therefore, this warrant further research on the effect of RFR on the human body.

Description of Studies

A total of 55 studies were in this systematic review. The publication year ranged from 1999 (de Seze et al., 1999) to 2019 (Ren et al., 2019; Zarei et al., 2019). The studies were conducted in various countries across different continents. A total of 18 countries were found among the included studies. The countries included, US (n=6), Iran (n=3), India (n=6), Hungry (n=1), Italy (n=3), Germany (n=2), Switzerland (n=5), Denmark (n=1), New Zealand (n=1), Poland (n=2), Australia (n=4), Korea (n=4), France (n=1), Sweden (n=1), Israel (n=1), Greece (n=1), and Jordan (n=1). Among the included studies, India and the US had conducted the most studies related to EMF exposure and its effect on the body. These two countries are countries with high cell phone ownership.

Ten thousand four hundred forty-six participants were found among the included studies. The sample size ranged from 1 (Kleiber, 2017) to 1269 (Söderqvist et al., 2008). Many of the studies included both male and female. However, some studies only included male (Agarwal et al., 2008; Avendaño et al., 2012; Banerjee et al., 2016; de Seze et al., 1999; Desai et al., 2009; Houston et al., 2016; Khalil et al., 2014; Kleiber, 2017; Li et al., 2010; Wdowiak et al., 2007) and one study (Deniz et al., 2017) included female participants. Also, one study (Al-Quzwini et al., 2016) used couples as a unit for participants. Participants ages ranged from 9.9±5 (Brzozek et al., 2019) to 79 (Curcio et al., 2015). The included studies investigated the effect of EMF on both children and adults. Forty studies included adult participants, and ten studies included children participants. There were two studies (Choi et al., 2014; Riddervold et al., 2008) included both children and adults in their investigation. Further, three studies (Li et al., 2017; Mahmoudabadi et al., 2015; Ren et al., 2019) investigated the effect of EMF on children during the prenatal period, where EMF exposure was measured during the period of pregnancy.

Seven different study designs were found among the included studies. The designs were case study (n=1), case-control (n=3), cross-sectional (n=27), experimental (n=9), longitudinal (n=1), prospective cohort (n=4), and systematic review (n=3). For the longitudinal studies, the duration of the study was one year (Brzozek et al., 2019). Participants in the prospective cohort studies were followed for an average of 426.86 days, ranging from 236 days (Thomas et al., 2010) to 913 days (Li et al., 2017). Twenty five studies used a survey to measure the exposure variable of EMF. Out of the 25 studies used surveys, 21 studies measured the mobile phone usage as a proxy measure of EMF measure. The other four studies (Al-Quzwini et al., 2016; Bagheri Hosseinabadi et al., 2019; Singh et al., 2016; Zarei et al., 2019) surveyed participants' distances away from mobile phone towers and power plants that emitted EMF. Twenty-one studies directly measured EMF exposure. The EMF exposure is from cell phones, ranging from 890 MHz (Hardell, 2010; Pau et al., 2005) to 8896 MHz (Sievert et al., 2005). Out of the 21 studies, there were five studies (Avendaño et al., 2012; Li et al., 2010, 2012, 2017; Ren et al.,

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2019) used devices such as RF Field Strength Meter and EMDEX Lite Meter to measure EMF exposure throughout the day. Participants would carry or wore the devices on their bodies during the study period to measure their average EMF exposure.

The outcomes variables examined among the included studies included, auditory-related function (n=6), brain/cognitive function (n=10), heart (n=4), central nervous system (n=2), fetal growth/childhood development (n=2), thyroid dysfunction (n=2), melatonin secretion (n=1), miscarriage (n=2), obesity (n=1), reproductive related function (n=8), speech problem (n=1), beta-trace protein secretion (n=1), symptoms of ill health (n=6), blood glucose levels (n=1), DNA (n=2), oral mucosal cells (n=1), salivary gland (n=2), and body temperature (n=1). For the studies investigating auditory-related function, two of the studies (Colletti et al., 2011; Sievert et al., 2005) examined the cochlea cells in the auditory systems. One study (Medeiros & Sanchez, 2016) examined tinnitus (ringing in the ear). It seems that EMF exposure does not affect the general function of the auditory functions (Bhagat et al., 2016; Medeiros & Sanchez, 2016; Panda et al., 2010; Pau et al., 2005; Sievert et al., 2005) but it affects the cochlear nerve (Colletti et al., 2011). For brain/cognitive function, six studies examined the cognitive function (Brzozek et al., 2019; Foerster et al., 2018; Kalafatakis et al., 2017; Riddervold et al., 2008; Schoeni et al., 2015; Thomas et al., 2010), while four studies examined the structural change in the brain (Curcio et al., 2015; Deniz et al., 2017; Huber et al., 2005; Redmayne et al., 2013). The two studies that examined the central nervous system (Hossmann & Hermann, 2003; Kwon et al., 2012) looked at the structure and function of the central nervous system as a whole. Among children participants, fetal growth and childhood development were examined by Sage et al. (2018) and Ren et al. (2019). de Seze et al. (1999) examined the changes in melatonin circadian profile, and Hardell et al. (2010) examined beta-trace protein using an immunonepholometric assay. The risk of miscarriage was investigated in the study by Li et al. (2017), and Mahomoudabadi et al. (2015) examined unexplained spontaneous abortion. Obesity was examined by Li et al. (2012) among children. The case study by Kleiber (2017) examined the blood glucose levels in the body.In the case study by Kleiber (2017), it found that exposure to EMF could lead to high blood glucose levels among a male diabetic patient. For reproductive-related function, all the studies focus on male participants. Sperm and semen were the targets of the investigation. Semen analysis was performed to investigate the quality of the sperm (Agarwal et al., 2008; Ahlbom et al., 2004; Avendaño et al., 2012; Houston et al., 2016; Li et al., 2010, 2010; Wdowiak et al., 2007). Speech problems were investigated by Zarei et al. (2019), and body temperature was investigated by Bortkiewicz et al. (2012). Symptoms of ill health or general health were examined using surveys (Belpomme et al., 2018; Cho et al., 2016a, 2016b; Röösli et al., 2004; Singh et al., 2016; Söderqvist et al., 2008). The case study by Kleiber (2017) examined the blood glucose levels in the body. Regarding the effect of EMF, 33 studies suggested there are adverse effects of EMF, and 19 studies suggested there are no adverse effects. It seems that EMF exposure does not affect the general function of the auditory functions (Bhagat et al., 2016; Medeiros & Sanchez, 2016; Panda et al., 2010; Pau et al., 2005; Sievert et al., 2005) but it affects the cochlear nerve (Colletti et al., 2011). Half of the included studies investigating the heart (n=2) found EMF could affect the function of the heart (Béres et al., 2018; Fang et al., 2016) while half of the included studies investigating the heart (n=2) did not found any significant changes to the heart (Choi et al., 2014; Perentos et al., 2007). In the case study by Kleiber (2017), it found that exposure to

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EMF could lead to high blood glucose levels among a male diabetic patient. For the brain, some studies suggested the EMF exposure affect cognitive function, such as memory (Foerster et al., 2018; Kalafatakis et al., 2017) but the other studies found EMF exposure does not affect cognitive functions including memory (Brzozek et al., 2019; Riddervold et al., 2008; Schoeni et al., 2015; Thomas et al., 2010). Regarding the structure, it is found the EMF exposure can affect the structures and functions (Curcio et al., 2015; Deniz et al., 2017; Huber et al., 2005; Redmayne et al., 2013). Both studies that examined the central nervous system found that EMF exposure had no significance in the central nervous system (Hossmann & Hermann, 2003; Kwon et al., 2012). It is found that prenatal exposure of EMF and exposure during childhood could lead to adverse effects of childhood development (Sage & Burgio, 2018) and fetal growth (Ren et al., 2019). Exposure to EMF could lead to genotoxicity (Bagheri Hosseinabadi et al., 2019; Kocaman et al., 2018). All studies that investigated the reproductive system found a negative association with EMF exposure (Agarwal et al., 2008; Ahlbom et al., 2004; Al Quzwini et al., 2016; Avendaño et al., 2012; Desai et al., 2009; Houston et al., 2016; Li et al., 2010; Wdowiak et al., 2007). Further, both Li et al. (2017) and Mahmoudabadi et al. (2015) found that EMF exposure is related to higher miscarriage and unexplained spontaneous abortion.

Baby et al. (2017) found EMF can negatively impact thyroid function while Bergmaschi et al. (2004) found the opposite of EMF does not change thyroid function. EMF exposure does not affect melatonin secretion (de Seze et al., 1999) and beta-trace protein (Hardell, 2010), but it does change the body tempo- atu- e (Bo- tkiewicz et al., 2012). Banerjee et al. (2016) found the EMF exposure could lead to the genotoxicity of oral mucosal cells. However, Khalil et al. (2014) found no effect of EMF on the salivary gland, and Goldwein et al. (2010) found EMF to have an impact on the salivary gland. All the studies that investigated the outcomes of general health and symptoms of ill health found EMF exposure negatively impacted health (Belpomme et al., 2018; Cho et al., 2016a, 2016b; Röösli et al., 2004; Singh et al., 2016; Söderqvist et al., 2008).

Discussion

There were a total of 55 studies included in this systematic review. Currently, it is inconclusive exposure to EMF could lead to various health outcomes. Exposure to EMF can lead to changes in the auditory system, the central nervous system, cognitive functions, thyroid functions, salivary gland, and reproductive systems. However, some studies found that EMF exposure does not affect bodily function. EMF exposure does not affect melatonin secretion nor beta-trace protein secretion. Although it is inconclusive that EMF could affect the body, caution should be made when around EMF. In the studies that examined EMF exposure and general health and symptoms of ill health, it is found that individuals with exposure to EMF are more likely to have poorer health outcomes.

Most While some of the included studies identify adverse effects of EMF exposure, however, it is essential to note that some of the included studies used the proxy of mobile phones uses as a measurement for EMF exposure. Even though EMF-emitting devices such as mobile phones, TV, computer, video games, or any devices that use Wi-Fi do emit EMF, it is not equivalent to a direct measure of EMF. From these studies, we can only assume that participants are being exposed to EMF but not knowing how much. Participants could also be exposed to EMF from other sources such as mobile phone towers and power lines. When some of the studies used the exposure variable of mobile phone usage, the studies might underestimate the participants'

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~~EMF exposure. The underestimation could be due to EMF exposure from other EMF emitting devices.~~

~~A majority of the~~ studies included in this ~~systematic review~~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.~~or experimental studies.~~ 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. ~~ed the findings of the studies in terms of the long term effect of EMF. Only a handful of studies (n=5) used a non-cross-sectional design. While cross-section and experimental design studies provided information on the specific impact of EMF on the human body, the dose-response relationship between EMF and health outcomes is also essential. Studies with longitudinal designs are needed better to understand the effect of EMF on the human body. For the special population of children, it is crucial to determine the impact of the EMF on their body, especially some of the studies included in this study had identified the association between EMF and adverse health outcomes. Due to the developing bodies of children, they might be more vulnerable to EMF exposure than adults.~~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.

~~From this review, some of the studies had claimed that the effects of EMF are due to the thermal effect from EMF. As EMF exposure to the body, the temperature increased inside the body. It is proposed that EMF and living tissues cause an energy transfer resulting in the rise of body temperature (Kıvrak et al., 2017). This increase in temperature causes the more inferior quality of sperm found among men. Also, individuals' headache experiences using their mobile phones for an extended period could be due to the theme effects of EMF. While the thermal impact of EMF can explain these effects on the body, there are still many effects of EMF that have researchers have not yet been able to explain. The mechanism explaining the association between EMF and specific health outcomes remained unclear. A better understanding of the EMF and the body are needed to increase our knowledge of EMF and the human body. There is a need for further studies in identifying the mechanism through the use of quality research protocol.~~

~~Although this systematic review examined various studies on the effect of EMF on mental health with different research designs, it is not without limits. Including studies with the exposure variable of using EMF-emitting devices might not fully capture the effect of EMF exposure. The authors are assuming using EMF-emitting devices is equivalent to exposure to EMF. The usage of EMF-emitting devices could be a proxy measure of EMF exposure. EMF-emitting devices do emit EMF when it is being used. Therefore, it is safe to assume EMF-emitting devices such as cell phones emitted EMF.~~

~~**Conclusion**~~

~~Currently, it remained inconclusive the effect of EMF on the human body. Although the effects of EMF on the human is inconclusive, we should be cautious when using EMF-emitting devices or near close to high EMF. While EMF exposure might not affect specific parts of our human body, but there are effects on other parts of our body. For example, all of the included studies had deemed that EMF exposure will affect the male reproductive system. Further studies with~~

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~~longitudinal designs are needed to determine the long term effect of EMF on the human body. Continue researches are also required to determine the mechanism of EMF affecting our body.~~

Mental health

~~Radiofrequency Radiation Exposures on Mental Health~~

~~Radiofrequency radiation (RFR) is non-ionizing radiation that is often emitted from electronic devices such as cell phones, computers, tablets, and television, including those utilizing wireless technology. Due to the advancement of technology and the reliance on electronic devices, humans are exposed to RFR daily. Some researchers have examined the effect of RFR on mental health. However, it is important to note that many of these studies examined the relationship between devices usage and mental health, rather than exposure to RFR on mental health. Here we provide a description and synthesis of some studies that examined the relationship between RFR exposure and mental health, particularly as they relate to depression, stress, and anxiety.~~

~~Depression Outcomes~~

~~Augner and Hacker (2012) conducted a survey study examining the relationship between cell phone usage and mental health among 196 young adults between the ages of 17 years and 35 years old. Participants in the study completed the Problematic Mobile Phone Use survey examining their daily mobile phone use in minutes and use of short message service along with their psychological and health conditions. For phone use related questions, the survey asked about participants' dependence on mobile phones, social interaction, and the consequences of using mobile phones. The WHO-5 well-being questionnaire was used to screen for depressive behaviors and daily hassles. Using a stepwise linear regression analysis with phone usage as the dependent variable, the study found that increase phone use in minutes is associated with higher depression scores (ß = .15, p = .033), with gender and conscientiousness being significant covariates. Extended phone usage is associated with more prolonged exposure to RFR. Therefore, it can be assumed there is relationship between RFR exposure and depressive symptoms among young adults.~~

~~Stress Outcomes~~

~~Using meta-analysis techniques,~~ Vahedi and Saiphoo (2018) conducted a meta-analysis of 39 independent studies examining an association between ~~found that~~ smartphone ~~usage~~use ~~is associated with a higher level of~~and stress. ~~A total of 39 independent studies totaling 21,736 individuals were included in the meta-analysis.~~ The ~~analysis~~authors reported that smartphone use ~~has~~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 ~~usage~~use on stress and anxiety independently and RFR exposure was not measured~~. Also, the usage of smartphone usage can only be used as proxy for RFR exposure and the study did not measure RFR exposure directly~~. The authors found stronger correlation between anxiety and stress and "problematic" phone

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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.

~~Röösli et al. (2004) conducted a questionnaire survey examining the relationship between ill-health and RFR. A total of 429 individuals completed the questionnaires between July 2001 and June 2002. The questionnaires included questions about symptoms of ill health and exposure to RFR sources. Out of the 429 participants, 394 participants reported suffering from symptoms of ill health. 19% of the 394 participants reported experiences nervousness or distress associated with RFR exposures. It is one of the most stated ill-health symptoms concerning RFR exposure. There was no gender effect found among the sample (p = .66) regarding exposure of RFR to ill health, including nervousness or distress.~~

~~Anxiety Outcomes~~

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~~to~~ 17 years~~ old~~. 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 ~~survey~~ study outcomes suggested that moderate use of electronic devices wa~~i~~s related to a higher risk for anxiety ~~(RR 1.52, CI 1.06, 2.18)~~ among 14 ~~to~~ 17 years old. The survey also found the use of electronic devices is related to depression and several other undesirable mental health indicators ~~(RR 1.61, CI 1.03, 2.52)~~. ~~Higher screen media usage would lead to lower in psychological well-being, more likely to display poor emotion regulation, an inability to finish tasks, lower curiosity, and more difficulty making friends, lower in self-control, more likely to diagnosis with depression or anxiety or needed treatment for mental or behavioral health conditions. Because the study is using self-report data, there is possible social and recall bias. In addition, the study did not directly measure RFR exposure and using electronic device usages as a proxy measure of RFR exposure.~~ 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.* (2020) 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.

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Wdowiak ~~et al~~*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 ~~between the~~ ages ~~of~~ 25 ~~to 3~~ 35 years. Participants respo~~s~~nded to ~~a survey consisted of~~ the International Physical Activity Questionnaire, Beck Depression Inventory, and Stat-Trait Anxiety Inventory. RFR exposure was measured by a~~ESM 140~~ dosimeter over 10 hours, which register~~ed~~s the frequency and level of the electric components of RFR~~the electromagnetic field~~ in a person's close environment (e.g., GSM, UMTS, DECT, and WLAN). ~~The study found that shopping center staffs significantly spent more time on their mobile phone than medical staffs, which could affect the amount of RFR exposure different between the two groups.~~ The ~~results of the~~ study found that anxiety correlated negatively with ~~the~~ exposure to GSM900 ~~(r = .18)~~ but~~and~~ positively with exposure to GSM1800 ~~(r = .005)~~ among women working in shopping centers. Anxiety was also correlated positively with daily mobile phone use time ~~(r = .007)~~. This study had a ~~Also, the study found a correlation between depression and exposure to RFR among female medical personnel.~~ 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. ~~Because of the positive correlation found between exposure to RFR and mental health parameter, this suggested that increase exposure to RFR could lead to increase mental health related symptoms. Despite the relationship found between RFR exposure and mental health, caution should be made regarding the results due to lack of covariates used in the analysis.~~

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.

~~Summary of RFR Exposures on Mental Health~~

~~This review found that many of the current literature examined the relationship between electronic device usages and mental health. While electronic device usages can be link to exposure to RFR, it is difficult to conclude the association between exposure to RFR and mental health. Caution should be made when discussing the relationship between RFR exposure to mental health based on current literatures.~~ Among the ~~20~~ 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. ~~there were only 3 studies directly measure exposure RFR and 3 studies used survey to measure RFR exposure. M~~Moreover, many of the studies ~~examining the relationship a~~are cross-sectional studies making it difficult to draw conclusions about the effects of RFR or cell phone use on mental health~~, which limited our understanding of the relationship between the two variables, especially for a prolonged period~~. Screen time appears to have strong associations with various mental health indicators and the

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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. ~~Also, many of the studies did not measure RFR exposure directly. Using a proxy measure of mobile phone use and exposure to wireless technology might not fully capture the effect of RFR exposure. More studies are needed to examine the impact of RFR on mental health. Further, a more well-rounded design study is necessary to examine the relationship, such as using statistical analysis that accounted for the effect of social media use and blue light from screening devices. In conclusion, exposure to RFR could potentially impact mental health by increase the risk of depression, increasing stress, and anxiety.~~

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 [HAK29]: 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. [CrossRef]

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

~~**Results**~~

~~*Description of Studies*~~

~~A total of 20 studies were included in this systematic review. The publication year ranged from 2008 (Kleinlogel et al., 2008a, 2008b) to 2019 (Ranjbaran et al., 2019). The studies were included across multiple countries and region, such as Austria (Augner & Hacker, 2012; Vernon et al., 2018), China (Zhu et al., 2016), France (Denny-Bas et al., 2014), Germany (Sauter et al., 2011), Iran (Ranjbaran et al., 2019), Japan (Ikeda & Nakamura, 20140500; Minagawa & Saito, 2014; Tamura et al., 2017), New Zealand (Redmayne et al., 2013), Poland (Wdowiak et al., 2018), South Korea (Cho et al., n.d.), Sweden (Thomée et al., 2010, 2011), Switzerland (Kleinlogel et al., 2008a, 2008b; Röösli et al., 2004), Uganda (Pearson et al., 2017), and US (Twenge & Campbell, 2018).~~

~~A total of 78155 participants were included in this systematic review. However, 21736 participants were from the meta-analysis study conducted by Vahedi and Saiphoo (2018). The sample size ranged from 15 healthy males (Kleinlogel et al., 2008a, 2008b) to 5164 (Minagawa & Saito, 2014). Most of the studies included healthy adults (n=10), where the three studies only included male participants (Kleinlogel et al., 2008a, 2008b; Sauter et al., 2011) only included males and the study by Wdowiak et al. (2018) only included female participants. Zhu et al. (2016) included participants with traumatic brain injuries and titanium mesh cranioplasty, and Ranjbaran et al. (2019) only included medical students in Iran working with MRI machines. There were a total of 5 studies have only children under the ages of 18 years old involved in their studies (Ikeda & Nakamura, 20140500; Redmayne et al., 2013; Tamura et al., 2017; Twenge & Campbell, 2018; Vernon et al., 2018). One study targets older adults as participants (Minagawa & Saito, 2014). The study by Augner et al. (2012) included participants between the ages of 17 to 35, which included both underaged and legal age participants. Also, the unit of sample for Pearson et al. (2017) is household rather than the number of individuals. The~~

participants' age range included in this systematic review is from 2 years (Twenge & Campbell, 2018) old to 103 years old (Minagawa & Saito, 2014).

The type of studies designed found included cross-sectional (n=18), qualitative (n=1), meta-analysis (n=1), and prospective cohort design (n=2). For the study with prospective cohort design, the duration between pre- and post-test were 365 days (Thomée et al., 2011; Zhu et al., 2016). A majority of the studies (n=15) use survey methods to measure the exposure and outcome variables. Thomée et al. (2010) used interviews to collect data. The exposure variables found among the included studies were EMF exposure (Kleinlogel et al., 2008a, 2008b; Röösli et al., 2004; Sauter et al., 2011; Wdowiak et al., 2018; Zhu et al., 2016), cell phones and WIFI usage (Augner & Hacker, 2012; Cho et al., n.d.; Ikeda & Nakamura, 20140500; Minagawa & Saito, 2014; Pearson et al., 2017; Ranjbaran et al., 2019; Redmayne et al., 2013; Tamura et al., 2017; Thomée et al., 2010, 2011; Twenge & Campbell, 2018; Vahedi & Saiphoo, 2018; Vernon et al., 2018), and perceived risk of the proximity of a cell phones towers (Denny-Bas et al., 2014). It is important to note that only three studies (Kleinlogel et al., 2008a, 2008b; Sauter et al., 2011) had participants directly expose to EMF, other studies (Röösli et al., 2004; Wdowiak et al., 2018; Zhu et al., 2016) used a survey to determine exposure to EMF. Different outcome variables were found among the included in the systematic review, but they all related to mental health. The outcomes found included psychological well-being, depressive symptoms, stress, and anxiety.

Out of the included studies, 13 (Augner & Hacker, 2012; Cho et al., n.d.; Ikeda & Nakamura, 20140500; Ranjbaran et al., 2019; Redmayne et al., 2013; Röösli et al., 2004; Tamura et al., 2017; Thomée et al., 2010, 2011; Twenge & Campbell, 2018; Vahedi & Saiphoo, 2018; Vernon et al., 2018; Wdowiak et al., 2018) studies determine that there are adverse effects on mental health in exposing to the exposure variables; while seven studies (Denny-Bas et al., 2014; Kleinlogel et al., 2008a, 2008b; Minagawa & Saito, 2014; Pearson et al., 2017; Sauter et al., 2011; Zhu et al., 2016) determine that is no adverse effects on mental health. Some of the results included cell phones usage is related to higher levels of depressive symptoms (Augner & Hacker, 2012; Ikeda & Nakamura, 20140500; Redmayne et al., 2013; Thomée et al., 2010, 2011; Twenge & Campbell, 2018; Wdowiak et al., 2018), higher levels of stress (Twenge & Campbell, 2018; Vahedi & Saiphoo, 2018), and higher levels of stress (Augner & Hacker, 2012; Röösli et al., 2004; Thomée et al., 2010; Vahedi & Saiphoo, 2018). On the other hand, the study by Zhu et al. (2016) found that exposure to RF-EMF after cranioplasty was associated with a lower risk of depression and anxiety among individuals with traumatic brain injuries. Also, it has been found the exposure to RF-EMF is not associated with poorer human cognitive and cognition functions (Kleinlogel et al., 2008a, 2008b; Sauter et al., 2011). Also, it has been found that for older adults, cell phones used are associated with lower levels of depressive symptoms for older adults (Minagawa & Saito, 2014) and higher mental well-being in a household (Pearson et al., 2017).

Discussion

Among the included articles in this systematic review, it is unclear on the effects of EMF and EMF-emitted devices on mental health among humans. While usage of EMF-emitted devices could increase depressive symptoms and stress, but direct exposure to EMF did not have a significant effect on mental health and mental well-being. Also, the exposure of EMF did not have a substantial impact on human cognition.

~~Caution should be made when interpreting the effects of EMF and EMF-emitted devices on mental health. At the same time, a majority of studies examined the exposure variable of EMF-emitted devices usage and not EMF directly. We can only assume the participants within each study are exposure to EMF from cell phones, TV, computer, video games, or any devices that used Wi-Fi. These are standard devices that emitted EMF. It is important to note that they did not measure the exposure to EMF directly for these studies. Therefore, we are assuming participants being exposed to EMF.~~

~~Further, many of the studies that measured the exposure variable of EMF-emitted devices usage were based on survey data and cross-sectional data. It is difficult to determine the relationship between exposure to EMF and mental health outcomes. For example, when the participants were using EMF-emitting devices, their activities could affect their mental health. Therefore, the adverse mental health outcomes could be due to the activities performed rather than the exposure to EMF. Many individuals spend their time on the internet on social media. It has been found in other studies that there is a positive relationship between the usage of social media and mental health outcomes. A systematic review conducted by Keles et al. (2020) found an association between online social media usage and mental health problems in adolescents. The review found that as time spent on online social media, the risk for depression, anxiety, and psychological distress increase (Keles et al., 2020). Therefore, other confounder variables should not be neglect when examining the effect of EMF on mental health.~~

~~More studies are needed to determine the effect of EMF on mental health. Many of the included studies are cross-sectional studies by design. This limited to establishing the relationship between EMF and mental health. Among the included 20 studies, only two studies were longitudinal studies with a prospective cohort design. Studies with longitudinal designs are needed to better understand the relationship between EMF and mental health, especially for unique populations of children and older adults. In addition to longitudinal designed, more studies are needed to determine the effect of EMF by directly measuring EMF exposure. Using proxy responses of survey but underestimate or overestimate the exposure of EMF. Researchers need to identify approaches and methods to determine EMF exposure from EMF-emitted devices safely. Without directly measuring the amount of EMF exposure, it might be challenging to determine any relationship between EMF and mental health and other health-related outcomes. In addition to study designs, the method of analysis needs to be considered too. Many of the included studies did not employ a complex survey design in their analysis. This will limit the generalizability of the study results.~~

~~Although this systematic review examined various studies on the effect of EMF on mental health with different research designs, it is not without its limits. Including studies with the exposure variable of using EMF-emitting devices might not fully capture the effect of EMF exposure. The authors are assuming using EMF-emitting devices is equivalent to exposure to EMF. The usage of EMF-emitting devices could be a proxy measure of EMF exposure. EMF-emitting devices do emit EMF when it is being used. Therefore, it is safe to assume EMF-emitting devices such as cell phones emitted EMF.~~

~~Conclusion~~

~~Currently, it is inconclusive whether exposure to EMF is associated with adverse mental health outcomes. Studies included in this systematic review have mix results regarding the effects of EMF on mental health. More studies are needed to determined eh exact impact of~~

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~~EMF on mental health. Better study designs such as longitudinal studies and using complex survey design in the analysis. Researchers need to identify a better approach to measuring EMF exposure without harming the participants. Future investigations should further address the relationship between EMF and mental health outcomes by directly measuring EMF exposure, rather than using a proxy measure.~~

Sleep

~~One of the health-related outcomes being examined related to RFR exposures is related to sleeping. Sleep is an essential part of everyday life. Individuals with sleep problems tend to have a poor quality of life. Lack of sleep could impact cognitive function, mood changes, weakened immunity, high blood pressures, weight gain, and other adverse health outcomes. According to the Center for Disease Control and Prevention, one-third of US adults reporting that they do not get the recommended amount of sleep each day. It had links that RFR exposure to sleeping behaviors and problems. Multiple studies had examined the relationship between sleep and exposure to RFR. In the following sections, studies examining the relationship between RFR exposure and sleeping outcomes will be discussed categorized by specific sleeping outcomes, such as sleeping time, sleep quality, and insomnia.~~

~~*Sleeping Time Outcome*~~

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.~~Carter et al. (2016) conducted a meta-analysis with 20 studies, including 125198 children on the relationship between sleep-related outcomes and bedtime media devices. It was found that usage of the bedtime media device is associated with inadequate sleep quantity (OR = 2.17, 95% CI [1.42, 3.32]). In other words, compared to children who did not use media devices before bedtime, children who used are more likely to sleep less. Usage of media devices, such as cell phones, computers, and tablets, could lead to an increase in RFR exposure. Using media devices as a proxy measure for RFR exposure, an increase in RFR exposure could lead to a decrease in sleep time for children. The study also found the using bedtime media devices is associated with poor sleep quality (OR = 1.46, 95% CI [1.14, 1.88]) and excessive daytime sleepiness (OR = 2.72, 95% CI [1.32, 5.61]). Despite the

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~~results, it is important to note that using media device usages is only a proxy of RFR exposure. Therefore, cautions should be taken when interpreting the results relating to RFR exposure.~~

Fobian ~~et al~~*et al.* (2016) examined the effect of media use on sleep-related variables among 55 adolescents ~~(with the~~ mean age, 15 ~~of 14.89~~ years) by using a ~~old. The study used a~~ self-reported survey of Media Use Scale to access average daily media use and actigraphy~~celerometer~~ (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.~~t was found that media use decrease sleep efficiency (r = -0.29, p < .05). The study also accounted for the gender, age, race, and media use after bed during analysis. The results suggested that using media devices affect sleeping time. It could lead to sleeping later at night and waking up later in the morning. This suggested that using media devices, which increase exposure RFR, could affect the sleep time of adolescents. Media use is a proxy for RFR exposure; therefore, cautions should be taken when interpreting the results relating to RFR exposure. Further, social and recall bias are often associated with self-reported survey.~~

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.

~~A study by~~ Huber ~~et al~~*et al.* (2002) ~~found the sleep electroencephalogram (EEG) changes during sleep after being exposed to RFR. In the study,~~exposed 16 healthy young males ~~(between the~~ ages, ~~of~~ 20 ~~to~~ 25 years) to sham or RFR (pulse-modulated 900 MHz electromagnetic field vs continuous wave; 1 W/kg specific absorption rate) ~~were exposed~~ 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

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effects in this study. ~~to RFR before sleeping. Exposure to RFR altered the EEG during sleep. The exposure to RFR before sleep alters the waking regional cerebral blood flow, which could alter the brain physiology. This suggested that RFR exposure could lead to sleep disturbance, such as shorter duration of continued sleep.~~

Hung ~~et al~~*et al.* (2007) examined the relationship between RFR exposure and electroencephalogram readings during sleep ~~effect of RFR exposure to~~ in 10~~ten~~ healthy males (mean age, 22 years). ~~The purpose of the study was to investigate the relationship between RFR exposure and electroencephalogram (EEG) during sleep.~~ Participants were exposed to RFR for 30 minutes with a 90 minutes sleep opportunity after. The authors reported~~results of the analysis found~~ 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. ~~RFR exposure from talking on mobile phones lead to sleep latency.~~ In other words, exposure to RFR from a phone in "talk" mode resulting in higher RFR exposure, ~~after talking on the phones could~~ was associated with ~~lead to~~ a delay in time to fall sleep~~ing time and shorten the sleeping duration~~. 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 b~~Sleep Quality Outcome~~

~~Using electroencephalogram (EEG) techniques, Lebedeva et al. (1999) found that after exposure to RFR, EEG patterns changes during sleep. It was found that exposure to RFR could disrupt the brain function during sleep. Therefore, disrupting sleeping patterns. RFR impact the sleep structure of human being by reducing slow wave and REM stage sleep percentage. Effecting the sleep structure could lead to poorer sleep quality. In other words, exposure to RFR before sleep could affect the quality of sleep, including REM sleep. REM sleep is an important part of sleep stages. Disrupting REM sleep could lead to poorer health outcomes.~~

~~Loughran et al. (2005) investigated the relationship between RFR exposure to sleeping electroencephalogram (EEG) among 50 participants. Participants were exposed to RFR for 30 minutes before sleeping. Their EEG was measured during sleep. The results found that exposure to RFR before sleep could lead to a decrease in rapid eye movement (REM) sleep latency and increase EEG spectral power during the initiation of sleep. This relationship could lead to poorer quality of sleep.~~

~~Lustenberger et al. (2013) examined the quality of sleep after being exposed to RFR among 16 male participants. Participants' electroencephalogram (EEG) was recorded during sleep while being exposed to pulsed RFR. It was found that after RFR exposure, participants' sleep slow-~~

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~~wave activity increased toward the end of the sleep period. EEG also increases when exposed to RFR during sleep. The relationship between RFR and sleep slow-wave activity negatively affects the quality of sleep. It could lead to poorer performance when waking up in the morning.~~

~~Insomnia~~

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~~Using the survey of the Pittsburgh Sleep Quality Index, the Fatigue Assessment Scale, and the Bergen Insomnia Scale, Exelmans and Van den Bulck (2016) found an association between smartphone usage and sleep-related outcomes among adults. Using hierarchical regression analyses, it was found that bedtime mobile phone use is a significant predictor for poor sleep quality while adjusting for gender, age, and education levels (ß = .136, p < .01). This suggested that the frequency of mobile phone use after lights out increases the chances of poorer sleep quality. The study found a significantly relationship between mobile phones use and insomnia (ß = .134, p < .01, r = .142, p < .01) adjusting for the covariates of gender, age, and education levels. Increase mobile phone use lead to increase exposure to RFR, which could affect sleep quality and increase the risk of insomnia.~~

~~Lange et al. (2017) used data from the German Health Interview and Examination Survey for Children and Adolescents (KiGGS study) to examined the relationship between the use of electronic devices and insomnia. Participants were 7533 adolescents between the ages of 11 to 17 years. Using binary logistic regression, it was found that using electronic media devices for more than eight hours per day is 2.92 (95% CI [1.65, 5.18]) and 2.16 (95% CI [1.04, 4.48]) times the odds of complaining about insomnia than using electronic media devices lesser than fours per day for boys and girls. The analysis adjusted for age, socio-economic status, emotional problems, and medical conditions. The study suggested that everyday users of electronic media devices could lead to insomnia. Media used is used as a proxy for RFR exposure. Caution should be taken when interpreting results relating to RFR exposure and insomnia. And recall and social bias could influence the generalizability of the results.~~

~~Summary of RFR Exposures on Sleep~~

~~It is evident that exposure to RFR could affect sleep. Current literature had demonstrated the effects of RFR on sleep, especially on sleep quality, sleeping time/duration, and insomnia. In this review, among the 30 studies found to examined the relationship between RFR and electronic devices usage and sleep, 13 studies directly measured RFR exposure and two studies used survey to identify RFR exposure. Poorer sleep could lead to adverse health outcomes and performance after waking up from sleep. Many studies had examined the relationship between exposure to RFR before bedtime and its effect on sleep. Further studies are needed on the everyday exposure to RFR and its impact on sleep. As electronic devices, such as mobile phones and computers, are being used every day, devices users are consistently exposed to RFR. Therefore, further studies are needed to determine everyday exposure to RFR on the different sleep-related outcomes.~~

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Description of Studies

A total of 30 studies were included in this systematic review. The publication year ranged from 2001 (Jech et al., 2001; Lebedeva et al., 2001) to 2020 (Danker-Hopfe et al., 2020). The studies were conducted in diverse countries. The countries found among the included studies included Amsterdam (Huss et al., 2015), Australia (Bartel et al., 2019; Gamble et al., 2014; Loughran et al., 2005; Perentos et al., 2007), Austria (Vernon et al., 2018), Czech Republic (Jech et al., 2001), Germany (Danker-Hopfe et al., 2011, 2020; Exelmans & Van den Bulck, 2016; Lange et al., 2017; Wagner et al., 2000), Hong Kong (Mak et al., 2014), Iran (Ghadimi-Moghadam et al., 2018), Japan (Kato et al., 2018; Munezawa et al., 2011; Nakatani-Enomoto et al., 2013), Netherland (Martens et al., 2017), Russia (Lebedeva et al., 2001), Sweden (Lowden et al., 2019; Thomée et al., 2011), Switzerland (Huber et al., 2002; Lustenberger et al., 2013, 2015), Turkey (Durusoy et al., 2017), UK (Hung et al., 2007), and the US (Fobian et al., 2016; Rosen et al., 2016). Among the included studies, Australia and Germany had the most studies conducted in examining the effect of EMF-emission devices on various outcomes of sleep. There are a total of 128,084 participants among the included studies. The sample size ranged from 10 adults (Hung et al., 2007) to 94777 adolescents (Munezawa et al., 2011). Out of the 30 included studies, 18 studies focused on adults, 11 studies on children and adolescents, one study on older adults. Among the studies focus on adult, one study focus on adults with narcolepsy (Jech et al., 2001) and one study focus on older adults (Danker-Hopfe et al., 2020). A majority of the included studies (n=24) included both genders (male and female) in their respective studies. Six studies only included male participants (Danker-Hopfe et al., 2011; Huber et al., 2002; Lebedeva et al., 2001; Lustenberger et al., 2013, 2015; Wagner et al., 2000). The participants' ages ranged from 6.7 years (Huss et al., 2015) to 80 years (Danker-Hopfe et al., 2020). For mean ages, Kato et al. (2018) have the mean ages of 6±0 years, the lowest mean ages among the included studies. Danker-Hopfe et al. (2020) had the highest mean ages of 67.8±5.7 years.

Regarding study designs, five different types of designs were found. Eighteen studies were cross-sectional design studies; eight were experimental designs, two were longitudinal design, one was prospective cohort design and one meta-analysis. For the longitudinal studies, the duration between pre- and post-test were 730 days (Martens et al., 2017). The duration between the pre- and post-test was unclear for the other longitudinal study (Kato et al., 2018). For the prospective cohort study by Thomée et al. (2011), the duration between pre- and post-test were 365 days. A majority of studies (n=18) used surveys and questionnaires to measure both exposure and outcome variables. Exposure variables found among the included studies can be divided into two board categories of EMF-emitted devices usage (n=13) and EMF (n=17).

For EMF-emitted devices usage, all of the studies expect the meta-analysis conducted by Carter et al. (2016) used a survey to determine the frequency, intensity, and duration of the usage of EMF-emitted devices. The survey focuses on cell phone use after night out or before bedtime (Exelmans & Van den Bulck, 2016; Gamble et al., 2014; Munezawa et al., 2011; Rosen et al., 2016; Saling & Haire, 2016; Vernon et al., 2018) and general use of electronic devices (e.g., TV, video game, smartphone, screen used, media used, listen to music, and Wi-Fi) (Carter et al., 2016; Fobian et al., 2016; Kato et al., 2018; Lange et al., 2017; Mak et al., 2014; Rosen et al., 2016; Thomée et al., 2011). For EMF exposure, six studies (Durusoy et al., 2017; Ghadimi-

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Moghadam et al., 2018; Hung et al., 2007; Huss et al., 2015; Lowden et al., 2019; Martens et al., 2017) used a survey to determine EMF exposure. Four of the six studies (Durusoy et al., 2017; Ghadimi Moghadam et al., 2018; Huss et al., 2015; Martens et al., 2017) inquired information on EMF exposure from phone towers or phone base stations. Eleven studies expose participants to EMF of 900 MHz (Danker-Hopfe et al., 2011, 2020; Huber et al., 2002; Jech et al., 2001; Lebedeva et al., 2001, 2001; Loughran et al., 2005; Lustenberger et al., 2013, 2015; Nakatani-Enomoto et al., 2013; Perentos et al., 2007; Wagner et al., 2000).

The outcome variables for the included studies are related to sleep and tiredness. The sleep variables examined included sleep latency, sleep stages (e.g., duration and frequency), sleep time, sleep patterns, sleep disturbances, sleep problems, sleep quantity, sleep quality, sleep architecture, and heart rate during sleep. Two studies (Exelmans & Van den Bulck, 2016; Saling & Haire, 2016) used a survey to determine the tiredness and fatigue of the participants after sleeping. Eleven studies (Danker-Hopfe et al., 2020; Huber et al., 2002; Hung et al., 2007; Lebedeva et al., 2001; Loughran et al., 2005; Lowden et al., 2019; Lustenberger et al., 2013, 2015; Nakatani-Enomoto et al., 2013; Perentos et al., 2007; Wagner et al., 2000) used polysomnography and electrophysiological techniques to examined the sleep-related outcomes.

Twenty-one include studies determined there is an adverse effect on sleep-related outcome variables from the exposure variables. However, nine studies claimed that the exposure variables have no limited impact on sleep. Some studies found that exposure to EMF has little to no effect on human sleep (Danker-Hopfe et al., 2011, 2020; Lowden et al., 2019; Nakatani-Enomoto et al., 2013; Perentos et al., 2007). Many of the studies found the use of EMF-emitted devices had a negative influence on sleep. It has been found that cell phone used before bedtime is associated with more reduced sleep quality, including delay sleep onset, insomnia, and higher sleep disturbances (Carter et al., 2016; Exelmans & Van den Bulck, 2016; Fobian et al., 2016; Munezawa et al., 2011; Saling & Haire, 2016). Further, some studies found exposure to EMF before bedtime is also related to poorer sleep quality. Exposure to EMF could lead to delay in sleep onset and brain activity during sleep (Huber et al., 2002; Hung et al., 2007; Lebedeva et al., 2001; Loughran et al., 2005; Lustenberger et al., 2013; Martens et al., 2017).

Discussion

From the included studies, it remined unclear the effect of EMF on sleep. While a majority of included studies suggested that exposure to EMF and using EMF-emitting devices impacted sleep quality but there are studies also claimed that exposure to EMF does not significantly effect on sleep. There are different sleep-related factors that EMF could have an influence on. Factors such as sleep quality, sleep duration, sleep stages, sleep onset, insomnia, and sleep architecture are some of the sleep-related factors that the included studies investigated.

It is important to note that many of the studies included in the systematic review used the exposure variable of usage of EMF-emitting devices. The usage of EMF-emitting devices is different than measuring EMF exposure directly. EMF-emitting devices such as cell phones, TV, computer, and other screen devices can emitted EMF with the use of Wi-Fi. EMF could be emitted from phone tower as well. Therefore, some studies examined the exposure of EMF and estimating the distances between the participants and phone towers. However, measuring the

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~~usage of EMF-emitting devices and the distances with phone towers are only proxy response to EMF exposure, it is not exactly the same as measuring the amount of EMF expose.~~

~~Many of the included studies used survey to determine the exposure to EMF by determining the usage of EMF-emitting devices, particularly for cell phones. Cell phone usage before bedtime was a common exposure variable among the included studies. These studies also found that using cell phone before bedtime is related to poorer sleep quality, increase tiredness, and link to insomnia. However, it is important to note that this relationship might not be due to exposure to EMF. It been found that b~~lue light effects from cell phones, computers, tablets, and TV since the latter has been ~~are~~ associated with insomnia (Shechter ~~et al~~*et al*., 2018) and might~~. Blue light from screen devices~~ suppress ~~the~~melatonin secretion~~ of melatonin,~~ thereby affecting sleep quality~~ which could affect the quality of sleep~~ (Mortazavi ~~et al~~*et al*., 2018). Finally, ~~In other words, the poorer quality of sleep found in the included studies could be due to blue light from electronic devices rather than cause by EMF. There is a need to identify confounder variables that could affect sleep-related outcomes in regard to exposure to EMF.~~

~~many studies we reviewed~~ ~~There is a need for further investigation on the effects of EMF on sleep. From the included studies in this systematic review, it is difficult to determined eh relationship between EMF and sleep-related outcomes. Many of the studies~~ used cross-sectional study design which~~. It~~ 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.~~Among the 30 included studies, only 10% (n=3) of the studies used a longitudinal study to examine the relationship between exposure and outcome variables. Also, using proxy responses of survey might underestimate or overestimate the exposure of EMF. Researchers need to identify approaches and methods to determine EMF exposure from EMF-emitted devices safely. Without directly measuring the amount of EMF exposure, it might be challenging to determine any relationship between EMF and sleep-related outcomes, especially many of the EMF-emitting devices also emitted blue light as well. In addition to study designs, the method of analysis needs to be considered too. Some of the included studies did not employ a complex survey design in their analysis. This will limit the generalizability of the study results.~~

~~Although this systematic review examined various studies on the effect of EMF on sleep-related outcomes with different research designs, it is not without its limits. Including studies with the exposure variable of using EMF-emitting devices might not fully capture the effect of EMF exposure. The authors are assuming using EMF-emitting devices is equivalent to exposure to EMF. The usage of EMF-emitting devices could be a proxy measure of EMF exposure. EMF-emitting devices do emit EMF when it is being used. Therefore, it is safe to assume EMF-emitting devices such as cell phones emitted EMF.~~

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~~**Conclusion**~~

~~Currently, it is inconclusive whether exposure to EMF is associated with adverse sleep-related outcomes. Studies included in this systematic review have mix results regarding the effects of EMF on sleep. More studies are needed to determine the exact impact of EMF on sleep. Better study designs such as longitudinal studies and using complex survey design in the analysis. Researchers need to identify a better approach to measuring EMF exposure without harming the participants. Future investigations should further address the relationship between EMF and sleep-related outcomes by directly measuring EMF exposure, rather than using proxy measures.~~

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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~~*et al*.	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~~*et al*.	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 ~~usage~~use in 1999, 2005, 2009. Assessed both how often and how long mobile phone~~s~~ used.	Yes	Long term mobile phone use ~~was~~ 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. ~~**(146% risk increase [7%-464%]**~~
Authors' response to: The case of acoustic neuroma:	Benson *et al*.	Government and NGO	Prospective cohort	791 710 UK middle-aged women	1999-2011	791 710	Acoustic neuroma	Surveys on mobile phone use in 1999	No	Extended analysis rendered acoustic neuroma risk

comment on mobile phone use and risk of brain neoplasms and other cancers (2014)								2005 2009 2011. Assessed both how often and how long mobile phone used.		insignificant and there was no increased risk with duration of use.
Has the incidence of brain cancer risen in Australia since the introduction of mobile phones 29 years ago? **(2016)**	Chapman ~~et al~~*et al*.	No funding	Descriptive incidence study	19,858 males and 14,222 females diagnosed with brain cancer in Australia between 1982 and 2012	1982-2012	34,080	Brain cancer incidence	Based on annual reports of mobile phone accounts, grouped into time-related exposure categories.	No	No evidence of any rise in any age group that could be plausibly attributed to mobile 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~~*et al*.	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 ~~strange~~ 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	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	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 lobes - incidence	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%])**
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	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~~*et al*.	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"	No	No clear trend change in glioma incidence rates was observed. Medium strength study - Simulation studies have poor ability to point toward causality,

								use, proportion of heavy users, and estimation of lag/induction period		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~~*et al*.	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 of Danish cohort study. **(2011)**	Frei ~~et al~~*et al*.	Government	Prospective cohort	All Danes aged ≥30 and born in Denmark after 1925, subdivided into subscribers and non-subscribers of mobile phones before 1995.	1990-2008	358,403 phone subscription holders accrued 3 8 million person years and 10,729 CNS tumors	Brain cancer incidence	Mobile phone subscriptions	No	No increased risks of tumours of the central nervous system, providing little evidence for a causal 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	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	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

								coverage maps (year of measure not described)		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~~*et al*.	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~~*et al*.	Governme nt	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 international case–control study**. (2011)**	INTERPH ONE group	Governme nt and private	Population -based Case-control	Cases: all patients with a schwannoma of the acoustic nerve diagnosed in study region in 2000-2004. Controls: 2 for each case from population-based sampling frame.	2000-2004	1105 cases and 2145 controls	Acoustic neuroma incidence	Face-to-face interviews. Questions about all ionizing and non-ionizing radiation exposure (this is as much detail given)	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 for users who began regular use 10 years or more before date of diagnosis.

				Both individual and frequency matching used depending on site. Matched for age, sex, region, and ethnicity (only in Israel)						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~~*et al*.	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	Johansen	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,	No	No increased risk observed for the cancers considered a priori to be possibly associated with the radiofrequency fields emitted by mobile

system and arrhythmiarelated heart disease **(2004)**								system used (NMT, GSM or both) and age at first subscription were collected.		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~~*et al*.	No funding	Descriptive 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~~*et al*.	Government 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, meningioma, 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~~*et al*.	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 frequency of use.	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%])**
Mobile phone use and glioma risk: comparison of epidemiological study results with incidence trends in the United States **(2012)**	Little ~~et al~~*et al*.	Governme nt	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	Momoli ~~et al~~*et al*.	Governme nt and private	Population -based case-control	Canadians 30–59 years of age who live in Canadian INTERPHONE study regions and diagnosed w/ glioma, meningioma,	2001-2004	Cases: 405 Controls: 516	Glioma, meningioma, acoustic neuroma, parotid gland	In-person face-to-face interviews. Questions asked about patterns of use (daily amount and	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

Glioma, Meningioma, Acoustic Neuroma, and Parotid Gland Tumors **(2017)**				acoustic neuroma, or malignant and benign parotid glandtumors. Frequency-matched (age and region) controls from provincial registry			incident tumors	"regular" use), network operators, use of hands-free devices, and use in urban and rural areas		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~~*et al*.	Private – funded directly by telecom association	Descriptive incidence study	U.S. men and women aged 6-20 years with ganglioglioma 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~~*et al*.	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 Southeast England, and 18–69 in the Northern UK, and live in study region	1999-2004	Cases: 678 cases of acoustic neuroma. Controls: 3553 frequency (age-, sex-, and region-) matched controls of randomly-sampled population from population registers	Acoustic neuroma incidence	Face-to-face and phone interviews. Start and end date of use, the average amount of time of use and number of calls.	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. 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~~*et al*.	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~~*et al*.	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	Schuz ~~et al~~*et al*.	Government and NGO	Nationwide retrospective cohort	All private cellular telephone subscribers in Denmark 1992-1995	1995-2006	2 9 million Danish mobile phone subscribers	Vestibular schwannoma incidence	Mobile phone subscription – no mobile phone use characterizati	No	No evidence that mobile phone use is related to the risk of vestibular schwannoma. Medium

Cohort Study **(2011)**								on (how much exposure per person)		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~~*et al*.	No funding	Descriptive 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~~*et al*.	Government 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 adolescents: a multicenter case-control study **(2011)**	Aydin ~~et al~~*et al*.	Government	Case-control	All children and adolescents aged 7-19 years who 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	2004-2008	Cases: 352 patients diagnosed w/ brain tumors Controls: 646 controls from national population registries of participating countries	Brain cancer incidence	Face-to-face and telephone 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.	No	Mobile phone users had difference in brain tumor risk compared with nonusers, risk 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~~*et al*.	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-,	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	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

				region-, and tumor laterality-matched (does not mention frequency vs. individual) controls from population registries				actual dose of radiation for each case and control		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~~*et al*.	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~~*et al*.	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-	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	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

				and sex-) matched controls.				telephones used regularly. Start and stop dates of use were recorded.		sampling bias. Interviewer bias due to non-blinded interviews also possible.
Cellular telephone use and risk of acoustic neuroma **(2004)**	Christensen ~~et al~~*et al*.	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. Start and stop dates of use were recorded.	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 could have resulted in overmatching.
Cellular telephone use and time trends for brain, head and neck tumours **(2003)**	Cook ~~et al~~*et al*.	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~~*et al*.	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	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	Yes	No association when comparing users to non-users, but association for highest cumulative users. Medium strength study – control for confounders and effective exposure

				individually (age-, sex-, and region-) matched controls per case randomly selected from voter rolls 2005-2008				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.		assessment. Authors note they found recall bias and selection bias is possible. ~~Further, the r~~ Aascertainment of controls via voter rolls may not 1) ~~ot~~ be representative of the population – not compulsory in France or~~and~~ 2) ~~does not~~ match years of case diagnosis and sampling bias~~s~~ is likely. Interviewer bias due to non-blinded interviews ~~s~~ 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~~*et al*.	Governme nt 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 lymphoma, and combined all cancer. 4 individually (sex-, and age-) matched controls per case from UK national registry	1999-2001	Cases: 1397 cases of cancer Controls: 5588 controls	Brain, CNS, leukemia, non-Hodgkin's lymphom a, and combined all cancers from mother's exposure during pregnancy	Modeled power density from mobile phone base stations based on location – used fieldwork to create models that take into account rural vs. urban	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, 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	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~~*et al*.	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 from population register.	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 phone, years of use, make/model, mean number/ length of daily calls, cumulative use in hours.	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 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~~*et al*.	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,	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 (~~espec ally to~~including US).

								cumulative use in hours.		
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~~*et al*.	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, cumulative use in hours.	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 not be generalizable outside of these Swedish regions (~~especially to~~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~~*et al*.	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 (~~espec ally to~~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~~*et al*.	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~~especially to~~ 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~~*et al*.	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 controls from national registry.	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 of use, make/model, mean number/ length of daily calls, cumulative use in hours.	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 ~~same~~ biases such as~~as other Ha dell stud es~~: recall, interviewer, and sampling ~~b as~~. Results may not be generalizable outside of these Swedish regions (including~~espec ally to~~ 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~~*et al*.	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 ~~ame b~~ biases ~~as other Hardell stud es~~: recall, interviewer, and sampling bias. Results may not be generalizable outside of ~~these~~ Swedish regions (including US~~espec ally to 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~~*et al*.	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

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.		increased risk of malignant brain cancer. Low to 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~~especially to 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~~*et al*.	Government, NGO, and private	Case-case analysis	20-60 year-olds diagnosed with glioma from neurosurgery clinics of Helsinki and Tampere university hospitals in	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,	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

				Finland between November 2000 and October 2002. The study sample represents a subset of the Finnish Interphone study.				average amount of phone use, cumulative call time, side of head phone I used.		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-control study **(2006)**	Hepworth ~~et al~~*et al*.	Government and private	Population-based Case-control	Cases aged 18 to 69 years diagnosed with a 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.	2000-2004	Cases: 966 cases Controls: 1716 controls	Glioma incidence	Computer-assisted face-to-face interviews. Data on network operator, start and stop year, and the number and duration of calls made and received.	No	No increased risk of glioma in short/medium term exposure. Medium to strong study – large sample size, effective exposure 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~~*et al*.	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	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	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

				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				number of calls.		cases were deceased – proxy interviews were conducted, introducing recall bias.
Cellular Telephones and Cancer—a Nationwide Cohort Study in Denmark **(2001)**	Johansen ~~et al~~*et al*.	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 Population Register	Incidence of all cancers available in Danish Cancer Registry	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 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~~*et al*.	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	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,

				from the Governing State and Local Sourcebook						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~~*et al*.	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~~espec ally to US~~).
Long-Term Mobile Phone Use and Brain Tumor Risk **(2005)**	Lonn ~~et al~~*et al*.	Governme nt and private	Population -based case-control	All glioma/ meningioma cases aged 20–69 years in the geographic areas covered by the regional cancer registries in Umea, Stockholm, Goteborg, and Lund, Sweden from 2000-2002. Non-matched	2000-2002	Cases: 371 glioma, 273 meningioma Controls: 674 controls	Glioma, meningio ma incidence	Face-to-face interviews. Data on regular use, cumulative phone use, number of calls, years of regular use.	No	No association for any amount of phone use or length of use. Low to medium strength study – medium sample size, effective exposure assessment, and confounder control. Recall bias, sampling bias (pop-based case-control design), no accounting for

				controls from population registry						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~~especially to US~~).
Adult and childhood leukemia near a high-power radio station in Rome, Italy **(2002)**	Michelozzi ~~et al~~*et al*.	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~~*et al*.	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	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	No	No association between cell phones and acoustic neuroma. Low strength – confounder control and effective exposure assessment, but low sample size, interviewer bias (non-

				York Presbyterian Medical Center 1997-1999. 86 frequency (age-, sex-, race-, and hospital-) matched in-patient controls with a variety of nonmalignant conditions				use, manufacturer, and average monthly bill.		blinded interviews), no accounting for induction period, and recall bias. Results may not be generalizable because controls were hospitalized patients.
Handheld Cellular Telephone Use and Risk of Brain Cancer **(2000)**	Muscat ~~et al~~*et al*.	Governme nt 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~~*et al*.	Governme nt, 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	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

								calls, and side of head.		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~~ et al,	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	Soderqvist ~~et al~~ et al,	Government and NGO	Population-based Case-control	Patients with salivary gland tumors in 9 Swedish counties	2000-2003	Cases: 69 cases Controls: 262 controls	Salivary gland tumors	Questionnaire. Data about current and previous use	No	No increased risk of salivary gland tumors from wireless phones. Low strength study –

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case–control study **(2012)**				2000-2003. Controls age-, county-, sex-matched from national registry (individual vs. frequency method not listed)				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.		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~~	Government	Population-based case control	Hospitalised acoustic neuroma cases aged 30–69 years from 30 Tokyo neurosurgery departments 2000-2004. Individually matched controls (age, sex, residency) from random digit dialing of population.	2000-2004	Cases: 101 acoustic neuroma cases Controls: 339 controls	Acoustic neuroma incidence	Computer-assisted in-person interviews. Data on regular users, make/models, start and stop dates, the average duration and frequency of calls	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, 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~~	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	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

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				rates as comparison group.						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~~ *et al,*	Governme nt	Retrospect ive 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, and Scotland.. National "expected" cancer rates as comparison group.	1974-1986	3,305 adult leukemia cases, 8,307 bladder cancer cases, and 1,540 skin melanoma cases.	Leukemia, bladder cancer, and skin melanom a 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 ~~are~~ outside of what children would experience in a school environment, no correction 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

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										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~~ *et al.*	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~~-EMFs~~ 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~~ *et al.*	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

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										authors note some neoplasms may be misclassified. ~~Relat onsh p w th overall cancer but not spec f c types makes ove all esults less conv nc ng.~~
Radio-frequency radiation exposure from AM radio transmitters and childhood leukemia and brain cancer **(2007)**	Ha ~~et al~~ *et al.*	Governme nt	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:**

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										59% [19%-111%] odds increase)
Investigation of increased incidence in childhood leukemia near radio towers in Hawaii: preliminary observations **(1994)**	Maskarinec ~~et al~~et al.	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~~et al.	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.

Data on mobile phone use and cancer incidence rates in the United States is difficult to compare with the European studies on mobile phone use and cancer risks largely due to differences in technology standards between the US and Europe in the

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infancy of mobile phone network technology development – including 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."

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Table 2: Cancer studies: review articles

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Study Name **(Year)**	Authors	Funding Source	Study Type	# of Epidemiolog~~c~~ ~~al~~y 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~~*et al.*	No funding	Non-systematic Review	Unclear ~~(some pages of full text are m ss ng). At ost 18-20 b/c that's as many as were publ shed at th s t me.~~	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. ~~Weaker rev ew no~~Non-systematic review and does not identify possible biases effectively~~ enough~~.	N/A

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Epidemiological risk assessment of mobile phones and cancer: where can we improve? **(2006)**	Auvinen ~~et al~~*et al.*	Governm ent and NGO	Non-systematic Review	15	All cancers	Major ~~issues a c~~ uncertaintiesy in exposure assessment, ~~due to~~ unknown biological mechanism, and lack of acceptable comparison group (everyone is exposed to mobile phone RF and similar frequencies). A~~lso, a~~uthors note that detailed exposure history is required vs asking ~~s mple~~ 'have you used a cell phone?' ~~s ot effect ve~~. 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 ~~cases/controls~~ 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	No funding	Non-systematic Review	3	~~For RF EMF, focus o~~ ~~G~~lioma 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	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~~*et al.*	Governm ent	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 ~~taken nto account~~considered in Interphone studies, which could have hindered exposure assessment. Very difficult to compare and pool case-controls due to differing designs and ~~espec ally d ffer ng control for~~ 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	Habash ~~et al~~*et al.*	No funding	Systematic Review	21	Acoustic neuroma, glioma,	Authors note issues with recall bias in case-control participants and short follow-up periods. Generally note issues in exposure	Unclear, no evidence of increases in benign head and neck tumors, but	N/A

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Fields and Health: 2004–2007 **(2009)**					meningioma, and tumors of the parotid gland.	assessment ~~up until when this review was completed~~.	long-term use may result in brain cancers. More research needed. Highly quality review overall, but not focused specifically on cancer.	
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~~*et al.*	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 ~~based on Hill's criteria that the~~ RFR/ glioma and acoustic neuroma relationship ~~should~~ is causal based on Hill criteria~~be labeled as causal~~. They note ~~specifically~~ 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 ~~taking~~ to account considering all available studies. ~~of the studies completed up to this point – seems to be using cherry picking of studies. Specifically not including Interphone studies.~~	N/A
Radio frequency electromagnetic fields: Cancer, mutagenesis, and genotoxicity **(2003)**	Heynick ~~et al~~*et al.*	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 ~~the~~ weight of ~~the~~ evidence indicates no~~that~~ RFR cancer effect in both occupational settings and ~~due to~~with mobile phone use~~s does not cause cancer. Specifically references many of the Hardell papers that showed an effect – authors note that the numbers of cases and controls in the early studies are too low to~~	N/A

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							aser be credence to the results. For the 2002 Hardell study on acoust c neuroma, aga n too few cases/ controls n assoc at on found.	
Mobile phones and health: A literature overview **(2005)**	Karger et al et al.	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 cons dered biased – no causal implications should be drawn. Spec f cally nNoted that one of the key findings indicating association from Hardell (2000) has been identified as possibly due to random chance and over-adjustment/ overfitting of models. Some studiesHardell's stud es are also criticized for not checking for recall bias and exposure misclassification. Auv e et al. study also oted as a g al ncrease n bra n tumors, but aga n could be due to chance, m sclass f cat on, and uncontrolled confound ng.	No association between mobile phone radiation and cancer was found in epidemiolog caly studies, wh ch s cons stent w th the ge e al esults of exper mental stud es. Th s rev ew was pre nterphone wh ch also d d not f nd ncreased r sk for the ost pa t.	N/A
Epidemiological Evidence for a Health Risk from Mobile Phone Base Stations **(2010)**	Khurana et al et al.	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 et al.	None	Systematic review (but does not list systematic methods)	42	All cancers	Multiple issues noted in existing research: few studies assessed the risk of cell phone use >of more than 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, t s virtually impossible to eliminate exposure to RFR from other sources for studying the isolated effects of cell phones on health. 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	Krewski et al et al.	None	Non-systematic review	14 (epidemiolog c aly cancer	All cancers	Author notes limited duration of mobile phone use by many target populations, the lack of	Author does not make final determination of views on relationship, as	N/A

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Fields and Health: 2001–2003 **(2007)**				studies), 4 review studies		rigorous exposure measures, and the possibility of recall bias and response error.	the review covers many outcomes. Based on what's presented, it seems like they view the study results as inconclusive.	
The Controversy about a Possible Relationship between Mobile Phone Use and Cancer **(2009)**	Kundi et al	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 reviews completed to date.	**Combined OR for Glioma:** **1.5 (1.2-1.8); no other endpoints are statistically significant**
Are Mobile Phones Harmful? **(2000)**	Blettner and Berg	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	Governm ent	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 Some cherryp ck ng of highlight method deficits olog cal co- in presented studies. For example cerns and results n th s review provides- extensive comments on some studies but not others methodolog cal ssues n Interphone stud es (l ttle effect found), wh le not hold ng Hardell and other stud es to sa e sta da d. Also n example of result cherryp ck ng s the lack of nclus on of excludes the large Rothman et al et al. cohort study showing no effect. Conclus ons presented n th s rev ew	N/A

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							~~place emphas s on an mal results, wh ch are not appropr ate as the base of support for an RFR- cancer relat onsh p n human popula ons.~~	
Review on health effects related to mobile phones. Part II: results and conclusions **(2011)**	Moussa	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	None	Non-systematic review	14 cancer studies	All cancers	Some issues noted in~~are~~ 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, r~~-and the r~~arity of observed malignancies, variable ways of using the phone by the user (e.g. ~~-e.~~ left or right ear, ~~head sets~~headsets/speaker/blue tooth).	No final view about cancer is presented.	N/A
Review of Published Literature between 2008 and 2018 of Relevance to Radiofrequency Radiation and Cancer **(2020)**	U.S. Food and Drug Administration	Government	Systematic review	69 epidemiolog~~-c ay~~l cancer studies	Focus on brain tumors, acoustic neuroma, vestibular schwannoma, parotid gland, skin cancers, leukemia,	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 incidence + evidence of subgroup effects, selection bias in some studies.	Authors conclude that "E~~x~~isting ~~ep dem olog c~~ evidence is insufficient to suggest that use of cell phones can is~~be cons dered as an n~~ independent ~~et olog cal~~ factor ~~capable of~~ influencing ~~the~~ incidence of intracranial and some other tumors in the ~~general~~ general population. Any existing risk is ~~Ex st ng ep de olog cal ev de ce nd cates that f any r sk does ex st, t s~~ extremely	One of the best reviews completed. Examination of nearly all relevant studies.~~N/A~~

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							low compared to both the natural incidence of the disease and known controllable risk factors." ~~One of the best rev ews completed. Exam nat on of ea ly all eleva t stud es.~~	
Epidemiology of Gliomas **(2015)**	Ostrom ~~et al~~ *et al.*	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 stud es rev ewed n th s rev ew; largely rely on IARC monograph.~~	~~N/A~~Few studies reviewed in this review largely rely on IARC monograph.
Electromagnetic fields (EMF): Do they play a role in children's environmental health ~~(CEH)~~? **(2007)**	Otto ~~et al~~ *et al.*	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~~ *et al.*	None	Systematic review and meta-analysis	55 epidemiolog ~~c~~ ~~al~~ 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 ~~:~~ ~~op n on:~~ "~~n~~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." ~~Also note that there s~~ Insufficient data to make determination of risks for children and ~~fo~~ those with 10+ years of	**Glioma, meningioma, acoustic neuroma: No association in meta-analysis ORs**

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							exposure. ~~Very- n- depth rev ew art cle and extremely w~~Well-sourced review.	
Cancer risks related to low-level RF/MW exposures, including cell phones **(2013)**	Szmigielski	None	Non-systematic review	~15 epidemiolog~~c av~~ 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 ~~Conclus on: "publ shed~~ studies do not show that mobile phones can increase considerably the risk of cancer (~~. Th s conclus on s backed up by the la~~lack of ~~a~~ solid biological mechanism ~~+, and the fact that~~ brain cancer rates ~~are~~ not going up significantly)." ~~Does ot ev ew all ava lable art cles, but conclus ons are st ll warranted.~~	Authors did not review all available articles. ~~N/A~~
How dangerous are mobile phones, transmission masts, and electricity pylons? **(2005)**	Wood	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	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 ~~Co clus o + "T~~The study~~ep dem olog cal~~ results fall do not support cancer causation of RFR exposures~~short of the st e gth a d co s ste cy of ev dence wh ch s requ red to come to a conclus on that RF em ss ons are a cause of hu a ca ce ."~~.	N/A
Cellular phone use and brain tumor: a meta-analysis **(2008)**	Kan ~~et al~~ *et al.*	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~~Conclus on: "~~ no overall increased risk of brain tumors among cellular phone users. ~~The p~~Potential elevated risk of brain tumors after 10+	**No association in overall use. Pooled analysis for 10+ year users: OR of 1.25 [1.01-1.54]**

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							years or more of cellular phone use should be confirmed by additional data from future studies."	
Cell phones and brain tumors: a review including the long-term epidemiologic data **(2009)**	Khurana et al et al.	None	Systematic review and meta-analysis	11 studies	Brain tumors (10+ years of latency	Generally, poor review of the methodological problems, similar to other reviews studies by Hardell group – e.g. bias. 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 usageuse and the development of an ipsilateral brain tumor." Some authors are members of the Hardell group, which consistently finds effects in the studies. Possibly by design of the review, authors only include studies from Interphone and Hardell group.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 et al.	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 Conclusion: " The totality of evidence does not indicate a substantially increased risk of intracranial tumors from mobile phone use for a period of at least 5 years." Important to note that this meta-analysis does not consider any studies with latency period longer than 5 years. However, multiple Hardell studies used a different conclusion than M-A by Hardell authors.	**No association in overall pooled estimates or separately for glioma, meningioma, and acoustic neuroma**
Mobile phone radiation causes brain tumors and should be classified	Morgan et al et al.	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 fieldsConclusion: "radiofrequency fields should be classified as a	N/AThis review was not inclusive of all

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as a probable human carcinogen (2A) **(2015)**							Group 2A probable human carcinogen under the criteria used by the International Agency for Research on Cancer." ~~Th s rev ew has notable che yp ck g of esults and strange op n ons of some stud es not shared by other rev ews. Th s rev ew reads more l ke an op o p ece tha a rev ew of the l terature. It should be noted that some authors of th s rev ew have other co t ove s al a d outspoken v ews related to cell phones and RFR.~~	relevant publications.
Mobile Phone Use and Risk of Tumors: A Meta-Analysis **(2009)**	Myung ~~et al~~et al.	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 ~~s not exactly sc ent f c n ass gn ng scores and~~ misses some sources of bias/error – like exposure classification.	Authors find~~Conclus on:~~ "possible evidence linking mobile phone use to an increased risk of tumors." ~~Th s blanket conclus on s not warranted, as the o~~Only consistent effect ~~was stud es~~ w/ 10+ years of latency. Also o~~O~~ne of the ~~r~~ M-A ORs showed a protective effect. ~~Note that results of th s M-A a e b~~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)**	Soderqvis t ~~et al~~et al.	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 ~~and seems to be more interested n expla n ng why Hardell group results are not b ased.~~	Conclusion: large Danish cohort study has methodological problems and concerns about funding from telecoms. Seems to not be inclusive of all relevant studies~~Th s art cle aga n reads l ke an op n on p ece w th cherryp ck ng of results. Member of the Hardell~~	N/A

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							~~group~~ ~~s also an author on th s paper~~.	
Children's health and RF EMF exposure. Views from a risk assessment and risk communication perspective **(2011)**	Wiedemann and Schutz	Private	Non-systematic review	13 childhood cancer epidemiolog~~e aly~~ 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~~Conclus on: "The a~~ available evidence does not support~~prov de an d cat o fo a~~ association between RFR ~~EMF~~ exposure and brain cancer or leukemia in children. ~~S m larly, for the elat o sh p betwee RF EMF exposure and ch ldhood leukaem a, the balance of ev dence does not support a co ect o ." The~~ ~~a~~Authors noted ~~that~~ ~~n~~many ~~of the~~ studies showing a relationship between childhood leukemia and RFR ~~EMF~~ 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	Biological Levels	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	Cells	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	

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										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	Cells	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	Organ	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	Organ	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	Organ	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	Many potential confounders unaccounted for

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										>33 hours talk/month	
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	Systems	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 opposite one in contact with phone	Organ	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)	National Health and Medical Research Council Australia	Longitudinal	Healthy Australian students; mean age 10 years	412	Cognitive functions	Systems	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

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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	Systems	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	Cells	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)		Experimental	Italian adults diagnosed with symptomatic focal epilepsy (ages 21-79 years)	12	Brain electrical (EEG)	Organs	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)	Motorola Inc.	Experimental	Healthy French males 20-32 years old	37	Melatonin secretion	Systems	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)		Experimental	Healthy US female medical students aged 18 to 25 years	60	Hippocampus	Organs	Cell phones use	Mixed	Longer daily phone use risk for lack of attention/ concentration, but no effect on size of hippocampus	

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An Investigation on the Effect of Extremely Low Frequency Pulsed Electromagnetic Fields on Human ECGs	Fang *et al.* (2016)	RMIT University, Australia + Shanghai University	Experimental	Healthy Australian adults aged 20 to 38 years	22	Heart	Organs	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	Prospective cohort	Healthy Swiss adolescents (12-17 years old; mean, 14 years)	895	Memory performance (brain)	Organs	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)		Cross-sectional	Healthy Israeli adults (ages 19-33 years, mean 27 years)	50	Parotid gland - salva secretion rate and protein concentrations	Organs	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)	Cancer-och Allergifonden, Cancerhjalpen and Orebro University Hospital Cancer Fund	Cross-sectional	Healthy Swiss adults (18-30 years old)	62	ß-trace protein	Cells	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	Systems	RFR exposure	No	Little evidence of RFR effect on functional and structural integrity of brain. Mostly thermal effects	

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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	Systems	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)	Organs	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	Organs	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	Systems	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	Li *et al.* (2017)	National Institute of Environmenta	Prospective cohort	Healthy US pregnant women	913	Miscarriage risk	Systems	EMDEX Lite meter for measurement	Yes	Exposure to higher RFR level associated	

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Risk of Miscarriage: A Prospective Cohort Study		I Health Sciences						of RFR exposure		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	Systems	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	Cells	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	Systems	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	Systems	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	112	Audiology systems	Systems	Mobile phone use	No	No effect on hearing	Small sample size

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				years for controls)							
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	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	Organs	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	Organs	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	Systems	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.

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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)	Organs	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)	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)	Organs	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	Systems	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	Body	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

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adolescents aged 15–19 years											unaccounted for
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)	Organs	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	Cells	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	Systems	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

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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 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)		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	Kleinloge l *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	5 164	Depressive symptoms	Survey with the exposure of cell phone use (e.g., duration	No	Cell phone use associated with fewer depressive symptoms (beneficial) in women but not men (after	Social and recall bias; Use of cell phones rather than RFR exposure

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				mean age of 76 years old			intensity frequency)		controlling for covariates)	
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)		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)	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

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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	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	Very narrow exposure window + disorders examined subject to variability in grading. Most comparison tests of exposure and health condition

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disorders in women									effect associated with WLAN.	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)	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)		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

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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) on the macrostructure of sleep	Danker-Hopfe *et al.* (2011)	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)	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	Exelmans *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	55	Sleep offset and	Survey on media use including	Yes	Media use is associated with poorer sleep	Social and recall bias, did not use

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				(ages 14-15 years; mean 15 years)		sleep efficiency	television computer, cell phones and video games		efficiency sleep onset, and sleep offset	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)		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)	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	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.

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									night wakenings and parasomnias, and bedtime resistance. Cordless phone use not related to any sleeping scores	
Electromagnetic field of mobile phones affects visual event related potential in patients with narcolepsy: Mobile Phone Affects ERP in Narcolepsy	Jech *et al.* (2001)		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)		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	55	Sleep stage (duration and	900 MHz from mobile phones, 217 Hz pulsed field 30	Yes	Decrease in rapid eye movement sleep latency and increased EEG spectral power in	

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				mean age 31 years)		alternation)	minutes before sleep		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	Munezawa *et al.* (2011)		Cross-sectional	Healthy Japanese adolescents between the	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

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Disturbances among Japanese Adolescents: A Nationwide Cross-Sectional Survey				ages of 13 to 18 years old						
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	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

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Psychosocial Development										
Human sleep EEG under the influence of pulsed radio frequency electromagnetic fields.	Wagner et al. (2000)	Technologi ezentrum of Deutsche Telekom Ag	Experimen tal	Health German males (19-36 years mean age 24 years)	20	Sleep architectu re	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

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