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Cell phone radiation: Evidence from ELF and RF studies supporting more inclusive risk identification and assessment☆

Carl Blackman

Raleigh, NC 27607, USA

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Abstract

Many national and international exposure standards for maximum radiation exposure from the use of cell phone and other similar portable devices are ultimately based on the production of heat particularly in regions of the head, that is, thermal effects (TE). The recent elevation in some countries of the allowable exposure, that is, averaging the exposure that occurs in a 6 min period over 10 g of tissue rather than over 1 g allows for greater heating in small portions of the 10-g volume compared to the exposure that would be allowed averaged over 1-g volume. There is concern that 'hot' spots, that is, momentary higher intensities, could occur in portions of the 10-g tissue piece, might have adverse consequences, particularly in brain tissue.

There is another concern about exposure to cell phone radiation that has been virtually ignored except for the National Council of Radiation Protection and Measurements (NCRP) advice given in a publication in 1986 [National Council for Radiation Protection and Measurements, Biological Effects and Exposure Criteria for Radiofrequency Electromagnetic Fields, National Council for Radiation Protection and Measurements, 1986, 400 pp.]. This NCRP review and guidance explicitly acknowledge the existence of non-thermal effects (NTE), and included provisions for reduced maximum-allowable limits should certain radiation characteristics occur during the exposure.

If we are to take most current national and international exposure standards as completely protective of thermal injury for acute exposure only (6 min time period) then the recent evidence from epidemiological studies associating increases in brain and head cancers with increased cell phone use per day and per year over 8–12 years, raises concerns about the possible health consequences on NTE first acknowledged in the NCRP 1986 report [National Council for Radiation Protection and Measurements, Biological Effects and Exposure Criteria for Radiofrequency Electromagnetic Fields, National Council for Radiation Protection and Measurements, 1986, 400 pp.].

This paper will review some of the salient evidence that demonstrates the existence of NTE and the exposure complexities that must be considered and understood to provide appropriate, more thorough evaluation and guidance for future studies and for assessment of potential health consequences. Unfortunately, this paper is necessary because most national and international reviews of the research area since the 1986 report [National Council for Radiation Protection and Measurements, Biological Effects and Exposure Criteria for Radiofrequency Electromagnetic Fields, National Council for Radiation Protection and Measurements, 1986, 400 pp.] have not included scientists with expertise in NTE, or given appropriate attention to their requests to include NTE in the establishment of public-health-based radiation exposure standards. Thus, those standards are limited because they are not comprehensive.

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1. Introduction

1.1. The current approach to exposure limits (based on heating and electric current flow in tissues)

It is universally accepted that radiofrequency radiation (RFR) can cause tissue heating (thermal effects, TE) and that extremely low-frequency (ELF) fields, e.g., 50

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E-mail address: Carl.Blackman@gmail.com.

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and 60 Hz, can cause electrical current flows that shock and even damage or destroy tissues. These factors alone are the underlying bases for present exposure standards. EMF exposures that cause biological effects at intensities that do not cause obvious thermal changes, that is, non-thermal effects (NTE), have been widely reported in the scientific literature since the 1970s including beneficial applications in development and repair processes. The current public safety limits do not take modulation into account and thus are no longer sufficiently protective of public health where chronic exposure to pulsed or pulse-modulated signal is involved, and where sub-populations of more susceptible individuals may be at risk from such exposures.

1.2. Modulation as a critical element

Modulation signals are one important component in the delivery of EMF signals to which cells, tissues, organs and individuals can respond biologically. At the most basic level, modulation can be considered a pattern of pulses or repeating signals which have specific meaning in defining that signal apart from all others. Modulated signals have a specific 'beat' defined by how the signal varies periodically or aperiodically over time. Pulsed signals occur in an on–off pattern, which can be either smooth and rhythmic, or sharply pulsed in quick bursts. Amplitude and frequency modulation involves two very different processes where the high-frequency signal, called the carrier wave, has a lower frequency signal that is superimposed on or 'rides' on the carrier frequency. In amplitude modulation, the lower frequency signal is embedded on the carrier wave as changes in its amplitude as a function of time, whereas in frequency modulation, the lower frequency signal is embedded as slight changes in the frequency of the carrier wave. Each type of low-frequency modulation conveys specific 'information', and some modulation patterns are more effective (more bioactive) than others depending on the biological reactivity of the exposed material. This enhanced interaction can be a good thing for therapeutic purposes in medicine, but can be deleterious to health where such signals could stimulate disease-related processes, such as increased cell proliferation in precancerous lesions. Modulation signals may interfere with normal, non-linear biological functions. More recent studies of modulated RF signals report changes in human cognition, reaction time, brainwave activity, sleep disruption and immune function. These studies have tested the RF and ELF-modulated RF signals from emerging wireless technologies (cell phones) that rely on pulse-modulated RF to transmit signals. Thus modulation can be considered as information content embedded in the higher frequency carrier wave that may have biological consequences beyond any effect from the carrier wave directly.

In mobile telephony, for example, modulation is one of the underlying ways to categorize the radiofrequency signal of one telecom carrier from another (TDMA from CDMA from GSM). Modulation is likely a key factor in determining whether and when biological reactivity might be occurring, for example in the new technologies which make use of modulated signals, some modulation (the packaging for delivery for an EMF 'message') may be bioactive, for example, when frequencies are similar to those found in brain wave patterns. If a new technology happens to use brain wave frequencies, the chances are higher that it will have effects, in comparison, for example, to choosing some lower or higher modulation frequency to carry the same EMF information to its target.

This chapter will show that other EMF factors may also be involved in determining if a given low-frequency signal directly, or as a modulation of a radiofrequency wave, can be bioactive. Such is the evolving nature of information about modulation. It argues for great care in defining standards that are intended to be protective of public health and well-being. This chapter will also describe some features of exposure and physiological conditions that are required in general for non-thermal effects to be produced, and specifically *to illustrate how modulation is a fundamental factor which should be taken into account in public safety standards.*

2. Laboratory evidence

Published laboratory studies have provided evidence for more than 40 years on bioeffects at much lower intensities than cited in the various widely publicized guidelines for limits to prevent harmful effects. Many of these reports show EMF-caused changes in processes associated with cell growth control, differentiation and proliferation, that are biological processes of considerable interest to physicians for potential therapeutic applications and for scientists who study the molecular and cellular basis of cancer. EMF effects have been reported in gene induction, transmembrane signaling cascades, gap junction communication, immune system action, rates of cell transformation, breast cancer cell growth, regeneration of damaged nerves and recalcitrant bone-fracture healing. These reports have cell growth control as a common theme. Other more recent studies on brainwave activity, cognition and human reaction time lend credence to modulation (pulsed RF and ELF-modulated RF) as a concern for wireless technologies, most prominently from cell phone use.

In the process of studying non-thermal biological effects, various exposure parameters have been shown to influence whether or not a specific EMF can cause a biological effect, including intensity, frequency, the co-incidence of the static magnetic field (both the natural earth's magnetic field and anthropogenic fields), the presence of the electrical field, the magnetic field, or their combination, and whether EMF is sinusoidal, pulsed or in more com-

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plex wave forms. These parameters will be discussed below.

Experimental results will be used to illustrate the influence of each EMF parameter, while also demonstrating that it is highly unlikely the effects are due to EMF-caused current flow or heating.

2.1. Initial studies that drew attention to NTE

Several papers in the 1960s and early 1970s reported that ELF fields could alter circadian rhythms in laboratory animals and humans. In the latter 1960s, a paper by Hamer [2] reported that the EMF environment in planned space capsules could cause human response time changes, i.e., the interval between a signal and the human response. Subsequent experiments by a research group led by Adey were conducted with monkeys, and showed similar response time changes and also EEG pattern changes [3,4]. The investigators shifted the research subject to cats and decided they needed to use a radiofrequency field to carry the ELF signal into the cat brain, and observed EEG pattern changes, ability to sense and behaviorally respond to the ELF component of RFR, and the ability of minor electric current to stimulate the release of an inhibitory neurotransmitter, GABA, and simultaneous release of a surrogate measure, calcium ions, from the cortex [5,6]. At this time Bawin, a member of the research group, adopted newly hatch chickens as sources of brain tissue and observed changes in the release of calcium ions from in vitro specimens as a function of ELF frequency directly or as amplitude modulation ('am') of RFR (RFRam) [7–11]. Tests of both EMF frequency and intensity dependences demonstrated a single sensitive region (termed 'window') over the range of frequency and intensity examined. This series of papers showed that EMF-induced changes could occur in several species (human, monkey, cat and chicken), that calcium ions could be used as surrogate measures for a neurotransmitter, that ELF fields could produce effects similar to RFRam (note: without the 'am', there was no effect although the RFR intensity was the same), and that the dose and frequency response consisted of a single sensitivity window.

Subsequent, independent research groups published a series of papers replicating and extending this earlier work. Initial studies by Blackman, Joines and colleagues [12–25] used the same chick brain assay system as Bawin and colleagues. These papers reported multiple windows in intensity and in frequency within which calcium changes were observed in the chick brain experimental systems under EMF exposure. Three other independent groups offered confirmation of these results by reporting intensity and frequency windows for calcium, neurotransmitter or enolase release under EMF exposure of human and animal nervous system-derived cells in vitro by Dutta et al. [26–29], of rat pancreatic tissue slices by Albert et al. [30], and of frog heart by Schwartz et al. [31] but not frog-heart atrial strips in vitro [32]. This series of papers showed that multiple frequency and intensity windows were a common phenomenon that required the development of new theoretical concepts to provide a mechanism of action paradigm.

2.2. Refined laboratory studies reveal more details

Additional aspects of the EMF experiments with the chick brain described by Blackman and colleagues, above, also revealed critical co-factors that influenced the action of EMF to cause changes in calcium release, including the influence of the local static magnetic field, and the influence of physico-chemical parameters, such as pH, temperature and the ionic strength of the bathing solution surrounding the brain tissue during exposure. This information provides clues for and constraints on any theoretical mechanism that is to be developed to explain the phenomenon. Most current theories ignore these parameters that need to be monitored and controlled for EMF exposure to produce NTE. These factors demonstrate that the current risk assessment paradigms, which ignore them, are incomplete and thus may not provide the level of protection currently assumed.

2.3. Sensitivity of developing organisms

An additional study was also conducted to determine if EMF exposure of chicken eggs while the embryo was developing could influence the response of brain tissue from the newly hatched chickens. The detailed set of frequency and intensity combinations under which effects were observed, were all obtained from hatched chickens whose eggs were incubated for 21 days in an electrically heated chamber containing 60-Hz fields. Thus tests were performed to determine if the 60-Hz frequency of ELF fields (10 V/m in air) during incubation, i.e., during embryogenesis and organogenesis, would alter the subsequent calcium release responses of the brain tissue to EMF exposure. The reports of Blackman et al. [19] and Joines et al. [25] showed that the brain tissue response was changed when the field during the incubation period was 50 Hz rather than 60 Hz. This result is consistent with an anecdotal report of adult humans, institutionalized because of chemical sensitivities, who were also responsive to the frequency of power-line EM fields that were present in the countries where they were born and raised [33]. This information indicates there may be animal and human exposure situations where EMF imprinting during development could be an important factor in laboratory and epidemiological situations. EMF imprinting, which may only become manifest when a human is subjected to chemical or biological stresses, could reduce ability to fight disease and toxic insult from environmental pollution, resulting in a population in need of more medical services, with resulting lost days at work.

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3. Fundamental exposure parameters—to be considered when establishing a mode (or mechanism) of action for non-thermal EMF-induced biological effects

3.1. Intensity

There are numerous reports of biological effects that show intensity "windows", that is, regions of intensity that cause changes surrounded by higher and lower intensities that show no effects from exposure. One very clear effect by Blackman and colleagues is 16-Hz, sine wave-induced changes in calcium efflux from brain tissue in a test tube because it shows two very distinct and clearly separated intensity windows of effects surrounded by regions of intensities that caused no effects [17]. There are other reports for similar multiple windows of intensity in the radiofrequency range [22,26,29,31]. Note that calcium ions are a secondary signal transduction agent active in many cellular pathways. These results show that intensity windows exist, they display an unusual and unanticipated "non-linear" (non-linear and non-monotonic) phenomenon that has been ignored in all risk assessment and standard setting exercises, save the NCRP 1986 publication [1]. Protection from multiple intensity windows has never been incorporated into any risk assessment; to do so would call for a major change in thinking. These results mean that lower intensity is not necessarily less bioactive, or less harmful.

Multiple intensity windows appeared as an unexpected phenomenon in the late 1970s and 1980s. There has been one limited attempt to specifically model this phenomenon by Thompson et al. [34], which was reasonably successful. This modeling effort should be extended because there are publications from two independent research groups showing multiple intensity windows for 50, 147, and 450 MHz fields when amplitude modulated at 16 Hz using the calcium ion release endpoint in chicken brains, in vitro. The incident intensities (measured in air) for the windows at the different carrier frequencies do not align at the same values. However, Joines et al. [23,24] and Blackman et al. [20] noted the windows of intensity align across different carrier frequencies if one converts the incident intensity to the intensity expected within the sample at the brain surface. This conversion was accomplished by correcting for the different dielectric constants of the sample materials due to the different carrier frequencies. The uniqueness of this response provides a substantial clue to theoreticians but it is interesting and disappointing that no publications have appeared attempting to address this relationship. It is obvious that this phenomenon is one that needs further study.

3.2. Frequency

Frequency-dependent phenomena are common occurrences in nature. For example, the human ear only hears a portion of the sound that is in the environment, typically from 20 to 20,000 Hz, which is a frequency "window". Another biological frequency window can be observed for plants grown indoors. Given normal indoor lighting the plants may grow to produce lush vegetation but not produce flowers unless illuminated with a lamp that emits a different spectrum of light partially mimicking the light from the sun. Thus, frequency windows of response to various agents exist in biological systems from plants to homo sapiens.

In a similar manner, there are examples of EMF-caused biological effects that occur in a frequency-dependent manner that cannot be explained by current flow or heating. The examples include reports of calcium ion efflux from brain tissue in vitro by Blackman and Joines and colleagues at low frequency [15,19] and at high frequency modulated at low frequency [20,35,24]. An additional example of an unexpected result is by Liboff [36].

In addition, two apparently contradictory multiple-frequency exposure results provide examples of the unique and varied non-thermal interactions of EMF with biological systems. Litovitz and colleagues showed that an ELF sinusoidal signal could induce a biological response in a cell culture preparation, and that the addition of a noise signal of equal average intensity could block the effect caused by the sinusoidal signal, thereby negating the influence of the sinusoidal signal [37]. Similar noise canceling effects were observed using chick embryo preparations [38,39]. It was also shown that the biological effects caused by microwave exposures imitating cell phone signals could be mitigated by ELF noise [40]. However, this observation should not be generalized; a noise signal is not always benign. Milham and Morgan [41] showed that a sinusoidal ELF (60-Hz) signal was not associated with the induction of cancer in humans, but when that sinusoidal signal was augmented by a noise signal, basically transients that added higher frequencies, an increase in cancer was noted in humans exposed over the long-term. Thus, the addition of noise in this case was associated with the appearance of a health issue. Havas [42–44] has described other potential health problems associated with these higher frequency transients, termed "dirty power." The bioactive frequency regions observed in these studies have never been explicitly considered for use in any EMF risk assessments, thus demonstrating the incomplete nature of current exposure guideline limits.

There are also EMF frequency-dependent alterations in the action of nerve growth factor (NGF) to stimulate neurite outgrowth (growth of primitive axons or dendrites) from a peripheral-nerve-derived cell (PC-12) in culture shown by Blackman et al. [45,46] and by Trillo et al. [47]. The combined effect of frequency and intensity is also a common occurrence in both the analogous sound and the light examples given above. Too much or too little of either frequency or intensity show either no or undesirable effects. Similarly, Blackman et al. [15] has reported EMF responses composed of effect "islands" of intensity and frequency combinations, surrounded by a "sea" of intensity and frequency combinations of null effects. Although the mechanisms responsible

for these effects have not been established, the effects represent a here-to-fore unknown phenomenon that may have complex ramifications for risk assessment and standard setting. Nerve growth and neurotransmitter release that can be altered by different combinations of EMF frequencies and intensities, especially in developing organisms like children, could conceivably produce over time a subsequent altered ability to successfully or fully respond behaviorally to natural stressors in the adult environment; research is urgently needed to test this possibility in animal systems.

Nevertheless, this phenomenon of frequency dependence is ignored in the development of present exposure standards. These standards rely primarily on biological responses to intensities within an arbitrarily defined engineering-based frequency bands, not biologically based response bands, and are solely based on an energy deposition determinations.

4. Static magnetic field—a completely unexpected complexity

The magnetic field of the earth at any given location has a relatively constant intensity as a function of time. However, the intensity value, and the inclination of the field with respect to the gravity vector, varies considerable over the face of the earth. More locally, these features of the earth's magnetic field can also vary by more than 20% inside manufactured structures, particularly those with steel support structures.

At the Bioelectromagnetics Society annual meeting in 1984 [48], Blackman revealed his group's discovery that the intensity of the static magnetic field could establish and define those oscillatory frequencies that would cause changes in calcium ion release in his chick brain preparation. This result was further discussed at a NATO Advanced Research workshop in Erice, Italy in the fall of 1984 and by publications from that meeting and subsequent research: Blackman et al. [14,18] and Liboff et al. [36,49,50]. Substantial additional research on this feature was reported by Liboff and colleagues [51,52,50]. Blackman et al. also reported on the importance of the relative orientation of the static magnetic field vector to the oscillating magnetic field vector [21] and demonstrated a reverse biological response could occur depending on parallel or perpendicular orientations of the static and oscillating magnetic fields [53].

There have been many attempts to explain this phenomenon by a number of research teams led by Smith [49], Blackman [15], Liboff [36,54], Lednev [55], Blanchard [56], Zhadin [57], del Giudice [58], Binhi [59–62], and Matronchik [63] but none has been universally accepted. Nevertheless, experimental results continued to report static and oscillating field dependencies for non-thermally induced biological effects in studies led by Zhadin [64,65], Vorobyov [66], Baureus Koch [67], Sarimov [68], Prato [69,70], Comisso [71], and Novikov [72].

With this accumulation of reports from independent, international researchers, it is now clear that if a biological response depends on the static magnetic field intensity, and even its orientation with respect to an oscillating field, then the conditions necessary to reproduce the phenomenon are very specific and might easily escape detection (see for example, Blackman and Most [73]. The consequences of these results are that there may be exposure situations that are truly detrimental (or beneficial) to organisms, but that are insufficiently common on a large scale that they would not be observed in epidemiological studies; they need to be studied under controlled laboratory conditions to determine impact on health and wellbeing.

5. Electric and magnetic components—both biological active with different consequences

Both the electric and the magnetic components have been shown to directly and independently cause biological changes. There is one report that clearly distinguishes the distinct biological responses caused by the electric field and by the magnetic field. Marron et al. [74] show that electric field exposure can increase the negative surface charge density of an amoeba, Physarum polycephalum, and that magnetic field exposure of the same organism causes changes in the surface of the organism to reduce its hydrophobic character. Other scientists have used concentric growth surfaces of different radii and vertical magnetic fields perpendicular to the growth surface to determine if the magnetic or the induced electric component is the agent causing biological change. Liburdy et al. [75], examining calcium influx in lymphocytes, and Greene et al. [76], monitoring ornithine decarboxylase (ODC) activity in cell culture, showed that the induced electric component was responsible for their results. In contrast, Blackman et al. [77,78] monitoring neurite outgrowth from two different clones of PC-12 cells and using the same exposure technique used by Liburdy and by Greene showed the magnetic component was the critical agent in their experiments. EMF-induced changes on the cell surface, where it interacts with its environment, can dramatically alter the homeostatic mechanisms in tissues, whereas changes in ODC activity are associated with the induction of cell proliferation, a desirable outcome if one is concerned about wound healing, but undesirable if the concern is tumor cell growth. This information demonstrates the multiple, different ways that EMF can affect biological systems. Present analyses for risk assessment and standard setting have ignored this information, thus making their conclusions of limited value.

6. Sine and pulsed waves—like different programs on a radio broadcast station

Important characteristics of pulsed waves that have been reported to influence biological processes include the following: (1) frequency, (2) pulse width, (3) intensity, (4) rise and fall time, and (5) the frequency, if any, within the pulse ON

time. Chiabrera et al. [79] showed that pulsed fields caused de-differentiation of amphibian red blood cells. Scarfi et al. [80] showed enhanced micronuclei formation in lymphocytes of patients with Turner's syndrome (only one X chromosome) but no change in micronuclei formation when the lymphocytes were exposed to sine waves (Scarfi et al. [81]). Takahashi et al. [82] monitored thymidine incorporation in Chinese hamster cells and explored the influence of pulse frequency (two windows of enhancement reported), pulse width (one window of enhancement reported) and intensity (two windows of enhancement reported followed by a reduction in incorporation). Ubeda et al. [83] showed the influence of difference rise and fall times of pulsed waves on chick embryo development.

6.1. Importance for risk assessment

It is important to note that the frequency spectrum of pulsed waves can be represented by a sum of sine waves which, to borrow a chemical analogy, would represent a mixture of chemicals, anyone of which could be biologically active. Risk assessment and exposure limits have been established for specific chemicals or chemical classes of compounds that have been shown to cause undesirable biological effects. Risk assessors and the general public are sophisticated enough to recognize that it is impossible to declare all chemicals safe or hazardous; consider the difference between food and poisons, both of which are chemicals. A similar situation occurs for EMF; it is critical to determine which combinations of EMF conditions have the potential to cause biological harm and which do not.

Obviously, pulse wave exposures represent an entire genre of exposure conditions, with additional difficulty for exact independent replication of exposures, and thus of results, but with increased opportunities for the production of biological effects. Current standards were not developed with explicit knowledge of these additional consequences for biological responses.

7. Mechanisms

Two papers have the possibility of advancing understanding in this research area. Chiabrera et al. [84] created a theoretical model for EMF effects on an ion's interaction with protein that includes the influence of thermal energy and of metabolism. Before this publication, theoreticians assumed that biological effects in living systems could not occur if the electric signal is below the signal caused by thermal noise, in spite of experimental evidence to the contrary. In this paper, the authors show that this limitation is not absolute, and that different amounts of metabolic energy can influence the amount and parametric response of biological systems to EMF. The second paper, by Marino et al. [85], presents a new analytical approach to examine endpoints in systems exposed to EMF. The authors, focusing on exposure-induced lymphoid phenotypes, report that EMF may not cause changes in the mean values of endpoints, but by using recurrence analysis, they capture exposure-induced, statistically significant, non-linear movements of the endpoints to either side of the mean endpoint value. They provide further evidence using immunological endpoints from exposed and sham treated mice [86–88]. Additional research has emerged from this laboratory on EMF-induced animal and human brain activity changes that provides more evidence for the value of their research approach (Marino et al. [89–92], Kolomytkin et al. [93] and Carrubba et al. [94–98]). Further advanced theoretical and experimental studies of relevance to non-thermal biological effects are emerging; see for example reports by Binhi et al. [59–62], Zhadin et al. [64,99,65], and Novikov et al. [72]. *It is apparent that much remains to be examined and explained in EMF biological effects research through more creative methods of analysis than have been used before. The models described above need to be incorporated into risk assessment determinations.*

8. Problems with current risk assessments—observations of effects are segregated by artificial frequency bands that ignore modulation

One fundamental limitation of most reviews of EMF biological effects is that exposures are segregated by the physical (engineering/technical) concept of frequency bands favored by the engineering community. This is a default approach that follows the historical context established by the incremental addition of newer technologies that generate increasingly higher frequencies. However, this approach fails to consider unique responses from biological systems that are widely reported at various combinations of frequencies, modulations and intensities.

When common biological responses are observed without regard for the particular, engineering-defined EMF frequency band in which the effects occur, this reorganization of the results can highlight the commonalities in biological responses caused by exposures to EMF across the different engineering-defined frequency bands. An attempt to introduce this concept to escape the limitations of the engineering-defined structure occurred with the development of the 1986 NCRP radiofrequency exposure guidelines because published papers from the early 1970s to the mid 1980s (to be discussed below) demonstrated the need to include amplitude modulation as a factor in setting of maximum exposure limits. The 1986 NCRP guideline [1] was the one and only risk evaluation that included an exception for modulated fields.

The current research and risk assessment attempts are no longer tenable. The 3-year delay in the expected report of the 7-year Interphone study results has made this epidemiological approach a 10-year long effort, and the specific exposure conditions, due to improved technology, have changed so that the results may no longer be applicable to the current

exposure situation. It is unproductive to continue to fund epidemiological studies of people who are exposed to a wide variety of diversified, uncontrolled, and poorly characterized EMF in their natural and work environments. In place of the funding of more epidemiological studies should be funding to support controlled laboratory studies to focus on the underlying processes responsible for the NTE described above, so that mechanisms or modes of action can be developed to provide a theoretical framework to further identify, characterize and unify the action of the heretofore ignored exposure parameters shown to be important.

8.1. Potential explanation for the failure to optimize research in EMF biological effects

Unfortunately, risk evaluations following the 1986 NCRP example [1], returned to the former engineering-defined analysis conditions, in part because scientists who reported non-thermal effects were not placed on the review committees, and in the terms of Slovic [100] "Risk assessment is inherently subjective and represent a blend of science and judgment with important psychological, social, cultural, and political factors. ... Whoever controls the definition of risk controls the rational solution to the problem at hand. ... Defining risk is thus an exercise in power." It appears that by excluding scientists experienced with producing non-thermal biological effects, the usually sound judgment by the selected committees was severely limited in its breadth-of-experience, thereby causing the members to retreat to their own limited areas of expertise when forced to make judgments, as described by Slovic [100], "Public views are also influenced by worldviews, ideologies, and values; so are scientists' views, particularly when they are working at limits of their expertise." The current practice of segregating scientific investigations (and resulting public health limits) by artificial divisions of frequency dramatically dilutes the impact of the basic science results, thereby reducing and distorting the weight of evidence in any evaluation process (see evaluations of bias by Havas [101], referring to NRC 1997 [102] compared to NIEHS 1998 [103] and NIEHS 1999 [104]).

9. Suggested research

Are there substitute approaches that would improve on the health-effects evaluation situation? As mentioned above, it may be useful in certain cases to develop a biologically based clustering of the data to focus on and enrich understanding of certain aspects of biological responses. Some examples to consider for biological clustering include: (1) EMF features, such as frequency and intensity inter-dependencies, (2) common co-factors, such as the earth's magnetic field or co-incident application of chemical agents to perturb and perhaps sensitize the biological system to EMF, or (3) physiological state of the biological specimen, such as age or sensitive sub-populations, including genetic predisposition as described by Fedrowitz et al. [105,106], and for human populations, recently reported by Yang et al. [107].

To determine if this approach has merit, one could combine reports of biological effects found in the ELF (including sub-ELF) band with effects found in the RF band when the RF exposures are amplitude modulated (AM) using frequencies in the ELF band. The following data should be used: (a) human response time changes under ELF exposure [2], (b) monkey response time and EEG changes under ELF exposure [3,4], (c) cat brain EEG, GABA and calcium ion changes induced by ELF and AM-RF [8,9,7,10,6,11,108,5], (d) calcium ion changes in chick brain tissue under ELF and AM-RF [8,9,7,10,13–15,21,16–18,12,19,20,22,35,23–25,11], and (e) calcium changes under AM-RF in brain cells in culture [26–28] and in frog heart under AM-RF [31]. The potential usefulness of applying biological clustering in the example given above even though AM is used, is that the results may have relevance to assist in the examination of some of the effects reportedly caused by cellular phone exposures which include more complex types of modulation of RF. This suggestion is reasonable because three groups later reported human responses to cell phone emissions that include changes in reaction times – Preece et al. [109,110], Koivisto et al. [111,112] and Krause et al. [113,114] – or to brain wave potentials that may be associated with reaction time changes—Freude et al. [115,116].

Subsequently, Preece et al. [117] tested cognitive function in children and found a trend, but not a statistically significant change in simple reaction time under exposure, perhaps because he applied a Bonferroni correction to his data (alpha for significance was required to be less than 0.0023). It would appear that a change in the experimental protocol might provide a more definitive test of the influence of exposure on simple reaction time because it is known that a Bonferroni correction is a particularly severe test of statistical significance, or as the author observed, "a particularly conservative criterion."

Krause et al. [118] examined cognitive activity by observing oscillatory EEG activity in children exposed to cell phone radiation while performing an auditory memory task and reported exposure related changes in the ~4–8 Hz EEG frequencies during memory encoding, and changes in that range and also ~15 Hz during recognition. The investigators also examined cognitive processing, an auditory memory task or a visual working memory task, in adults exposed to CW or pulsed cell phone radiation on either the right or left side of the head, and reported modest changes in brain EEG activity in the ~4–8 Hz region, compared to CW exposure, but with caveats that no behavior changes were observed, and that the data were varying, unsystematic and inconsistent with previous reports (Krause et al. [119]). Haarala and colleagues conducted an extensive series of experiments, examining reaction time [120], short-term memory [121], short-term memory in children [122], and right versus left hemisphere exposure [123]. Although these studies did not

support the positive effects from exposure reported by others, they provided possible explanations for the apparent lack of agreement.

Other research groups have also examined the effects of cell phone radiation on the central nervous system, including Borbely et al. [124], Huber et al. [125], Loughran et al. [126], and D'Costa et al. [127], who found changes in sleep EEG patterns and other measures during or after short-term exposures, while others, such as Fritzer et al. [128] exposed for longer time periods found no changes in sleep parameters, EEG power spectra, correlation dimension nor cognitive function. The work of Pritchard [129] served as the basis to examining correlation dimensions, which is opening a potentially fertile avenue for investigation. Although this approach provides more indepth information on ongoing processes and function, it has not yet been used to address potential consequences associated with long-term cell phone use.

The papers published in the 1960s through 1991, described in earlier sections of this paper, foreshadowed the more recent publications in 1999 through 2008 showing response time changes, or associated measures, in human subjects during exposure to cell phone-generated radiation. It is unfortunate that essentially none of the earlier studies was acknowledged in these recent reports on cognition, reaction time and other measures of central nervous system processes. Without guidance from this extensive earlier work, particularly those demonstrating the variety of exposure parameter spaces that must be controlled to produce repeatable experiments, the development of the mechanistic bases for non-thermal effects from EMF exposures will be substantially delayed. The omission of the recognition of the exposure conditions that affect the biological outcomes continues as recently as the National Academy of Science 2009 publication [130] of future directions for research, which emphasizes the modest perspective in the results from committee members working at the limits of expertise, as anticipated by Slovic [100].

Let us hope that subsequent national and international committees that consider future directions for EMF research include members who have performed and reported non-thermal effects, in order to provide a broader perspective to develop programs that will more expeditiously address potential health problems as well as to provide guidance to industry on prudent procedures to establish for their technologies.

At present, we are left with a recommendation voiced in 1989 by Abelson [131] in an editorial in Science Magazine that addressed electric power-specific EMF, but is applicable to higher frequency EMF as well, to "adopt a prudent avoidance strategy" by "adopting those which look to be 'prudent' investments given their cost and our current level of scientific understanding about possible risks."

10. Conclusions

There is substantial scientific evidence that some modulated fields (pulsed or repeated signals) are bioactive, which increases the likelihood that they could have health impacts with chronic exposure even at very low exposure levels. Modulation signals may interfere with normal, non-linear biological processes. Modulation is a fundamental factor that should be taken into account in new public safety standards; at present it is not even a contributing factor. To properly evaluate the biological and health impacts of exposure to modulated RFR (carrier waves), it is also essential to study the impact of the modulating signal (lower frequency fields or ELF-modulated RF). Current standards have ignored modulation as a factor in human health impacts, and thus are inadequate in the protection of the public in terms of chronic exposure to some forms of ELF-modulated RF signals. The current IEEE and ICNIRP standards are not sufficiently protective of public health with respect to chronic exposure to modulated fields (particularly new technologies that are pulse-modulated and heavily used in cellular telephony). The collective papers on modulation appear to be omitted from consideration in the recent WHO and IEEE science reviews. This body of research has been ignored by current standard setting bodies that rely only on traditional energy-based (thermal) concepts. More laboratory as opposed to epidemiological research is needed to determine which modulation factors, and combinations are bioactive and deleterious at low intensities, and are likely to result in disease-related processes and/or health risks; however this should not delay preventative actions supporting public health and wellness. If signals need to be modulated in the development of new wireless technologies, for example, it makes sense to use what existing scientific information is available to avoid the most obviously deleterious exposure parameters and select others that may be less likely to interfere with normal biological processes in life. The current membership on Risk Assessment committees needs to be made more inclusive, by adding scientists experienced with producing non-thermal biological effects. The current practice of segregating scientific investigations (and resulting public health limits) by artificial, engineering-based divisions of frequency needs to be changed because this approach dramatically dilutes the impact of the basic science results and eliminates consideration of modulation signals, thereby reducing and distorting the weight of evidence in any evaluation process.

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Apparent decreases in Swedish public health indicators after 1997—Are they due to improved diagnostics or to environmental factors?

Örjan Hallberg [a,*], Olle Johansson [b]

[a] *Hallberg Independent Research[1], Polkavägen 14B, 142 65 Trångsund, Sweden*

[b] *The Experimental Dermatology Unit, Department of Neuroscience, Karolinska Institute, 171 77 Stockholm, Sweden*

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Abstract

The object of this work was to review recent trends in public health in Sweden. Data on different adverse health indicators were collected from official Swedish registries. We found that population health generally improved during the early 1990s but suddenly started to deteriorate from 1997 onwards. This quite dramatic change is not likely to be explained only by improved diagnostics but physical causes need immediately to be searched for. A connection with the increasing exposure of the population to GHz radiation from mobile phones, base stations and other communication technologies cannot be ruled out.

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Keywords: Alzheimer's disease; Heart malformations; Lung cancer; Melanoma; Prostata carcinoma; Traffic accidents; Mobile phone speech time

1. Introduction

During the first half of the 1990s, the Swedish population appeared increasingly healthy. Sick leave registrations decreased; in addition, lung cancer among older men steadily decreased and the incidence of prostate cancer levelled out, becoming stable or slightly decreasing between 1993 and 1997. In Stockholm, even the number of traffic accidents with injuries went down each year from 1985 to 1996. Mortality due to Alzheimer's disease increased in the early 1980s, but remained steady at 2.5–4 per 100,000 person-years (age standardized) from 1990 to 1997.

Objective of the present study: After 1997, public health appeared to decline markedly. Was this decrease the result of improvements in detection and diagnosis, or did maladies actually increase? In this paper, we take a look at several health trends, one by one, and analyze the suggested causes underlying the adverse health- and traffic safety indicators.

2. Materials and methods

All data were retrieved from the official databases of the National Health and Welfare Board (Socialstyrelsen; SoS) and of the Swedish Road Administration (Vägverket; VV). Hallberg and Johansson (2004) have presented worrying trends related to public health in Sweden [1]. Hallberg (2007) showed that many adverse health indicators were worse in sparsely populated areas, as hypothesized caused by higher average output power from mobile phones in those areas [2].

3. Results and discussion

1. Lung cancer among elderly men increased markedly beginning after 1997 (Fig. 1). For men aged 80–84 years, the incidence increased from 160 to 230/100,000. For men aged 85+, the incidence increased from 95 to a high of 180/100,000 in 2005. The SoS has not publicly offered any explanation for these increases or commented on this matter.
2. In 1997, the incidence of prostate cancer abruptly increased in all age groups (Fig. 2). In Stockholm, the number of cases in men aged 50–59 stayed fairly stable

* Corresponding author.
E-mail address: oerjan.hallberg@swipnet.se (Ö. Hallberg).

[1] This Research Institution was founded in 2001 and is registered by the Swedish National Patent and Registration Office.

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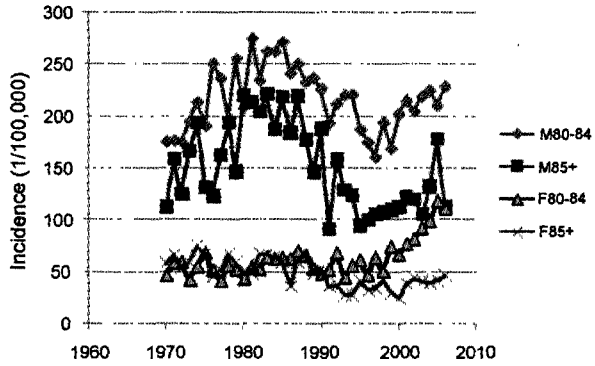

Fig. 1. Lung cancer in the elderly (male (M) and female (F)) has increased in Sweden since 1997.

at around 30 cases per year up to 1996, despite the fact that PSA tests were used routinely starting in 1991. After 1996, when 33 cases of prostate cancer were reported, the number of cases increased to around 300 per year in 2004 and 2005. SoS originally suggested that the apparent increase in prostate cancer was due to the improved diagnostic capabilities of the PSA test. When asked again, the SoS said, "It cannot, however, be ruled out that a certain increase would have been noticed even without these PSA tests, but we don't know how large this increase would have been." Notably, however, the step-like increase in prostate cancer did not coincide with the introduction of the PSA test in 1991.

3. For several decades, the rate of skin melanoma was very stable among younger people (<50 years), despite publicity about the dangers of sun exposure. However, after 2000 the incidence of melanoma of the head and neck region suddenly started to increase in this population (Fig. 3). Simultaneously, the rate of more benign skin tumours dropped, and the sum total of tumours and melanoma continued to increase. However, small carcinomas that would previously have developed into relatively benign tumours now seem to increasingly develop into melanoma. SoS has not commented on this in their reports.

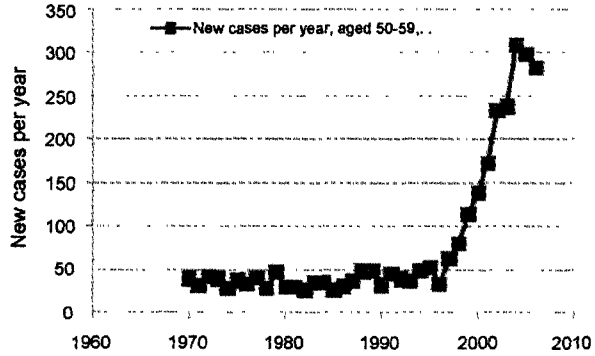

Fig. 2. The number of newly reported cases of prostate cancer in men aged 50–59 years in Stockholm County, Sweden.

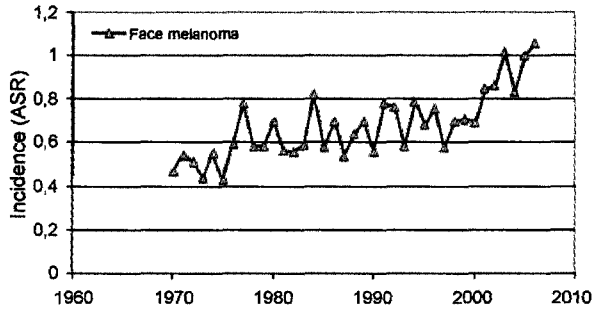

Fig. 3. Melanoma of the face has increased in Sweden among people <60 years since 2000.

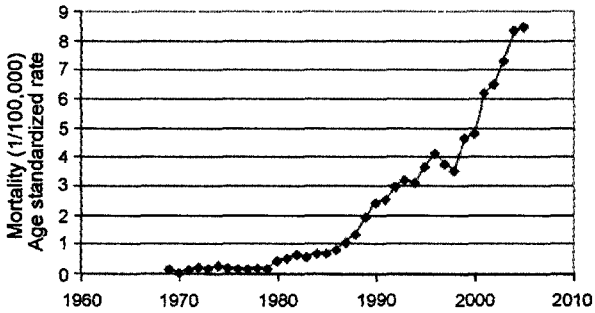

Fig. 4. Alzheimer's mortality has increased steeply since 1998 in Sweden.

4. Mortality associated with Alzheimer's disease has increased dramatically since 1998 (Fig. 4). Today, the incidence is 9/100,000, an increase of 300% in 10 years. When queried, the SoS suggested that this increase can be attributed to an increase in the practice of declaring Alzheimer's disease as the cause of death when signing the death certificate. SoS also claims that there are no grounds for stating that mortality has actually increased. However, a thorough analysis of the data indicates that there is an increase in mortality in older people with this disease [3].
5. In 1985, the number of people seriously injured in Stockholm traffic accidents was around 650. Subsequently, there was a decrease in injuries to a low of 350 in 1997. After 1997, the number of people injured annually started

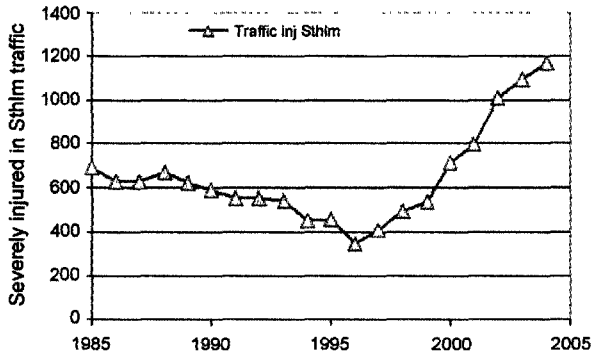

Fig. 5. Traffic injuries in Stockholm have increased since 1997.

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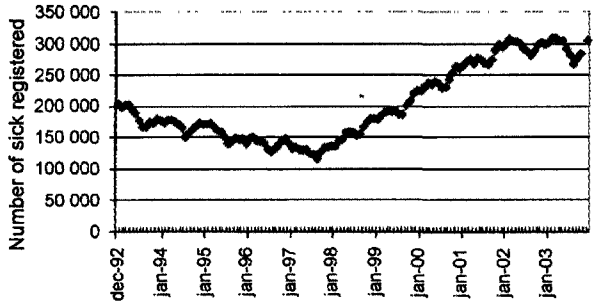

Fig. 6. The number of people in Sweden registered as sick suddenly increased starting in September 1997.

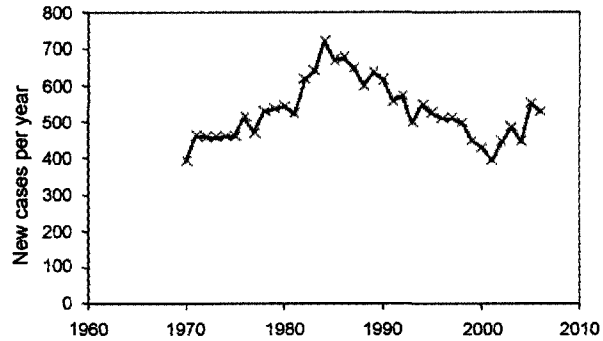

Fig. 7. Brain tumours among in the elderly (>60 years) have increased since 2001 in Sweden.

increasing, reaching 1200 in 2005 (Fig. 5). According to VV, this trend is partly the result of the introduction of a better reporting system in Stockholm. Nonetheless, the increasing number of people severely injured in Swedish traffic ended the downward trend observed until 1997: This number has rapidly increased since 2000. Today, VV reports that the number of people who were severely injured per killed increased rapidly in Stockholm County in the time period 2000–2004.

6. The total number of people taking sick leave was just over 200,000 in 1992. This number decreased steadily to around 125,000 in September 1997. After that time, the trend broke, and we saw an increase to over 300,000 people registering as sick in 2003 (Fig. 6). The authorities have not given any explanation for this abrupt increase in the number of people who registered as sick. It is not likely due to improved diagnostics, but rather to the fact that more people needed to take sick leave. In November 2001, the leader of the KD party, Alf Svensson, commented that "sick-cheating" was one explanation. In contrast to earlier trends, the increase in sickness appears to be greater in more sparsely populated regions. In the beginning of the 80s, it was considered healthy to live in the countryside, since people were healthier there. A closer analysis of sick leave data in different counties shows that the Northern counties and the Gotland island were the last counties to show an increase in sick leave rates. These counties did not show increasing rates until February 1998. In contrast, the increase was observed early on in Blekinge and Kronoborg, where the increase was noticeable in September/October of 1997.
7. The number of new brain tumours in people >60 years old suddenly increased after 2000 (Fig. 7). This development paralleled the increase of melanoma in the face region of people <60 years. In general, the incidence of brain tumours is increasing most in more sparsely populated regions where mobile phones often need to use full output power [2,4].
8. The percentage of newborns with heart problems began to increase after 1998 (Fig. 8). It was recently reported that fetuses and neonates react to their mother's mobile phone use with an increased pulse rate and decreased blood flow [5]. Another report published in the well-known journal *Epidemiology* [6] suggests that such mobile phone use may also influence emotional development and may increase the risk of hyperactivity, behaviour problems, and relational problems with other children up to the time that children start school.

A dramatic environmental change took place in Sweden in the autumn of 1997. At this time, GSM 1800 MHz transmitters were put into use to increase transmission capacity, especially in urban areas, see Fig. 8. Much of the population began to be exposed to 1.8 GHz microwaves both at night and during the day. In the Stockholm area, people began to steer cars using only their right hands while holding the mobile phones by their left hands. The Post- and Telecom Administration states that GSM 1800 MHz began to be used in 1997, but has no information on starting months in different counties. When Telia were queried about starting dates

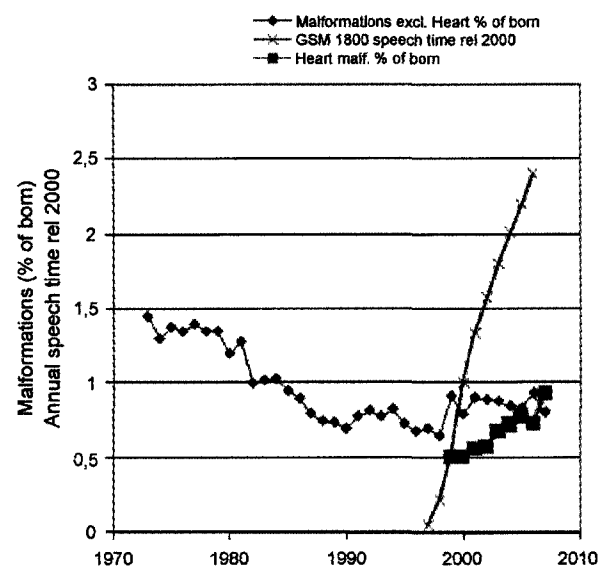

Fig. 8. The percentage of newborns with heart problems has increased since 1998 in Sweden. Also shown is the annual speech time in dual band mobile phones relative to year 2000. The down going trend of malformed newborns excluding heart problems is now broken since 1998.

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for transmitter operation, Telia responded that they will not release this information. "The reason is that this information reasonably has no association with sick registration levels in Sweden in 1997." In 2001, the roll-out of the 3G network started and the use of the higher and probably more biological hazardous frequency, around 2.1 GHz, increased. More details about relevant events in 1997 are described in reference [1].

4. Conclusion

The negative trends in public health indicators in Sweden are not fully explained by better diagnostics, better instrumentation, or better doctors. Because these indicators may reflect real world changes, efforts should be made, starting immediately, to determine the underlying cause or causes.

Conflict of interest

There is no conflict of interest known to the authors related to this work.

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Public health implications of wireless technologies

Cindy Sage[a,*], David O. Carpenter[b]

[a] *Sage Associates, 1396 Danielson Road, Santa Barbara, CA 93108, USA*
[b] *Institute for Health and the Environment, University at Albany, Rensselaer, NY, USA*

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Abstract

Global exposures to emerging wireless technologies from applications including mobile phones, cordless phones, DECT phones, WI-FI, WLAN, WiMAX, wireless internet, baby monitors, and others may present serious public health consequences. Evidence supporting a public health risk is documented in the BioInitiative Report. New, biologically based public exposure standards for chronic exposure to low-intensity exposures are warranted. Existing safety standards are obsolete because they are based solely on thermal effects from acute exposures. The rapidly expanding development of new wireless technologies and the long latency for the development of such serious diseases as brain cancers means that failure to take immediate action to reduce risks may result in an epidemic of potentially fatal diseases in the future. Regardless of whether or not the associations are causal, the strengths of the associations are sufficiently strong that in the opinion of the authors, taking action to reduce exposures is imperative, especially for the fetus and children. Such action is fully compatible with the precautionary principle, as enunciated by the Rio Declaration, the European Constitution Principle on Health (Section 3.1) and the European Union Treaties Article 174.
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Keywords: Wireless technology; Brain cancer; Radiofrequency; Cell phones; Wireless antenna facilities; Childrens' health

1. Introduction and background

Exposure to electromagnetic fields (EMF) has been linked to a variety of adverse health outcomes that may have significant public health consequences [1–13]. The most serious health endpoints that have been reported to be associated with extremely low frequency (ELF) and/or RF include childhood and adult leukemia, childhood and adult brain tumors, and increased risk of the neurodegenerative diseases, Alzheimer's and amyotrophic lateral sclerosis (ALS). In addition, there are reports of increased risk of breast cancer in both men and women, genotoxic effects (DNA damage and micronucleation), pathological leakage of the blood–brain barrier, altered immune function including increased allergic and inflammatory responses, miscarriage and some cardiovascular effects [1–13]. Insomnia (sleep disruption) is reported in studies of people living in very low-intensity RF environments with WI-FI and cell tower-level exposures [85–93]. Short-term effects on cognition, memory and learning, behavior, reaction time, attention and concentration, and altered brainwave activity (altered EEG) are also reported in the scientific literature [94–107]. Biophysical mechanisms that may account for such effects can be found in various articles and reviews [136–144].

The public health implications of emerging wireless technologies are enormous because there has been a very rapid global deployment of both old and new forms in the last 15 years. In the United States, the deployment of wireless infrastructure has accelerated greatly in the last few years with 220,500 cell sites in 2008 [14–16]. Eighty-four percent of the population of the US own cell phones [16]. Annualized wireless revenues in 2008 will reach $144 billion and US spending on wireless communications will reach $212 billion by 2008. Based on the current 15% annual growth rate enjoyed by the wireless industry, in the next 5 years wireless will become a larger sector of the US economy than both the agriculture and automobile sectors. The annualized use of cell phones in the US is estimated to be 2.23 trillion minutes in 2008 [16]. There are 2.2 billion users of cell phones worldwide in 2008 [17] and many million more users of cordless phones.

Over 75 billion text messages were sent in the United States, compared with 7.2 billion in June 2005, according to

* Corresponding author. Tel.: +1 805 969 0557; fax: +1 805 969 5003.
E-mail address: sage@silcom.com (C. Sage).

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CTIA, the Wireless Association, the leading industry trade group [16]. The consumer research company Nielsen Mobile, which tracked 50,000 individual customer accounts in the second quarter of this year, found that Americans each sent or received 357 text messages a month then, compared with 204 phone calls. That was the second consecutive quarter in which mobile texting significantly surpassed the number of voice calls [17].

The Electronics Industries Alliance (EIA) represents 80% of the $550 billion US electronics industry "that provides two million jobs for American workers." Its members include companies from the consumer electronics and telecommunications industries, among others [17].

There is intense industry competition for market share. Telecom taxes form an immense revenue generator for the government sector. Sale of the airwaves (auctions selling off wireless bandwidth) is a multi-million dollar industry for governments, and multi-billion dollar global advertising budgets are common. Lobbying dollars from the telecom-related industries are estimated to be $300 million annually. The media is nearly silent on health issues, perhaps in part because of global advertising revenues that compromise journalistic independence and discourage balanced coverage of health, equity and economic issues.

2. Evidence supporting a public health risk

Even if there is only a small risk to health from chronic use of and exposure to wireless technologies, there is the potential for a profound public health impact. RF radiation now saturates the airwaves, resulting in exposure to both users and non-users. The effects are both short-term (sleep disruption, hormone disruption, impairment of cognitive function, concentration, attention, behavior, and well-being) and they are almost certainly long-term (generational impacts on health secondary to DNA damage, physiological stress, altered immune function, electrosensitivity, miscarriage risks, effects on sperm quality and motility leading to infertiility, increased rates of cancer, and neurological diseases including Alzheimer's disease and ALS—at least for ELF exposures). (Chapters 5–12 of the BioInitiative Report [1] and papers in this Supplement.)

There is credible scientific evidence that RF exposures cause changes in cell membrane function, metabolism and cellular signal communication, as well as activation of proto-oncogenes and triggering of the production of stress proteins at exposure levels below current regulatory limits. There is also generation of reactive oxygen species, which cause DNA damage, chromosomal aberrations and nerve cell death. A number of different effects on the central nervous system have also been documented, including activation of the endogenous opioid systems, changes in brain function including memory loss, slowed learning, motor dysfunction and performance impairment in children, and increased frequency of headaches, fatigue and sleep disorders. Melatonin secretion is reduced, resulting in altered circadian rhythms and disruption of several physiological functions. (Chapters 5–12 of the BioInitiative Report [1] and papers in this Supplement.)

These effects can reasonably be presumed to result in adverse health effects and disease with chronic and uncontrolled exposures, and children may be particularly vulnerable [1,19]. The young are also largely unable to remove themselves from such environments. Second-hand non-ionizing radiation, like second-hand smoke may be considered of public health concern based on the evidence at hand.

2.1. Malignant brain tumors

At present, the most persuasive evidence for cancer resulting from RF exposure is that there is a significantly increased risk of malignant glioma in individuals that have used a mobile phone for 10 or more years, with the risk being elevated only on the side of the head on which the phone is used regularly (ipsilateral use) [1,3,4,6–8,18]. While the risk for adults after 10 or more years of use is reported to be more than doubled, there is some evidence beginning to appear that indicates that the risk is greater if the individual begins to use a mobile phone at younger ages. Hardell et al. [18] reported higher odds ratios in the 20–29-year-old group than other age ranges after more than 5 years of use of either analog or cordless phones. Recently in a London symposium Hardell reported that after even just 1 or more years of use there is a 5.2-fold elevated risk in children who begin use of mobile phones before the age of 20 years, whereas for all ages the odds ratio was 1.4. Studies from Israel have found that the risk of parotid gland tumors (a salivary gland in the cheek) is increased with heavy cell phone use [7]. The risk of acoustic neuroma (a benign but space-occupying tumor on the auditory nerve) is also significantly increased on the ipsilateral side of the head after 10 or more years of mobile phone use [1,3]. This relationship has also been documented in some of the published reports of the WHO Interphone Study, a decade-long 13-country international assessment of cell phone risks and cancer [6,8].

Kundi reports that "(E)pidemiological evidence compiled in the last 10 years starts to indicate an increased risk, in particular for brain tumors (glioma, meningioma, acoustic neuroma), from mobile phone use. Considering biases that may have been operating in most studies the risk estimates are rather too low, although recall bias could have increased risk estimates. The net result, when considering the different errors and their impact is still an elevated risk" [19].

The latency for most brain tumors is 20 years or more when related to other environmental agents, for example, to X-ray exposure. Yet, for cell phone use the increased risks are occurring much sooner than twenty years, as early as 10 years for brain tumors in adults and with even shorter latencies in children. This suggests that we may currently be significantly underestimating the impact of current levels of

use of RF technology, since we do not know how long the average latency period really is. If it is 20 years, then the risk rate will likely be much higher than an overall doubling of risk for cell phone users if the peak comes later than 10 years. It may also signal very troubling risks for those who start using cell phones, and perhaps all wireless devices, in early childhood. We may not have proof of effect for decades until many hundreds of thousands of new cases of malignant gliomas are set in motion by long-term cell phone use.

The preliminary evidence that mobile phone use at younger ages may lead to greater risk than for older persons is of particular concern. There is a large body of evidence that childhood exposure to environmental agents poses greater risk to health than comparable exposure during adulthood [20,21]. There is reason to expect that children would be more susceptible to the effects of EMF exposure since they are growing, their rate of cellular activity and division is more rapid, and they may be more at risk for DNA damage and subsequent cancers. Growth and development of the central nervous system is still occurring well into the teenage years so that neurological changes may be of great importance to normal development, cognition, learning, and behavior.

A greater vulnerability of children to developing brain cancer from mobile phone use may be the consequence of a combination of patterns of use, stage of development and physical characteristics related to exposure. In addition to the fact that the brain continues to develop through the teen years, many young children and teenagers now spend very large periods of time using mobile phones. The brain is the main target organ of cell phones and cordless phones, with highest exposure to the same side as the phone is used. Further, due to anatomical reasons, the brain of a child is more exposed to RF radiation than the brain of an adult [22,23]. This is caused by the smaller brain size, a thinner pinna of the ear, thinner skin and thinner skull bone permitting deeper penetration into the child's brain. A recent French study showed that children absorb twice the RF from cell phone use as do adults [24].

In addition to concerns about cancer, there is evidence for short-term effects of RF exposure on cognition, memory and learning, behavior, reaction time, attention and concentration, altered brainwave activity (altered EEG) [95–108], and all of these effects argue for extreme caution with regard to exposure of children. The development of children into adults is characterized by faster cell division during growth, the long period needed to fully develop and mature all organ systems, and the need for properly synchronized neural development until early adulthood. Chronic, cumulative RF exposures may alter the normal growth and development of children and adversely affect their development and capacity for normal learning, nervous system development, behavior and judgment [1,97,102].

Prenatal exposure to EMF has been identified as a possible risk factor for childhood leukemia (1). Maternal use of cell phones has been reported to adversely affect fetal brain development, resulting in behavioral problems in those children by the time they reach school age [25]. Their exposure is involuntary in all cases. Children are largely unable to remove themselves from exposures to harmful substances in their environments.

2.2. *Plausible biological mechanisms for a relationship between RF exposure and cancer*

2.2.1. *DNA damage and oxidative stress*

Damage to DNA from ELF and from RF cell phone frequencies at very low intensities (far below FCC and ICNIRP safety limits) has been demonstrated in many studies [1,2,26–35]. Both single- and double-strand DNA damage have been reported by various researchers in different laboratories. This is damage to the human genome, and can lead to mutations which can be inherited, or which can cause cancer, or both.

Non-ionizing radiation is assumed to be of too low energy to cause direct DNA damage. However both ELF and RF radiation induce reactive oxygen species, free radicals that react with cellular molecules including DNA. Free-radical production and/or the failure to repair DNA damage (secondary to damage to the enzymes that repair damage) created by such exposures can lead to mutations. Whether it is greater free-radical production, reduction in anti-oxidant protection or reduced repair capacity, the result will be altered DNA, increased risk of cancer, impaired or delayed healing, and premature aging [36–54]. Exposures have also been linked to decreased melatonin production, which is a plausible biological mechanism for decreased cancer surveillance in the body, and increased cancer risk [34,39,44,46,47,49,50,54]. An increased risk of cancers and a decrease in survival has been reported in numerous studies of ELF and RF [55–69].

2.2.2. *Stress proteins (heat shock proteins or HSP)*

Another well-documented effect of exposure to low-intensity ELF and RF is the creation of stress proteins (heat shock proteins) that signal a cell is being placed under physiological stress) [70–80]. The HSP response is generally associated with heat shock, exposure to toxic chemicals and heavy metals, and other environmental insults. HSP is a signal of cells in distress. Plants, animals and bacteria all produce stress proteins to survive environmental stressors like high temperatures, lack of oxygen, heavy metal poisoning, and oxidative stress.

We can now add ELF and RF exposures to this list of environmental stressors that cause a physiological stress response. Very low-level ELF and RF exposures can cause cells to produce stress proteins, meaning that the cell recognizes ELF and RF exposures as harmful. This is another important way in which scientists have documented that ELF and RF exposures can be harmful, and it happens at levels far below the existing public safety standards. An additional concern is that if the stress goes on too long, the protective effect is diminished. The reduced response with prolonged exposure means the cell is less protected against

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damage, and this is why prolonged or chronic exposures may be harmful, even at very low intensities.

2.2.3. RF-induced gene expression changes

Many environment agents cause diseases, including cancer, not by direct damage to DNA but rather by up- or down-regulation of genes that regulate cell growth and function. Usually there are many genes whose expression is changed, and it is difficult to determine the exact changes responsible for the disease. Both ELF and RF exposures have been shown to result in altered gene expression. Olivares-Banuelos et al. [81] found that ELF exposure of chromaffin cells resulted in changed expression of 53 transcripts. Zhao et al. [82] investigated the gene expression profile of rat neurons exposed to 1800 MHz RF fields (2 W/kg) and found 24 up-regulated genes and 10 down-regulated genes after a 24-h exposure. The altered genes were involved in multiple cellular functions including cytoskeleton, signal transduction pathways and metabolism. Kariene et al. [83] exposed human skin to mobile phone radiation, and found by punch biopsy that 8 proteins were significantly altered in expression, consistent with gene induction. Several other studies have found altered gene expression following RF exposure, although none have been found that explain specific disease states [84].

DNA activation at very low ELF and RF levels, as in the stress response, and DNA damage (strand breaks and micronuclei) at higher levels, are molecular precursors to changes that are believed to lead to cancer. These, along with gene induction, provide plausible biological mechanisms linking exposure to cancer.

The biochemical pathways that are activated are the same for ELF and for RF exposures, and are non-thermal (do not require heating or induced electrical currents). This is true for the stress response, DNA damage, generation of reactive oxygen species as well as gene induction. Thus it is not surprising that the major cancers resulting from exposure to ELF and RF are the same, namely leukemia and brain cancer. The safety standards for both ELF and RF, based on protection from heating, are irrelevant and not protective. ELF exposure levels of only 5–10 mG have been shown to activate the stress response genes (http://www.bioinitiative.org, Sections 1 and 7 [1]).

3. Sleep, cognitive function and performance

The relationship of good sleep to cognition, performance and healing is well recognized. Sleep is a profoundly important factor in proper healing, anti-inflammatory benefits, reduction in physical symptoms of such as tendonitis, over-use syndrome, fatigue-induced lethargy, cognition and learning. Incomplete or slowed physiological recovery is common when sleep is impaired. Circadian rhythms that normalize stress hormone production (cortisol, for example) depend on synchronized sleep patterns.

People who are chronically exposed to low-level wireless antenna emissions report symptoms such as problems in sleeping (insomnia), as well as other symptoms that include fatigue, headache, dizziness, grogginess, lack of concentration, memory problems, ringing in the ears (tinnitus), problems with balance and orientation, and difficulty in multi-tasking [85–93,99]. In children, exposures to cell phone radiation have resulted in changes in brain oscillatory activity during some memory tasks [97,102]. Cognitive impairment, loss of mental concentration, distraction, speeded mental function but lowered accuracy, impaired judgment, delayed reaction time, spatial disorientation, dizziness, fatigue, headache, slower motor skills and reduced learning ability in children and adults have all been reported [85–108].

These symptoms are more common among "electrosensitive" individuals, although electrosensitivity has not been documented in double-blind tests of individual identifying themselves as being electrosensitive as compared to controls [109,110]. However people traveling to laboratories for testing are pre-exposed to a multitude of RF and ELF exposures, so they may already be symptomatic prior to actual testing. There is also evidence that RF exposures testing behavioral changes show delayed results; effects are observed after termination of RF exposure. This suggests a persistent change in the nervous system that may be evident only after time has passed, so is not observed during a short testing period.

3.1. Plausible biological mechanisms for neurobehavioral effects

3.1.1. The melatonin hypothesis

While there remains controversy as to the degree that RF and ELF fields alter neurobehavioral function, emerging evidence provides a plausible mechanism for both effects on sleep and cognition. Sleep is controlled by the central circadian oscillator in the suprachiasmatic nucleus, located in the hypothalamus. The activity of this central circadian oscillator is, in turn, controlled by the hormone, melatonin, which is released from the pineal gland [111]. There is considerable evidence that ELF exposure reduces the release of melatonin from the pineal gland—see Section 12 of the Bioinitiative Report [1]. There has been less study of the effects of RF exposure on melatonin release, but investigations have demonstrated a reduced excretion of the urinary metabolite of melatonin among persons using a mobile phone for more than 25 min per day [112]. In a study of women living near to radio and television transmitters, Clark et al. [113] found no effect on urinary melatonin metabolite excretion among pre-menopausal women, but a strong effect in post-menopausal women.

The "melatonin hypothesis" also provides a possible basis for other reported effects of EMFs. Melatonin has important actions on learning and memory, and inhibits electrophysiological components of learning in some but not all areas of the brain [114,115]. Melatonin has properties as a free-radical scavenger and anti-oxidant [116], and consequently,

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a reduction in melatonin levels would be expected to increase susceptibility to cancer and cellular damage. Melatonin could also be the key to understanding the relationship between EMF exposure and Alzheimer's disease. Noonan et al. [117] reported that there was an inverse relationship between excretion of the melatonin metabolite and the 1–42 amino acid form of amyloid beta in electric utility workers. This form of amyloid beta has been found to be elevated in Alzheimer's patients.

3.1.2. Blood–brain barrier alterations

Central nervous system effects of EMFs may also be secondary to damage to the blood–brain barrier (BBB). The blood–brain barrier is a critical structure that prevents toxins and other large molecules that are in peripheral blood from having access to the brain matter itself. Salford et al. [118] have reported that a 2-h exposure of rats to GSM-900 radiation with a SAR of 2–200 mW/kg resulted in nerve cell damage. In a follow-up study, Eberhardt et al. report that 2-h exposures to cell phone GSM microwave RF resulted in leakage of albumin across the blood–brain barrier and neuronal death [119]. Neuronal albumin uptake was significantly correlated to occurrence of damaged neurons when measured at 28 days post-exposure. The lowest exposure level was 0.12 mW/kg (0.00012 W/kg) for 2 h. The highest exposure level was 120 mW/kg (0.12 W/kg). The weakest exposure level showed the greatest effect in opening the BBB [118]. Earlier blood–brain studies by Salford and Schirmacher [120,121] report similar effects.

4. What are sources of wireless radiation?

There are many overlapping sources of radiofrequency and microwave emissions in daily life, both from industrial sources (like cell towers) and from personal items [cell and cordless phones, personal digital assistants (PDAs), wireless routers, etc.]. Published data on typical levels found in some cities and from some sources are available at http://www.bioinitiative.org [1,122–124].

Cell phones are the single most important source of radiofrequency radiation to which we are exposed because of the relatively high exposure that results from the phone being held right against the head. Cell phones produce two types of emissions that should be considered. First, the radiofrequency radiation (typically microwave frequency radiation) is present. However, there is also the contribution of the switching battery pack that produces very high levels of extremely low frequency electromagnetic field [125–127].

Cordless telephones have not been widely recognized as similar in emissions to cell phones, but they can and do produce significant RF exposures. Since people tend to use them as substitutes for in-home and in-office corded or traditional telephones, they are often used for long periods of time. As the range of cordless phones has increased (the distance away that you can carry on a conversation is related to the power output of the phone), the more powerful the RF signal will be. Hence, newer cordless phones may in some cases be similar to the power output of cell phones. The cumulative emissions from cell and cordless phones taken together should be recognized when considering the relative risks of wireless communication exposures.

PDAs such as the BlackBerry, Treo and iPhone units are 'souped-up' versions of the original voice communication devices (cell phones). The often produce far higher ELF emissions than do cell phones because they use energy from the battery very intensively for powering color displays and during data transmission functions (email, sending and receiving large files, photos, etc.) [125–127]. ELF emissions have been reported from PDAs at several tens to several hundreds of milligauss. Evidence of significantly elevated ELF fields during normal use of the PDA has public health relevance and has been reported in at least three scientific papers [125,128,129]. In the context of repetitive, chronic exposure to significantly elevated ELF pulses from PDAs worn on the body, relevant health studies point to a possible relationship between ELF exposure and cancer and pregnancy outcomes [130–133].

We include discussion of the ELF literature for two reasons. As mentioned above ELF activates the same biology as RF, it contributes to the total EMF burden of the body. In addition, PDAs and cell phones emit both radiofrequency/microwave radiation (RF) and extremely low frequency ELF from the battery switching of the device (the power source). Studies show that some devices produce excessively high ELF exposures during voice and data transmission. ELF is already classified as a 2B (Possible) Carcinogen by IARC, which means that ELF is indisputably an issue to consider in the wireless technology debate. ELF has been classified as a Group 2B carcinogen for all humans, not just children. The strongest evidence came from epidemiological studies on childhood leukemia, but the designation applies to all humans, both adults and children [1,25].

Wireless headsets that allow for conversations with cell phones at a distance from the head itself reduce the emissions. Depending on the type of wireless device, they may operate (transmit signal) only during conversations or they may be operational continuously. The cumulative dose of wireless headsets has not been well characterized under either form of use. Substantial cumulative RF exposure would be expected if the user wears a wireless headset that transmits a signal continuously during the day. However a critical factor is where the cell phone is placed. If worn on a belt with a headset, the exposure to the brain is reduced but the exposure to the pelvis may be significant.

Cell towers (called "masts" in Europe and Scandinavian countries) are wireless antenna facilities that transmit the cell phone signals within communities. They are another major source of RF exposures for the public. They differ from RF exposures from wireless devices like cell phones in that they produce much lower RF levels (generally 0.05 to 1–2 μW/cm^2 in the first several hundred feet around them) in comparison to several hundred microwatts per centimeter

squared for a cell phone held at the head. However they create a constant zone of elevated RF for up to 24 h per day. many hours per day, and the exposure is whole body rather than localized at the head. These facilities are the distribution system for wireless voice communications, internet connections and data transmission within communities. They are often erected on free-standing towers. They may be constructed on telephone poles or electrical poles. They may be built into the façade or rooftops of buildings behind wood screening. These are called stealth installations for wireless antenna facilities. Some installations are camouflaged to resemble 'false trees or rocks'. They emit RF to provide cell service to specific "cells" or locations that receive the signal.

Other forms of wireless transmission that are common in areas providing cell service are wireless land area networks (WLAN), (WiMAX) and WIFI networks. Some cities are installing city-wide WIFI service to allow any user on the street to log into the internet (without cables or wire connections). WIFI installations may have a signal reach for a few hundred feet where WiMAX installations may transmit signal more than 10 miles, so produce a stronger RF emission for those in close proximity. Each type has its particular signal strength and intended coverage area, but what they have in common is the production of continuous RF exposure for those within the area. We do not know what the cumulative exposure (dose) might be for people living, working or going to school in continuously elevated RF fields, nor are the possible health implications yet known. However, based on studies of populations near cell sites in general, there is a constellation of generally observed health symptoms that are reported to occur [85–107]. In this regard it is important to note that children living near to AM radio transmitters have been found to elevated risks of leukemia [134,135]. While AM radio RF fields are lower in frequency than that common in mobile phones, this is a total body irradiation with RF. The fact that leukemia, not brain cancer, is apparent in these studies suggests that leukemia is the cancer seen at the lowest levels of both ELF and RF fields under the circumstances of whole-body exposure.

Commercial surveillance systems or security gates pose an additional source of strong RF exposures. They are ubiquitous in department stores, markets and shops at the entry and exit points to discourage shoplifting and theft of goods. Security gates can produce excessively high RF exposures (although transitory) and have been associated with interference with pacemakers in heart patients. The exposure levels may approach thermal public safety limits in intensity, although no one expects a person to stand between the security gate bars for more than 6 min (safety limits for uncontrolled public access are variable depending on the frequency, but are all averaged over a 6-min exposure period).

RFID chips (radiofrequency identification chips) are being widely used to track purchases and for security of pets, and in some cases to keep track of patients with Alzheimer's disease and of children. RFID chips are implanted in fabrics, inserted in many types of commercial goods, and can be implanted under the skin. They create a detectable signal to track the location of people and goods.

5. Problems with existing public health standards (safety limits)

If the existing standards were adequate none of the effects documented above should occur at levels to which people are regularly exposed. The fact that these effects are seen with our current ambient levels of exposure means that our existing public safety standards are obsolete. It also means that new, biologically based public exposure standards for wireless technologies are urgently needed. Whether it is feasible to achieve low enough levels that still work and also protect health against effects of chronic RF exposure – for all age groups – is uncertain. Whether we can protect the public and still allow the kinds of wireless technology uses we see today is unknown.

The nature of electromagnetic field interactions with biological systems has been well studied [136–144]. For purposes of standard-setting processes for both ELF and RF, the hypothesis that tissue damage can result only from heating is the fundamental flaw in the misguided efforts to understand the basic biological mechanisms leading to health effects.

The thermal standard is clearly untenable as a measure of dose when EMF stimuli that differ by many orders of magnitude in energy can stimulate the same biological response. In the ELF range, the same biological changes occur as in the RF, and no change in temperature can even be detected. With DNA interactions the same biological responses are stimulated in ELF and RF ranges even though the frequencies of the stimuli differ by many orders of magnitude. The effects of EMF on DNA to initiate the stress response or to cause molecular damage reflect the same biology in different frequency ranges. For this reason it should be possible to develop a scale based on DNA biology, and use it to define EMF dose in different parts of the EM spectrum. We also see a continuous scale in DNA experiments that focus on molecular damage where single and double strand breaks have long been known to occur in the ionizing range, and recent studies have shown similar effects in both ELF and RF ranges [144].

Existing standard-setting bodies that regulate wireless technologies, assume that there are no bioeffects of concern at exposure levels that do not cause measurable heating. However, it has been established beyond any reasonable doubt that bioeffects and some adverse health effects occur at far lower levels of RF and ELF exposure where no heating (or induced current) occurs; some effects are shown to occur a thousand times or more below the existing public safety limits. New, biologically based public exposure limits are urgently needed. New wireless technologies for cell and cordless phones, other wireless communication and data transmission systems affect living organisms in new ways that our antiquated safety limits have not foreseen, nor protected against.

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The exposure of children to electromagnetic fields has not been studied extensively; in fact, the Federal Communications Commission (FCC) standards for exposure to radiofrequency radiation are based on the height, weight and stature of a 6-foot tall man, not scaled to children or adults of smaller stature. They do not take into account the unique susceptibility of growing children to exposures, nor are there studies of particular relevance to children.

In addition there is a problem in the consideration of the level of evidence taken into consideration by these bodies. There have not been adequate animal models shown to have cancer as an endpoint, and a perception that no single mechanism is proven to explain these associations. Thus these committees have tended to ignore or minimize the evidence for direct hazard to humans, and believe there is no proof of cause and effect. These bodies assume from the beginning that only conclusive scientific evidence (absolute proof) will be sufficient to warrant change, and refuse to take action on the basis of a growing body of evidence which provides early but consequential warning of risks.

The Radiofrequency Interagency Working Group of the US governmental agencies involved in RF matters (RFIAWG) issued a Guidelines Statement in June of 1999 that concluded the present RF standard "may not adequately protect the public" [145]. The RFIAWG identified fourteen (14) issues that they believe are needed in the planned revisions of ANSI/IEEE RF exposure guidelines including "to provide a strong and credible rationale to support RF exposure guidelines". In particular, the RFIAWG criticized the existing standards as not taking into account chronic, as opposed to acute exposures, modulated or pulsed radiation (digital or pulsed RF is proposed at this site), time-averaged measurements that may erase the unique characteristics of an intensity-modulated RF radiation that may be responsible for reported biologic effects, and stated the need for a comprehensive review of long-term, low-level exposure studies, neurological-behavioral effects and micronucleus assay studies (showing genetic damage from low-level RF) [145]. This important document from relevant US agencies questions existing standards in the following ways: (a) selection of an adverse effect level for chronic exposures not based on tissue heating and considering modulation effects; (b) recognition of different safety criteria for acute and chronic exposures at non-thermal or low-intensity levels; (c) recognition of deficiencies in using time-averaged measurements of RF that does not differentiate between intensity-modulated RF and continuous wave (CW) exposure, and *therefore may not adequately protect the public*; (d) having standards based on adult males rather than considering children to be the most vulnerable group.

6. Prudent public health responses

Emerging environmental health problems require preventative public health responses even where scientific and medical uncertainties still exist, but where policy decisions today may greatly reduce human disease and societal costs tomorrow.

Policy decisions in public health must address some amount of uncertainty when balancing likely benefits and estimated costs. Although new insight will allow better appreciation of difficult issues, such as those occurring in environmental and occupational health, an expanded perspective may also enlarge the list of problems that need to be managed. Ignoring the problems carries its own costs (as deferring a decision is a decision in itself). With environmental and other public health problems becoming increasingly complex and international in scope, scientific documentation alone rarely justifies simple solutions [146].

Social issues regarding the controversy over public and occupational exposures to ELF and RF center on the resolute adherence to existing ICNIRP and FCC/IEEE standards by many countries, in the face of growing scientific evidence of health risks at far lower levels [10]. The composition of these committees, usually with excessive representation of the physics and engineering communities rather than public health professionals, results in a refusal to adopt biologically based exposure standards. Furthermore, there is widespread belief that governments are ignoring this evidence and there is widespread distrust of and lack of confidence in governments and their health agencies. The basis on which most review bodies and standard-setting agencies have avoided the conclusion that the science is strong enough to warrant new safety limits for ELF and RF is to require a demonstration of absolute proof before taking action. A causal level of evidence, or scientific certainty standard is implicit in nearly all reviews of the ELF and RF science, although this runs counter to good public health protection policies.

There is no question that global implementation of the safety standards proposed in the Bioinitiative Report, if implemented abruptly and without careful planning, have the potential to not only be very expensive but also disruptive of life and the economy as we know it. Action must be a balance of risk to cost to benefit. The major risk from maintaining the status quo is an increasing number of cancer cases, especially in young people, as well as neurobehavioral problems at increasing frequencies. The benefits of the status quo are expansion and continued development of communication technologies. But we suspect that the true costs of even existing technologies will only become much more apparent with time. Whether the costs of remedial action are worth the societal benefits is a formula that should reward precautionary behavior. Prudent corporate policies should be expected to address and avoid future risks and liabilities, otherwise, there is no market incentive to produce safe (and safer) products.

The deployment of new technologies is running ahead of any reasonable estimation of possible health impacts and estimates of probabilities, let alone a solid assessment of risk. However, what has been missing with regard to EMF has been an acknowledgement of the risk that is demonstrated by

the scientific studies. There is clear evidence of risk, although the magnitude of the risk is uncertain, and the magnitude of doing nothing on the health effects cost to society is similarly uncertain. This situation is very similar to our history of dealing with the hazards of smoking decades ago, where the power of the industry to influence governments and even conflicts of interest within the public health community delayed action for more than a generation, with consequent loss of life and enormous extra health care costs to society. New standards are warranted now, based on the totality of scientific evidence; the risks of taking no-action, the large population at risk, costs associated with ignoring the problem in new and upgraded site selection and construction, and the loss of public trust by ignoring the problem.

Direct medical and rehabilitative health costs associated with treatment for diseases that are reasonably related to wireless technologies may be very large. Although there is uncertainty involved in how much disease is related to wireless exposures, the mere scale of the problem with several billion users of cell phones and even larger impacts on bystander populations (from cell site exposures, from other WI-FI and wireless exposures in-home and commercial use, etc.) the associated public health costs will likely be monumental. Furthermore the costs to families with cancers, neurological diseases or learning disabilities in children related in part or in whole to wireless technologies extend beyond medical costs. They may reasonably extend to family disruption and family psychological problems, losses in job productivity and income loss.

The history of governments and their official health agencies to deal with emerging and newly identified risks to health is not good [147–149]. This is particularly true where industry investments in new products and technologies occur without full recognition, disclosure or even knowledge of possible health consequences. Large economic investments in polluting industries often make for perilously slow regulatory action, and the public health consequences may be very great as a result [150,151].

Free markets do not internalize the costs to society of "guessing wrong". Unexpected or hidden health costs of new technologies may not be seen for many years, when the ability to recall or to identify the precise exposures related to disease outcomes is difficult or impossible. The penalty nearly always falls to the individual, the family or the taxpayer and not to the industry that benefits economically—at least in free-market economies. Thus, the profits go to industry but the costs may go to the individual who can suffer both diminished quality of life and health and economic disadvantage. If all disease endpoints that may be reasonably related to chronic exposure to electromagnetic fields are considered even a small attributable fraction for one or more industries, it will have enormous global impact on public health. The public health implications are immense. But they can be reduced by strong government and public health interventions providing information on alternatives to wireless technologies, public education campaigns, health advisories, requirements for redesign of wireless devices, proscription of use of wireless devices by children and teenagers, strong and independent research programs on causes and prevention of EMF-related diseases, and consultation with all stakeholders on issues relating to involuntary exposures (bystander or second-hand radiation exposures from wireless technologies) (Table 1).

Table 1
Public health implications of wireless technologies argue for change in governmental and health agency actions.

Secure US and EU legislative mandates for safer technologies for communication and data transmission, for security and surveillance needs.
Promote wired alternatives for voice and data communication (cable, fiber-optic)
Discourage or ban use of cell phones by children and young teen-agers
Provide permanent (unremovable) labels on cell phones "Not for use by children under the age of 16"
Implement national public education campaigns on health issues (cell phones, cordless phones, PDAs, wireless internet, city-wide WI-FI, WLAN and WiMAX exposures
Promote industry redesign for safer products: support innovation for alternatives and solutions
Slow or stop deployment of wireless technologies to discourage reliance on wireless technologies for communication and security needs
Put the burden of proof on industry to show "new wireless tech" is safe before deployment
Adopt and enforce restricted use areas for sensitive or more vulnerable segments of society including low-EMF environments in public areas and "No Cell" zones in airports, hospitals, schools
Acknowledge FCC and ICNIRP thermal safety standards are obsolete for wireless technologies
Appoint new standard-setting bodies familiar with biological effects to develop new guidelines for public safety limits.
Develop new biologically based standards that address low-intensity, chronic exposures
Require standard of evidence and level of proof = public health
Reject "causal" standard of evidence for taking action on science
Make industry financially liable for "guessing wrong" and ignoring health risks

The scientific information contained in this Supplement argues for thresholds or guidelines that are substantially below current FCC and ICNIRP standards for localized exposures to wireless devices and for whole-body exposure. Uncertainty about how low such standards might have to go to be prudent from a public health standpoint should not prevent reasonable efforts to respond to the information at hand. No lower limit for bioeffects and adverse health effects from RF has been established, so the possible health risks of wireless WLAN and WI-FI systems, for example, will require further research. No assertion of safety at any level of wireless exposure (chronic exposure) can be made at this time. The lower limit for reported human health effects has dropped 100-fold below the safety standard (for mobile phones and PDAs); 1000–10,000-fold for other wireless (cell towers at distance; WI-FI and WLAN devices). The entire basis for safety standards is called into question, and it is not unreasonable to question the safety of RF at any level.

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It is likely that for both ELF and RF, as for other carcinogens, there is no threshold of exposure that is without risk, but the magnitude of the risk increases linearly with the level of exposure. Our society will not go back to the pre-electric and pre-wireless age, but the clear evidence of health hazards to the human population from exposure mandates that we develop ways in which to reduce exposure through education, new technologies and the establishment of biomedically based standards.

7. Conclusions and recommended actions

New ELF limits are warranted based on a public health analysis of the overall existing scientific evidence. These limits should reflect environmental levels of ELF that have been demonstrated to increase risk for childhood leukemia, and possibly other cancers and neurological diseases. ELF limits should be set below those exposure levels that have been linked in childhood leukemia studies to increased risk of disease, plus an additional safety factor. It is no longer acceptable to build new power lines and electrical facilities that place people in ELF environments that have been determined to be risky. These levels are in the 2–4 milligauss (mG) range (0.2–0.4 μT), not in the 10 s of mG or 100 s of mG. The existing ICNIRP limit is 1000 mG (100 μT) and 904 mG (90.4 μT) in the US for ELF is outdated and based on faulty assumptions. These limits are can no longer be said to be protective of public health and they should be replaced. A safety buffer or safety factor should also be applied to a new, biologically based ELF limit, and the conventional approach is to add a safety factor lower than the risk level.

While new ELF limits are being developed and implemented, a reasonable approach would be a 1 mG (0.1 μT) planning limit for habitable space adjacent to all new or upgraded power lines and a 2 mG (0.2 μT) limit for all other new construction. It is also recommended that a 1 mG (0.1 μT) limit be established for existing habitable space for children and/or women who are pregnant (because of the possible link between childhood leukemia and *in utero* exposure to ELF). This recommendation is based on the assumption that a higher burden of protection is required for children who cannot protect themselves, and who are at risk for childhood leukemia at rates that are traditionally high enough to trigger regulatory action. This situation in particular warrants extending the 1 mG (0.1 μT) limit to existing occupied space. "Establish" in this case probably means formal public advisories from relevant health agencies. While it is not realistic to reconstruct all existing electrical distribution systems, in the short-term; steps to reduce exposure from these existing systems need to be initiated, especially in places where children spend time, and should be encouraged. These limits should reflect the exposures that are commonly associated with increased risk of childhood leukemia (in the 2–5 mG (0.2–0.5 μT) range for all children, and over 1.4 mG (0.14 μT) for children age 6 and younger). Nearly all of the occupational studies for adult cancers and neurological diseases report their highest exposure category is 4 mG (0.4 μT) and above, so that new ELF limits should target the exposure ranges of interest, and not necessarily higher ranges.

Avoiding chronic ELF exposure in schools, homes and the workplace above levels associated with increased risk of disease will also avoid most of the possible bioactive parameters of ELF discussed in the relevant literature.

It is not prudent public health policy to wait any longer to adopt new public safety limits for ELF. These limits should reflect the exposures that are commonly associated with increased risk of childhood leukemia (in the 2–5 mG (0.2–0.5 μT) range for all children, and over 1.4 mG (0.14 μT) for children age 6 and younger). Avoiding chronic ELF exposure in schools, homes and the workplace above levels associated with increased risk of disease will also avoid most of the possible bioactive parameters of ELF discussed in the relevant literature.

The rapid deployment of new wireless technologies that chronically expose people to pulsed RF at levels reported to cause bioeffects, which in turn, could reasonably be presumed to lead to serious health impacts, is a public health concern. There is suggestive to strongly suggestive evidence that RF exposures may cause changes in cell membrane function, cell communication, metabolism, activation of proto-oncogenes and can trigger the production of stress proteins at exposure levels below current regulatory limits. Resulting effects can include DNA breaks and chromosome aberrations, cell death including death of brain neurons, increased free-radical production, activation of the endogenous opioid system, cell stress and premature aging, changes in brain function including memory loss, retarded learning, performance impairment in children, headaches and fatigue, sleep disorders, neurodegenerative conditions, reduction in melatonin secretion and cancers (BioInitiative Report Chapters 5–10, 12) [1].

This information now argues for thresholds or guidelines that are substantially below current FCC and ICNIPR standards for whole-body exposure. Uncertainty about how low such standards might have to go to be prudent from a public health standpoint should not prevent reasonable efforts to respond to the information at hand. No lower limit for bioeffects and adverse health effects from RF has been established, so the possible health risks of wireless WLAN and WI-FI systems, for example, will require further research and no assertion of safety at any level of wireless exposure (chronic exposure) can be made at this time. The lower limit for reported human health effects has dropped 100-fold below the safety standard (for mobile phones and PDAs); 1000–10,000-fold for other wireless (cell towers at distance; WI-FI and WLAN devices). The entire basis for safety standards is called into question, and it is not unreasonable to question the safety of RF at any level.

A cautionary target level for pulsed RF exposures for ambient wireless that could be applied to RF sources from cell tower antennas, WI-FI, WI-MAX and other similar sources

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is proposed. The recommended cautionary target level is 0.1 microwatts per centimeter squared ($\mu W/cm^2$) (or 0.614 V per meter or V/m) for pulsed RF where these exposures affect the general public; this advisory is proportionate to the evidence and in accord with prudent public health policy. A precautionary limit of 0.1 $\mu W/cm^2$ should be adopted for outdoor, cumulative RF exposure. This reflects the current RF science and prudent public health response that would reasonably be set for pulsed RF (ambient) exposures where people live, work and go to school. This level of RF is experienced as whole-body exposure, and can be a chronic exposure where there is wireless coverage present for voice and data transmission for cell phones, pagers and PDAs and other sources of radiofrequency radiation. An outdoor precautionary limit of 0.1 $\mu W/cm^2$ would mean an even lower exposure level inside buildings, perhaps as low as 0.01 $\mu W/cm^2$. Some studies and many anecdotal reports on ill health have been reported at lower levels than this; however, for the present time, it could prevent some of the most disproportionate burdens placed on the public nearest to such installations. Although this RF target level does not preclude further rollout of WI-FI technologies, we also recommend that wired alternatives to WI-FI be implemented, particularly in schools and libraries so that children are not subjected to elevated RF levels until more is understood about possible health impacts. This recommendation should be seen as an interim precautionary limit that is intended to guide preventative actions; and more conservative limits may be needed in the future.

Broadcast facilities that chronically expose nearby residents to elevated RF levels from AM, FM and television antenna transmission are also of public health concern given the potential for very high RF exposures near these facilities (antenna farms). RF levels can be in the 10 s to several 100 s of $\mu W/cm^2$ in residential areas within half a mile of some broadcast sites (for example, Lookout Mountain, Colorado and Awbrey Butte, Bend, Oregon). Like wireless communication facilities, RF emissions from broadcast facilities that are located in, or expose residential populations and schools to elevated levels of RF will very likely need to be re-evaluated for safety.

For emissions from wireless devices (cell phones, personal digital assistant or PDA devices, etc.) there is enough evidence for increased risk of brain tumors and acoustic neuromas now to warrant intervention with respect to their use. Redesign of cell phones and PDAs could prevent direct head and eye exposure, for example, by designing new units so that they work only with a wired headset or on speakerphone mode.

These effects can reasonably be presumed to result in adverse health effects and disease with chronic and uncontrolled exposures, and children may be particularly vulnerable. The young are also largely unable to remove themselves from such environments. Second-hand radiation, like second-hand smoke is an issue of public health concern based on the evidence at hand.

In summary, the following recommendations are made:

- ELF limits should be set below those exposure levels that have been linked in childhood leukemia studies to increased risk of disease, plus an additional safety factor. It is no longer acceptable to build new power lines and electrical facilities that place people in ELF environments that have been determined to be risky (at levels generally at 2 mG (0.2 μT) and above).
- While new ELF limits are being developed and implemented, a reasonable approach would be a 1 mG (0.1 μT) planning limit for habitable space adjacent to all new or upgraded power lines and a 2 mG (0.2 μT) limit for all other new construction, It is also recommended for that a 1 mG (0.1 μT) limit be established for existing habitable space for children and/or women who are pregnant. This recommendation is based on the assumption that a higher burden of protection is required for children who cannot protect themselves, and who are at risk for childhood leukemia at rates that are traditionally high enough to trigger regulatory action. This situation in particular warrants extending the 1 mG (0.1 μT) limit to existing occupied space. "Establish" in this case probably means formal public advisories from relevant health agencies.
- While it is not realistic to reconstruct all existing electrical distributions systems, in the short-term; steps to reduce exposure from these existing systems need to be initiated and should be encouraged, especially in places where children spend time.
- A precautionary limit of 0.1 $\mu W/cm^2$ (which is also 0.614 V per meter) should be adopted for outdoor, cumulative RF exposure. This reflects the current RF science and prudent public health response that would reasonably be set for pulsed RF (ambient) exposures where people live, work and go to school. This level of RF is experienced as whole-body exposure, and can be a chronic exposure where there is wireless coverage present for voice and data transmission for cell phones, pagers and PDAs and other sources of radiofrequency radiation. Some studies and many anecdotal reports on ill health have been reported at lower levels than this; however, for the present time, it could prevent some of the most disproportionate burdens placed on the public nearest to such installations. Although this RF target level does not preclude further rollout of WI-FI technologies, we also recommend that wired alternatives to WI-FI be implemented, particularly in schools and libraries so that children are not subjected to elevated RF levels until more is understood about possible health impacts. This recommendation should be seen as an interim precautionary limit that is intended to guide preventative actions; and more conservative limits may be needed in the future.

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