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Subject: NTP General Public Comments Submission
Comment:

Comments on Reverberation Chamber Exposure System:

During the 1990s, I ran the Wireless Technology Research program, overseen by a U.S. government Interagency Working Group and funded through a trust organized by the wireless phone industry. In our original research agenda, long-term animal studies were contemplated, although they were later eliminated as the industry pulled funding. In the WTR program, we spent more than two years and $5M studying and evaluating different exposures systems so that the most rigorous exposure systems for predicting human risk could be used for our studies. The results of that work are published in the books whose cover pages are attached herewith, as well as in other presentations at professional meetings and special issues of journals throughout that time. The WTR exposure system work was front and center at every relevant toxicological meeting conducted through the 90s, so not a secret.

Overall, we learned in the WTR work that it was important to be conveying information over the signals -- voice or data -- in order to achieve the 'real-life' modulation impact on biological triggers that are known. For example, to take this into account in the WTR exposure systems, we ran a tape recording of voice during exposure times in order to achieve a closer approximation of real-life use. We also learned that, if studying brain tumors, it was important to have a 'head-only' exposure system as opposed to a 'whole-body' exposure system. We were able to achieve that type of exposure system for rats but found it to be not feasible for mice. Again, findings of rat studies using this approach are included in the books referenced as well as elsewhere.

When the NTP study was being designed, it was baffling that the exposure system developed under the WTR was not carried forward. The WTR system was the most extensive and rigorous system available at the time. In fact, Niels Kuster who was one of your named exposure system consultants, was part of the working groups that developed the WTR systems and indeed tried to purchase the system at auction when the WTR disbanded in 1999. Thus, the value of the system was known as well as the rationale used to develop it.

This lapse in using the appropriate exposure systems creates difficulties in interpreting the meaning of the NTP results.

First, when the 'whole-body' is exposed as in the NTP study, there are a host of physiological compensations triggered in response to the exposures in cells, tissues, organs and organ-systems that are near impossible to quantify in terms of how they impact the outcomes being studied. This could be

one of the reasons for the internal inconsistencies in the NTP study. The inconsistencies could well be the result of biological phenomena not measured in the study design and thus not interpretable as evidence of either effect or no-effect.

Further, it appears that the exposure systems used in the NTP study did not employ the type of modulation that occurs with real mobile phone use -- no information carried on the signals, no voice modulation, and no signal perturbations derived from other competitive signals in the environment which accrues in effect another, uncontrolled type of signal modulation. Taken together, the chance of triggering biological cascades could be exacerbated or limited by the system used. We know modulation to be the main trigger for bioactivity. See the attached paper for reference by Panagopoulos, Johansson and myself.

Finally, this incomplete exposure system could be, and in fact is likely, accruing imprecision across the independent variable that would tend to bias results toward the null or underestimate the true risks.

So, my main questions for the investigators are the following:

1. Given the shortcomings in the exposure system detailed above and expressed in the published literature prior to the designed of the study, what was the power of the NTP study to find statistically significant differences between exposed and unexposed in the study for each of the dependent variables studied?

2. Given the limitations that are derivative of those exposure-outcome specific power calculations, what admonitions in interpretation do the investigators prescribe?

Comments on Peer Review of NTP Findings in Rats and Mice

It is important to take into account the purpose of doing a study like this -- I assume the purpose is to predict possible risks of tumors in humans who use cell phones. The need for this study flowed from two flaws in the system propagated through U.S. government agencies as regards cell phone safety:

The first is the lapse in judgement that resulted in cell phones making into the marketplace without the benefit of pre-market testing. Had the findings presented in the NTP study been found in the context of pre-market testing, these questions that are being addressed now would have been able to have been addressed, not in the context of a wide-spread, after-the-fact human experiment, but as normal scientific iteration that would have either resulted in more refined studies ahead of deployment into commerce, or a prescription for technological changes in cell phone design that would have mitigated risks, or both.

The second lapse in judgement was the allowance by the U.S. government's Interagency Working Group that oversaw the work of the WTR to pull back wireless industry funding for these long-term bioassays

that were originally prescribed to be done under the WTR program. Had those studies been allowed to be completed, the NTP study would now be looked at in the context of scientific corroboration and not a study of first impression.

Given the above lapses, the NTP investigators were put in a no-win political situation as they deployed this study. It was not possible to design a pre-market study because the scenario was no longer pre-market, and it was not possible to design a study that would have direct and long-standing relevance to the actual risks to cell phone users because the exposures over time have been a rapidly moving target. Further, given that a basic underlying premise of these types of toxicological studies is that, where there is a risk to be found, cause induces effect, it is necessary to design the study with some knowledge of mechanisms of harm that are operating. And, it is possible that different iterations of the technology could have different variations on mechanism of harm. Attached is a paper that addresses such issues.

Finally, the quantitative measures of exposure used in the analyses appear to focus primarily on thermal effects and not non-thermal effects. See attached paper on the ramifications of such a limitation.

My main questions for the investigators are the following:

1. Given the changes in wireless technology signaling and devices over the past two decades -- the fifth generation of signaling is now being deployed suggesting that the technology and resultant exposures in people are changing every 4 to 5 years -- what admonitions in interpretation do the investigators prescribe as per the relevance of these findings to cell phones of yesterday and of today?

2. What mechanisms of harm were in the thinking of the NTP at the time the study was designed and initiated?

3. Given the above shortcomings, what admonitions in interpretation do the investigators prescribe?

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Review Article

Real versus Simulated Mobile Phone Exposures in Experimental Studies

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We examined whether exposures to mobile phone radiation in biological/clinical experiments should be performed with real-life Electromagnetic Fields (EMFs) emitted by commercially available mobile phone handsets, instead of simulated EMFs emitted by generators or test phones. Real mobile phone emissions are constantly and unpredictably varying and thus are very different from simulated emissions which employ fixed parameters and no variability. This variability is an important parameter that makes real emissions more bioactive. Living organisms seem to have decreased defense against environmental stressors of high variability. While experimental studies employing simulated EMF-emissions present a strong inconsistency among their results with less than 50% of them reporting effects, studies employing real mobile phone exposures demonstrate an almost 100% consistency in showing adverse effects. This consistency is in agreement with studies showing association with brain tumors, symptoms of unwellness, and declines in animal populations. Average dosimetry in studies with real emissions can be reliable with increased number of field measurements, and variation in experimental outcomes due to exposure variability becomes less significant with increased number of experimental replications. We conclude that, in order for experimental findings to reflect reality, it is crucially important that exposures be performed by commercially available mobile phone handsets.

1. Introduction

Determination of realistic exposures from mobile phones and other wireless devices of modern telecommunications remains an important scientific challenge, especially since it is key to defining public health protection. The situation is further complicated by divergent results reported in the related literature that very well could be due to unrealistic exposure conditions, which in turn lead to ineffective and misdirected interventions.

The International Agency for Research on Cancer (IARC), while still classifying Radio Frequency (RF) Electromagnetic Fields (EMFs) as possibly carcinogenic, criticized and excluded from consideration experimental studies that used commercially available mobile phone handsets in exposing biological samples, as having "unreliable dosimetry" [1], without further scientific rationale. Similarly the Health Protection Agency (HPA) criticized this exposure methodology reporting that the exposure is "highly variable" with "lack of control" due to network reasons (number of subscribers each moment) and movement of the animals within the vials/boxes in case of freely moving animals but recognizes that restriction of the animals during the exposures will result in additional stress. Their critique recommended that exposures should be performed by devices or handsets set to produce emissions at fixed frequency and output power by use of engineering or hardware controls [2]. In both reports the criticisms were based on the fact that real mobile phone emissions always include significant variations in their intensity, frequency, and other parameters, especially in the near-field of the antenna.

But billions of mobile phone users are daily exposed for increasing periods to real emissions from their handsets in the near-field of the antenna in contact with their ears/bodies, not to any simulated emissions with fixed parameters. Is it then scientifically correct to study the effects of a "highly variable" field by using fields with fixed parameters? In our opinion, it is not, especially in the case when the varying nature of the field seems to be an important reason for its increased biological activity.

The aim of the present study is to review biological and clinical experimental studies on mobile phone radiation effects which have employed exposures with real mobile phone emissions, as opposed to the mainstream studies which employ simulated mobile phone emissions produced by generators or test phones, and seek an explanation for the divergent results reported in the literature. In case that we find a significant conflict in the results between the two types of experimental exposures (real versus simulated), our aim is to attempt giving an explanation based on the differences between the two types of EMF-emissions.

We note that the issue of the present study applies also for every other type of RF/microwave emitting devices used in modern telecommunications, such as Internet connection wireless devices and local wireless networks (Wi-Fi), domestic cordless phones (DECT, Digitally Enhanced Cordless Technology), and baby monitors. The emissions from all these devices, although differing in specific frequencies and modulation types, are very similar. The reason that we concentrate on studies with mobile phone radiation (either real or simulated) is only the fact that they constitute the vast majority of the published studies testing the biological activity of RF/microwave EMFs.

2. Adaptation of Living Organisms to EMFs

Living organisms have been constantly exposed throughout evolution to terrestrial static electric and magnetic fields of average intensities ~130 V/m and ~0.5 G, respectively. While no adverse health effects are connected with usual exposure to these natural ambient fields, variations in their intensities on the order of 20% during "magnetic storms" or "geomagnetic pulsations" due to changes in solar activity with an average periodicity of about 11 years are connected with increased rates of animal/human health incidents, including nervous and psychic diseases, hypertensive crises, heart attacks, cerebral accidents, and mortality [3, 4].

It is clear that living organisms perceive EMFs as environmental stressors [4–7]. But since man-made EMFs constitute a very new stressor for living organisms within the billions of years of biological evolution, the cells have not developed defensive mechanisms, for example, special genes to be activated for protection against electromagnetic stress of man-made EMFs. This can be the reason why in response to man-made EMFs cells are found to activate heat-shock genes and produce heat-shock proteins very rapidly (within minutes) and at a much higher rate than for heat itself [6]. It seems to be for the same reason that mobile phone radiation is found to induce DNA damage and cell death in insect reproductive cells at a higher degree than other types of external stressors examined before like food deprivation or chemicals [8–10]. Thus it appears that cells are much more sensitive to man-made EMFs than to other types of stress previously experienced by living organisms such as heat, cold, starvation, or chemicals. But repetitive stress leading to continuous expression of heat-shock genes or DNA damage may lead to cancer [1, 11].

One reason for the increased biological activity of man-made EMFs can be that cells/organisms adapt more easily to any external stressor, and to EMFs, when this stressor is not of significantly varying type, in other words when its parameters are kept constant or vary only slightly. Since living organisms do not have defense mechanisms against variations on the order of 20% of natural EMFs as explained above, it is realistic to expect that they do not have innate defenses against unnatural (man-made) EMFs, which are mostly not static but varying (alternating, pulsed, modulated fields, including simultaneously several different frequencies, etc.) and totally polarized in contrast to natural EMFs. [We note that even though the polarities and intensities of the static terrestrial electric and magnetic fields do not change significantly (except during specific periods as explained) there are always small changes and local variations in the direction of the field lines that make these natural static fields only partially and never totally polarized [3, 4]. This is in contrast to all man-made EMFs which are totally and invariantly polarized due to the invariant geometry of their electric circuits.]

Indeed, pulsed or modulated electromagnetic signals (radiation) are found in numerous studies published since the midseventies to be more bioactive than continuous signals of identical other parameters (intensity, frequency, duration, waveform, etc.) [12–24]. Moreover, intermittent exposure to mobile phone radiation (real or simulated) with short intermittence durations (which makes the field even more variable) is repeatedly found to be more bioactive than the corresponding continuous exposure [25, 26]. This experimental evidence further supports the argument that the more complicated and variable the field/stressor is, the more difficult it is for a living organism to adapt to it.

3. The Increased Variability of EMFs Emitted by Mobile Telephony Antennas

All types of digital mobile telephony radiation, except for their RF carrier signal, employ Extremely Low Frequencies (ELF) necessary for the modulation and for increasing the capacity of transmitted information by pulsing the signal. The combination of the RF carrier and the ELF pulsing frequencies has been found to be more bioactive than the RF carrier alone [16, 21]. Moreover, according to a plausible suggested mechanism [27], (a) the ELF frequencies included in any pulsed or modulated RF signal are more responsible for the biological effects, (b) changes in field intensity play a major role, and (c) the pulsing of the signal makes it twice more bioactive. A constant carrier RF wave modulated by a constant ELF field can certainly be simulated but this is not the case in real mobile telephony signals, in which both the carrier and the modulation are constantly and

unpredictably varying in intensity, frequency, and waveform during a phone-conversation [7, 28–30].

The intensity of radiation varies significantly each moment during a usual phone-conversation depending on signal reception, number of subscribers sharing the frequency band each moment, air conductivity, location within the wireless infrastructure, presence of objects and metallic surfaces, "speaking" versus "nonspeaking" mode, and so forth. These variations are much larger than 20% of the average signal intensity (as opposed to the periodical variations in the terrestrial fields known to cause health effects). Moreover the phase of the carrier signal varies continuously during a phone-conversation, and the RF frequency constantly changes between different available frequency channels, especially in third generation (3G) radiation. The wave shape is also constantly changing depending on how the changing information transmitted each moment modulates the carrier wave. Thus, the parameters of this radiation change constantly and unpredictably each moment and large, sudden, unpredictable variations in the emitted EMF/radiation take place constantly during a usual phone-conversation. The more the amount of carried information is increased (by adding text, speech, pictures, music, video, internet, etc.) in more recent phone generations (G)/types (2G, 3G, 4G, etc.), the more complicated and unpredictably varying the cell phone signals become [2, 7, 28–30].

Thus, real digital mobile phone (and other wireless communication devices) emissions change constantly and unpredictably. As a consequence, living organisms cannot adapt to such a highly varying type of stress. Moreover, due to the unpredictably varying type of the real emissions, it is impossible to simulate them by EMFs of fixed parameters.

4. Real Exposure Studies as Opposed to Studies with Simulated Exposures

A significant number of studies have already been published which employed commercially available mobile phones during connection ("talk", "listen", or "call" modes) for exposure to a wide variety of animals (including humans)/biological samples, including *Drosophila* [6, 8, 26, 31–37], ants [38], chicken eggs [39], quails [40], human sperm *in vitro* [41, 42], human volunteers *in vivo* [43–52], mice or rats or guinea-pigs or rabbits *in vivo* [53–69], mouse cells *in vitro* [70], bees [71–73], protozoa [74], and even purified proteins *in vitro* [75]. An impressive percentage (95.8%) of these studies (46 out of 48 studies with real-life exposures) have recorded significant adverse biological or clinical effects, ranging from loss of orientation, kinetic changes, and behavioral or electroencephalographic (EEG) changes to decrease in male and female reproductive capacity, reproductive declines, molecular changes, changes in enzymatic activity, DNA damage and cell death, and histopathological changes in the brain. It was found that during "talk" mode (voice modulation) the exposure is significantly more bioactive than during "listen" mode due to the voice modulation and associated increased intensity of the emissions [7, 31]. From the remaining two studies, one reported no effect [55] and one reported an increase in short-term memory of children [47] which we do not count as an adverse effect although it may be.

On the contrary, more than 50% of the studies performed with simulated signals have showed no effects [1, 2, 76], even though several recent review studies suggest an overall predominance of studies showing effects regardless of real or simulated exposures [7, 77–80]. A recent meta-analysis of 88 studies published during 1990–2011 investigating genetic damage in human cells from RF radiation, 87 of which did not employ real telecommunication EMFs, reported no overall association with genotoxicity [81].

Although we may have missed a few more studies with real mobile phone exposures, it becomes evident that there is a strong conflict between the overall results of studies performed with real mobile phone emissions and the overall results of studies with simulated emissions from generators and "test" phones. Moreover, while within the group of studies with simulated emissions there is also a conflict between studies that find effects and studies that do not, the group of studies with real exposures demonstrates an impressive consistency in showing effects almost at 100%. Moreover, this impressive consistency is corroborated by increasing epidemiological evidence, especially during the last years, for an association between (real-life) mobile phone use and brain tumors [82–84], by statistical studies reporting symptoms of unwellness among people residing around mobile telephony base station antennas or among mobile phone users [85–90], and by open field studies reporting declines in bird and amphibian populations around mobile telephony base station antennas [91–95].

This apparent consistency of results in the laboratory studies with real emissions and their additional corroboration with recent epidemiological/statistical and open field studies' evidence seems to be unnoticed by health agencies and public health authorities which simply disregard these studies despite their important findings which imply the urgent establishment of much more stringent exposure limits than the current ones [96].

Although in most studies employing real mobile phone emissions the biological samples were exposed in close proximity (within the near-field up to approximately 5 cm) with the mobile phone handset, in several studies the samples/animals were exposed at greater distances in the far-field up to 1 m [32, 34, 35, 39, 51, 53, 56–58] where the intensity variations are much smaller and the dosimetry is absolutely "reliable" as is generally accepted for far-field antenna measurements [97]. In one of these studies it was found that at 20–30 cm distance from the mobile phone the biological effect (DNA damage) was even more intense than at zero distance [32].

A mobile phone antenna's near-field extends to a distance of 5.2 or 2.6 cm, for 900 or 1800 MHz, respectively (most commonly employed carrier frequencies in 2G mobile telephony radiation), according to the relation $r = \lambda/2\pi$, (r is the distance of near-field far limit from the antenna when the length of the antenna is smaller than the wavelength λ of the emitted radiation) [98].

In studies with real mobile phone emissions investigating the dependence of observed effects on dose (radiation

intensity and/or exposure duration) [8, 31–35, 39, 40, 62], the effects have been found to be dose dependent. The dependence on dose was in most cases nonlinear, although in two studies the dependence of certain effects on exposure duration was approximating linearity [35, 62].

The results of experiments with real-life (variable) mobile phone EMFs are indeed not identically reproducible, since between successive exposures at any specific location the exact characteristics of the emitted signal are always different. But the average field values over a few minutes' (or more) period are close to each other, and thus the results of different replicate experiments with real emissions as the independent variable, although not identical quantitatively, are qualitatively similar. Statistical significance in the results can be increased by increasing the number of experimental replications while keeping rigorous control of all other parameters (animal/sample conditions, temperature, humidity, light, stray EMFs within the lab, etc.). Then, as the number of replications increases, field variability becomes less significant [99].

5. Discussion

In the present study we showed that the percentages of positive results differ significantly between studies with real mobile phone exposures and studies with simulated exposures, regardless of biological samples or other procedure details. The basic difference between real and simulated mobile telephony EMFs is the inherent significant variability of the first which we believe is the reason for the strong divergence in the experimental results.

In spite of the criticism on the studies employing real exposures by health agencies [1, 2] (the different aspects of which we extensively addressed) and the consequent difficulty in the publication process, the number of studies with real mobile phone emissions is increasing rapidly in the peer-reviewed literature, especially during the last years. An increasing number of scientists realize that real exposures by commercially available mobile phone handsets are the only way to represent conditions experienced by users in real-life, since they are very different and considerably more bioactive than the exposures made by simulated fields.

Any variability in the field and correspondingly in the dosimetry does not change the fact that people are actually exposed daily for increasing periods to this "highly variable" field in contact with their heads/bodies and at different distances. The presented scientific data show that this constant variation in the field makes it considerably more active biologically.

In order to have a measure of this variability, RF and ELF measurements of average intensity ± standard deviation (SD) of the emitted real EMFs should be included in the studies, in addition to the Specific Absorption Rate (*SAR*) information supplied by the manufacturer (referring to a simulated human head [100]). With increasing number of measurements the SD decreases enough for the dosimetry to be judged as reliable [8, 26, 31–36, 99].

If we accepted that the real EMFs emitted by commercially available mobile phones are so much variable and their dosimetry is so much unreliable that the studies employing real EMF-emissions are not to be taken into account because of "unknown" dosimetry, then these devices should not be approved by the public authorities to be available in the market, since unpredictable unmeasurable signal changes can result in unpredictable biological alterations. Once these devices are approved for the market (a fact that we do not challenge) the definition of the exposure is the *exposure to a user's head during a usual phone-conversation*, and this, in our opinion, should be enough for the studies to be taken into account by health agencies and authorities. Nevertheless, the measurements of the emitted EMFs suggested above are important to better quantify real-life exposures, in addition to verifying that the average emissions by the handsets used in the experiments do not transcend the existing limits [96].

It is useful to create simulations in order to study in the lab conditions of specific environments which are not accessible for laboratory work (outer space, underwater high depths, etc.). The simulations in such cases should be as close as possible to the real conditions. However, using nonrealistic simulations, especially when real conditions are easily accessible to be studied in the lab with well-controlled other parameters, is, in our opinion, a serious scientific flaw that is pervading the mobile phone bioeffects literature. The employment of simplified nonrealistic simulations may be useful for specific purposes, for example, to study what the effects would be if the signal characteristics were different, in order to improve them.

Experiments comparing the biological activity between real and simulated mobile telephony EMFs with similar average parameter values should urgently be conducted in order to test the validity of our presented arguments. Studies performed with simulated fields/exposures, especially those that did not show any effects, should, in our opinion, be repeated with real exposures of similar average signal parameters while keeping all the remaining experimental variables identical. In case that these experiments verify our arguments, health agencies should immediately revise their guidelines in regard to which studies should be considered most important and on whether the available data are indeed conflicting or not. Moreover, according to the precautionary principle, the existing exposure criteria should drastically be revised, since the effects reported in all studies with real mobile phone emissions have been recorded with EMF-intensities well below (up to thousands of times below) the existing exposure limits [8, 26, 31–75, 96].

Without account for real exposure parameters, studies suffer from imprecision that likely biases results toward null hypotheses, increasing the probability that true health risks among consumers are being missed. Simulated signals with fixed parameters bear little, if any, resemblance to what mobile phone users actually experience, even when they employ combinations of simulated signals [101–103].

In order for the biological/clinical studies testing the bioactivity of mobile telephony radiation to account for real conditions, we conclude that exposures should be performed by real EMFs as these are emitted by commercially available mobile phones. The same holds for experiments with other types of EMFs employed in modern telecommunication

systems such as DECT phones and Wi-Fi. In addition to that, simulated emissions may be used to study, for example, the effects of separate parameters of the real EMFs, but in no way should simulated emissions substitute the real ones.

As the scientific database regarding the biological effects of EMFs emitted by modern telecommunications continues to grow, it is important for experimental study designs to grow in rigor and provide a more informed basis for interpretation. One important step is to employ real-life exposures.

To investigate the biological/health effects from a widely accessible device exposing daily billions of humans we should not try to simulate the device but simply use the device itself. In particular, we should not try to simulate its real varying emissions with totally unrealistic invariant ones. This is a serious scientific flaw that may lead to totally devious results with enormous adverse consequences for public health.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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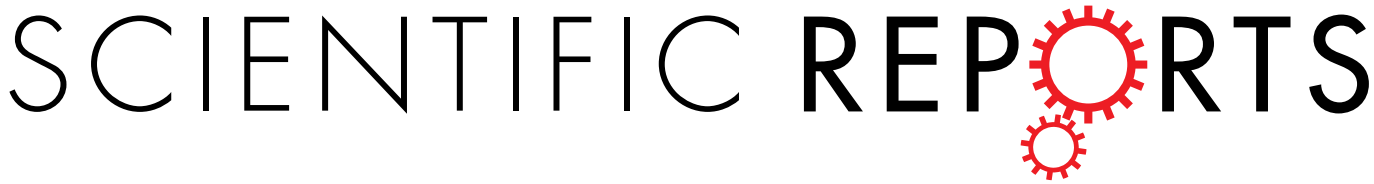

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Polarization: A Key Difference between Man-made and Natural Electromagnetic Fields, in regard to Biological Activity

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In the present study we analyze the role of polarization in the biological activity of Electromagnetic Fields (EMFs)/Electromagnetic Radiation (EMR). All types of man-made EMFs/EMR - in contrast to natural EMFs/EMR - are polarized. Polarized EMFs/EMR can have increased biological activity, due to: 1) Ability to produce constructive interference effects and amplify their intensities at many locations. 2) Ability to force all charged/polar molecules and especially free ions within and around all living cells to oscillate on parallel planes and in phase with the applied polarized field. Such ionic forced-oscillations exert additive electrostatic forces on the sensors of cell membrane electro-sensitive ion channels, resulting in their irregular gating and consequent disruption of the cell's electrochemical balance. These features render man-made EMFs/EMR more bioactive than natural non-ionizing EMFs/EMR. This explains the increasing number of biological effects discovered during the past few decades to be induced by man-made EMFs, in contrast to natural EMFs in the terrestrial environment which have always been present throughout evolution, although human exposure to the latter ones is normally of significantly higher intensities/energy and longer durations. Thus, polarization seems to be a trigger that significantly increases the probability for the initiation of biological/health effects.

Man-Made EMR is more Active biologically than Natural Non-Ionizing EMR. A large and increasing number of studies during the past few decades have indicated a variety of adverse biological effects to be triggered by exposure to man-made EMFs, especially of radio frequency (RF)/microwaves, and extremely low frequency (ELF). The recorded biological effects range from alterations in the synthesis rates and intracellular concentrations of different biomolecules, to DNA and protein damage, which may result in cell death, reproductive declines, or even cancer[1–7]. Under the weight of this evidence the International Agency for Research on Cancer (IARC) has classified both ELF magnetic fields and RF EMFs as possibly carcinogenic to humans[8,9]. The intensities of radiation and durations of exposure in all these studies were significantly smaller than those of corresponding exposures from natural EMFs in the terrestrial environment. Moreover, the field intensities applied in the studies were several orders of magnitude smaller than physiological fields in cell membranes, or fields generated by nerve and muscle excitations[10,11].

Solar EMR intensity incident upon a human body ranges normally between 8 and 24 mW/cm^2 (depending on season, atmospheric conditions, geographical location, etc) while corresponding intensity from a digital mobile phone handset upon a human head during "talk" emission is normally less than

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0.2 mW/cm^2 (Refs. 6,12,13). Similarly, terrestrial electric and magnetic fields, or infrared radiation from every human body at normal temperature, have significantly larger incident intensities and exposure durations on any human than most artificial EMF sources[14–16]. Why is then the first beneficial while the latter seem to be detrimental? In the present study we shall attempt to explain theoretically that the increased adverse biological action of man-made EMFs is due to the fact that they are polarized in contrast to the natural ones.

Man-Made EMR is Polarized, while Natural EMR is not. A field/wave is called linearly polarized when it oscillates on a certain plane which is called the "polarization plane". A combination of linearly polarized fields/waves can give circularly or elliptically polarized fields/waves.

Natural EMR/EMFs (cosmic microwaves, infrared, visible light, ultraviolet, gamma rays) and several forms of artificially triggered electromagnetic emissions (such as from light bulbs with thermal filaments, gas discharge lamps, x-rays, lasers, etc.) are not polarized. They are produced by large numbers of molecular, atomic, or nuclear transitions of random orientation and random phase difference between them (except for the lasers which are coherent). These are de-excitations of molecules, atoms, or atomic nuclei[17]. Each photon they consist of oscillates on a distinct random plane, and therefore it has a different polarization. Moreover the different photons are not produced simultaneously but they have random phase differences among them.

In contrast, man-made electromagnetic waves are produced by electromagnetic oscillation circuits ("Thomson" circuits), forcing free electrons to oscillate back and forth along a metal wire (electric circuit). Thus, they are not produced by excitations/de-excitations of molecules, atoms, or nuclei, and because the electronic oscillations take place in specific directions/orientations they are polarized (most usually linearly polarized). The plane of polarization is determined by the geometry of the circuit. [Lasers are coherent light emissions, not necessarily polarized, and condensed within a narrow beam with high intensity, but they may also be polarized]. Superposition of two fields of identical frequency and linear polarizations, equal amplitudes, and a phase difference 90° between them, or superposition of three such fields with a phase difference 120° between each two of them, and with specific geometrical arrangement, results in a circularly polarized field of the same frequency. The above combinations with unequal amplitudes results in elliptically polarized field of the same frequency[18]. Circularly and elliptically polarized 50–60 Hz electric and magnetic fields are formed around 3-phase electric power transmission lines. These fields are accused for an association with cancer[7,8].

Oscillating polarized EMFs/EMR (in contrast to unpolarized) have the ability to induce coherent forced-oscillations on charged/polar molecules within a medium. In case that the medium is biological tissue, the result is that all charged molecules will be forced to oscillate in phase with the field and on planes parallel to its polarization[19,20]. Several oscillating electromagnetic fields of the same polarization - such as the fields from different antennas vertically oriented - may also produce constructive interference effects and thus, amplify at certain locations the local field intensity, and the amplitude of oscillation of any charged particle within the medium (and within living tissue). At such locations, living tissue becomes more susceptible to the initiation of biological effects[21].

Only coherent polarized fields/waves of the same polarization and frequency are able to produce standing interference effects (fringes of maximum and minimum intensity)[22]. When the polarization is fixed (e.g. vertically oriented antennas) but there are differences in coherence and/or frequency between the sources, the interference effects are not standing at fixed locations, but change with time creating transient peaks at changing locations.

Natural light from two or more different sources does not produce interference effects, except under the specific conditions of the Young experiment, where the light from a single source passes through two identical slits which - in turn - become two identical-coherent secondary sources[18,23].

Unpolarized electromagnetic radiation can become polarized when it passes through anisotropic media, as are certain crystals. In fluids (gases and liquids) the molecules are randomly oriented, and macroscopically are considered isotropic inducing no polarization in the electromagnetic waves transmitted through them. Unpolarized natural light can become partly polarized to a small average degree after diffraction on atmospheric molecules, or reflection on water, mirrors, metallic surfaces, etc.[18]. Thus, living creatures exposed to natural radiation since the beginning of life on Earth, although have been exposed to partially polarized light at a small average degree under certain circumstances[24,25], have never been exposed to totally polarized radiation as is EMR/EMFs of modern human technology.

Field Intensity versus Wave Intensity of electromagnetic waves. A plane harmonic electromagnetic wave in the vacuum or the air has electric and magnetic field intensity components, given by the equations:

$$E = E_0 \sin(k_w r - \omega t) \quad (1)$$

$$B = B_0 \sin(k_w r - \omega t) \quad (2)$$

r is the distance from the source, t is the time, $\omega = 2\pi\nu = k_w \cdot c$, is the circular frequency of the wave (ν the frequency), and $k_w (= 2\pi/\lambda)$ is the wave number (λ the wavelength).

The velocity of the electromagnetic wave (and of any wave), is:

$$c = \lambda \cdot \nu \tag{3}$$

The wave intensity $\vec{J}$ ("Poynting vector"), is:

$$\vec{J} = \vec{c}\varepsilon_0 E^2 = c^2 \varepsilon_0 \vec{E} \times \vec{B} \tag{4}$$

And the average value of its amplitude:

$$J_{ave} = \frac{1}{2} c \varepsilon_0 E_0^2 \tag{5}$$

Thus, the wave intensity depends upon the square of the electric field intensity.

Superposition of Electromagnetic Waves/Fields

Superposition of Unpolarized EMR/EMFs. Consider two incoherent, unpolarized electromagnetic rays with electric components E_1, E_2, reaching a certain point P in space at a certain moment t in time. Let us assume for simplicity that the two waves are plane harmonic. The two vectors $\bar{E}_1$, $\bar{E}_2$ due to the different polarizations oscillate on different planes. Since the two waves are not polarized, their polarizations vary randomly with time. The total angle ϕ between the two vectors each moment is determined by the different polarizations, plus the different phases, and varies randomly in time.

The resultant electric field $\bar{E}$ (electric component of the resultant electromagnetic wave) each moment at point P, is given by the equation:

$$E = \sqrt{E_1^2 + E_2^2 + 2E_1E_2 \cos \phi} \tag{6}$$

E varies with time due to the temporal variations of E_1, E_2, $\cos\phi$. But the average value of $\cos\phi$ is zero:

$$\frac{1}{2\pi} \int_0^{2\pi} \cos\phi \, d\phi = 0,$$

and the averages of E^2, E_1^2, and E_2^2 are $E_0^2/2$, $E_{01}^2/2$ and $E_{02}^2/2$ respectively (E_0, E_{01}, E_{02} the amplitudes of E, E_1, E_2).

The average resultant electric field is then:

$$E_{ave} = \sqrt{\frac{1}{2}(E_{01}^2 + E_{02}^2)} \quad \text{or} \quad E_0^2 = E_{01}^2 + E_{02}^2 (=\text{constant})$$

and (according to Eq. 5):

$$J_{ave} = J_{1,ave} + J_{2,ave} (=\text{constant}) \tag{7}$$

Even when the two component waves have the same frequency and phase, due to the randomly changing polarizations, the result is still the same.

Thus, the total time average wave intensity due to the superposition of two (or more) rays of random polarizations (natural EMR/EMFs) is the sum of the two individual average intensities, and it is constant at every point and - macroscopically - there is no local variation in the resultant intensity, i.e. no interference effects.

Wave Intensity versus Field Intensity of Unpolarized EMR. Although the sum average wave intensity due to superposition of natural unpolarized waves is the sum of individual average intensities each one depending on the square amplitude of individual electric field (Eq. 7), the sum electric field from an infinite number of individual waves (as e.g. with natural light), is zero:

$$\lim_{n\to\infty} \sum_{i=1}^{n} \vec{E}_i = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \ldots + \vec{E}_n = 0 \tag{8}$$

Let us explain this in more detail: Consider many photons of natural unpolarized light superposed on each other at a particular point in space. Let us assume for simplicity that these photons have equal amplitudes and are of the same frequency but have different polarizations meaning that their electric vectors have all possible orientations forming angles between each two of them from 0° to 360°. Since all possible orientations have equal probabilities, the superposition of a large number of such equal vectors applied on the same point in space will be the sum of vectors applied on the centre of a sphere with their ends equally distributed around the surface of the sphere. The sum of an infinite number of such

vectors (all applied on the same point – centre of the sphere – and with their ends evenly distributed at all points of the sphere surface) tends to become zero.

In other words, at any given location, any moment, the sum electric field of a large number of incident photons of random polarization tends to be null, since the individual vectors are in all possible directions diminishing each other when superimposed (destructive interference of electric vectors). Similarly for the sum magnetic field:

$$\lim_{n\to\infty} \sum_{i=1}^{n} \vec{B}_i = 0$$

Thus, the result of superposition of a large number of incident natural waves is increased wave intensity, but negligible electric and magnetic fields approaching zero with infinite number of individual waves/photons. Since the electric forces on charged particles depend directly on electric and magnetic field intensities ($\vec{E}$, $\bar{B}$), but not on the wave intensity $\vec{J}$, unpolarized EMFs/EMR cannot induce any net forced-oscillations on any charged particles (e.g. biological molecules). They may only induce heat, i.e. random oscillations in all possible directions due to momentary non-zero field intensities, but this does not result to any net electric or magnetic field, or to any net forced-oscillation of charged molecules.

Superposition of Coherent Polarized Waves/Fields of the same polarization. When two or more waves/fields of the same polarization and frequency are in addition coherent, in other words, when their phase difference at the location of superposition is:

$$\varphi = 2n\pi, \text{ (with } n = 1, 2, 3, \ldots), \tag{9}$$

the result is constructive interference, meaning that the resultant wave has an amplitude (intensity) equal to the sum of amplitudes of the single waves that interfere at the particular location.

When two waves of same polarization have opposite phases at another location, in other words, when their phase difference is:

$$\varphi = (2n + 1)\pi, \tag{10}$$

then the result of their superposition is destructive interference, i.e. a wave of the same polarization but with diminished intensity.

The electrical components of two such waves (plane harmonic waves of the same polarization and frequency) reaching a certain location after having run different distances r_1, and r_2 from their two coherent sources, are given by the equations:

$$E_1 = E_{01} \sin(k_w r_1 - \omega t) \tag{11}$$

$$E_2 = E_{02} \sin(k_w r_2 - \omega t) \tag{12}$$

Again, the amplitude E_0 of the resultant electric field $\bar{E}$ (electric component of the resultant electromagnetic wave), is:

$$E_0 = \sqrt{E_{01}^2 + E_{02}^2 + 2E_{01}E_{02} \cos\varphi} \tag{13}$$

where $\varphi = \frac{2\pi}{\lambda}(r_1 - r_2)$ depending in this case only upon the difference in the distances run by the two waves, and not upon polarization.

At any location where: $\varphi = 2n\pi$, Eq. 13 gives:

$$E_0 = \sqrt{E_{01}^2 + E_{02}^2 + 2E_{01}E_{02}} \ (=|E_{01} + E_{02}|) \tag{14}$$

At these locations we have constructive interference.

At any location where: $\varphi = (2n+1)\pi$, Eq. 13 gives:

$$E_0 = \sqrt{E_{01}^2 + E_{02}^2 - 2E_{01}E_{02}} \ (=|E_{01} - E_{02}|) \tag{15}$$

At these locations we have destructive interference.

The intensity of the resultant wave at any location is:

$$\vec{J} = \vec{J}_1 + \vec{J}_2 \tag{16}$$

The amplitude of the resultant wave intensity will be, correspondingly:

$$J_0 = c\varepsilon_0(E_{01} + E_{02})^2 \tag{17}$$

(at the locations of constructive interference), and

$$J_0 = c\varepsilon_0(E_{01} - E_{02})^2 \tag{18}$$

(at the locations of destructive interference).

Thus, at the locations of constructive interference, the electric field vectors of the two waves/fields are parallel and in the same direction, and both the resultant field and the resultant wave intensity are maximum (Eqs. 14 and 17).

For two identical sources ($E_{01} = E_{02}$): $E_0 = 2E_{01}$ and $J_0 = 4c\varepsilon_0 E_{01}^2 = 4J_{01}$

For N identical sources:

$$E_0 = NE_{01} \tag{19}$$

and:

$$J_0 = N^2 J_{01} \tag{20}$$

This is why series of parallel RF/microwave antennas are often used to produce high-intensity beams in certain directions[18].

At the locations of destructive interference the electric field vectors of the two waves are anti-parallel, and thus, both the resultant field and the resultant wave intensity are minimum (Eqs. 15 and 18). For identical sources ($E_{01} = E_{02}$): $E = 0$, $J = 0$.

Thus, for N number of polarized coherent electromagnetic sources of the same polarization, frequency, and different intensities, with electric components E_1, E_2, …, E_N, it comes that at the locations of constructive interference, the resultant electric field is the sum electric field from all the individual sources (e.g. antennas):

$$E = E_1 + E_2 + E_3 + \ldots + E_N \tag{21}$$

The bigger the number of coherent superimposed waves/fields (from the same or different sources), the higher and narrower the peaks[18]. That situation can create very sharp peaks of wave and field intensities at certain locations, not easily detectable by field meters, where any living organism may be exposed to peak electric and magnetic field intensities. Such locations of increased field/radiation intensity, also called "hot spots", were recently detected within urban areas, due to wave/field superposition from mobile telephony base towers[21]. Any location along the midperpendicular to the distance d between two antennas is a location of constructive interference in the case of two identical antennas.

Thus, the difference between superposition of unpolarized and polarized electromagnetic waves/fields, is that while in the first case we have increased average wave intensity but zeroed net fields at any location, in the second case we have increased both wave intensity and fields at certain locations where constructive interference occurs. This difference is of crucial importance for understanding the differences in biological activity between natural and man-made EMFs/non-ionizing EMR.

Induction of Forced-Oscillations in living tissue by Polarized EMFs

All critical biomolecules are either electrically charged or polar[11]. While natural unpolarised EMF/EMR at any intensity cannot induce any specific/coherent oscillation on these molecules, polarized man-made EMFs/EMR will induce a coherent forced-oscillation on every charged/polar molecule within biological tissue. This is fundamental to our understanding of the biological phenomena. This oscillation will be most evident on the free (mobile) ions which carry a net electric charge and exist in large concentrations in all types of cells or extracellular tissue determining practically all cellular/biological functions[11]. Although all molecules oscillate randomly with much higher velocities due to thermal motion, this has no biological effect other than increase in tissue temperature. But a coherent polarized oscillation of even millions of times smaller energy than average thermal molecular energy[26] can initiate biological effects.

A forced-oscillation of mobile ions, induced by an external polarized EMF, can result in irregular gating of electrosensitive ion channels on the cell membranes. That was described in detail in Panagopoulos *et al.*[19,20]. According to this theory - the plausibility of which in actual biological conditions was verified by numerical test[27] - the forced-oscillation of ions in the vicinity of the voltage-sensors of voltage-gated ion channels can exert forces on these sensors equal to or greater than the forces known to physiologically gate these channels. Irregular gating of these channels can potentially disrupt any cell's electrochemical balance and function[11], leading to a variety of biological/health effects including the most detrimental ones, such as DNA damage, cell death, or cancer[28].

Most cation channels (Ca^{+2}, K^+, Na^+, etc) on the membranes of all animal cells, are voltage-gated[11]. They interconvert between open and closed state, when the electrostatic force on the electric charges of their voltage sensors due to transmembrane voltage changes, transcends some critical value. The voltage sensors of these channels are four symmetrically arranged, transmembrane, positively charged helical domains, each one designated S4. Changes in the transmembrane potential on the order of 30 mV are normally required to gate electrosensitive channels[29,30]. Several ions may interact simultaneously each

moment with an S4 domain from a distance on the order of 1 nm, since - except for the single ion that may be passing through the channel pore when the channel is opened - a few more ions are bound close to the pore of the channel at specific ion-binding sites (e.g. three in potassium channels)[31]. Details on the structure and function of cation electrosensitive channels can be found in[11,29,31].

Consider e.g. four potassium ions at distances on the order of 1 nm from the channel-sensors (S4), and an externally applied oscillating EMF/EMR. The electric (and the magnetic) force on each ion due to any unpolarized field is zero (Eq. 8). In contrast, the force due to a polarized field with an electrical component E, is $F = Ezq_e$. For a sinusoidal alternating field $E = E_0 \sin \omega t$, the movement equation of a free ion of mass m_i, is[19,20]:

$$m_i \frac{d^2 r}{dt^2} + \lambda \frac{dr}{dt} + m_i \omega_0^2 r = E_0 z q_e \sin \omega t \tag{22}$$

where r is the ion displacement due to the forced-oscillation, z is the ion's valence ($z = 1$ for potassium ions), $q_e = 1.6 \times 10^{-19}$ C the elementary charge, λ the damping coefficient for the ion displacement (calculated to have a value within a channel $\lambda \cong 6.4 \times 10^{-12}$ Kg/s), $\omega_0 = 2\pi\nu_0$ (ν_0 the ion's oscillation self-frequency taken equal to the ion's recorded spontaneous intracellular oscillation frequency on the order of 0.1 Hz), $\omega = 2\pi\nu$ (ν the frequency of the field/radiation), and E_0 the amplitude of the field[19,20].

The general solution of Eq. 22, is[19,20]:

$$r = \frac{E_0 z q_e}{\lambda \omega} \cos \omega t + \frac{E_0 z q_e}{\lambda \omega} \tag{23}$$

The term $\frac{E_0 z q_e}{\lambda \omega}$ in the solution, represents a constant displacement, but has no effect on the oscillating term $\frac{E_0 z q_e}{\lambda \omega} \cos \omega t$. This constant displacement doubles the amplitude $\frac{E_0 z q_e}{\lambda \omega}$ of the forced-oscillation at the moment when the field is applied or interrupted, or during its first and last periods, and the ion's displacement will be twice the amplitude of the forced-oscillation. For pulsed fields (such as most fields of modern digital telecommunications) this will be taking place constantly with every repeated pulse. Thus, pulsed fields are - theoretically - twice more drastic than continuous/non-interrupted fields of the same other parameters, in agreement with several experimental data[1,32].

The amplitude of the forced-oscillation (ignoring the constant term in Eq. 23), is:

$$A = \frac{E_0 z q_e}{\lambda \omega} \tag{24}$$

The force acting on the effective charge q of an S4 domain, via an oscillating single-valence free cation, is: $F = \frac{1}{4\pi\varepsilon\varepsilon_0} \cdot \frac{q \cdot q_e}{r^2}$, ($r$ is the distance of the free ion from the effective charge of S4). Each oscillating cation displaced by dr, induces a force on each S4 sensor:

$$dF = -\frac{q \cdot q_e}{2\pi\varepsilon\varepsilon_0 r^3} dr \tag{25}$$

While in the case of a non-polarized applied field $\sum d\vec{r} = 0$, and $\sum d\vec{F} = 0$, in the case of a polarized applied field, the sum force on the channel sensor from all four cations, is:

$$4dF = -2\frac{q \cdot q_e}{\pi\varepsilon\varepsilon_0 r^3} dr$$

This is an even more crucial difference between polarized and unpolarized EMFs in regard to biological activity than the ability of interference.

The effective charge of each S4 domain is found to be: $q = 1.7\, q_e$[30]. The minimum force on this charge required normally to gate the channel - equal to the force generated by a change of 30 mV in the membrane potential[30] - is calculated[19] to be:

$$dF = 8.16 \times 10^{-13} \text{N}.$$

The displacement of one single-valence cation within the channel, necessary to exert this minimum force is calculated from Eq. 25 to be:

$$dr = 4 \times 10^{-12} \text{m}$$

For 4 cations oscillating in phase and on parallel planes due to an external polarized field/radiation, the minimum displacement is decreased to: $dr = 10^{-12}$ m.

Therefore, any external polarized oscillating EMF able to force free ions to oscillate with amplitude $\frac{E_0 z q_e}{\lambda \omega} \geq 10^{-12}$ m, is able to irregularly gate cation channels on cell membranes. For $z = 1$ (potassium ions), and substituting the values for q_e, λ on the last condition, we get:

$$E_0 \geq 0.25\nu \times 10^{-3} \tag{26}$$

(ν in Hz, E_0 in V/m)

For double-valence cations ($z=2$) (e.g. Ca^{+2}) the condition becomes,

$$E_0 \geq \nu \times 10^{-4} \tag{27}$$

(ν in Hz, E_0 in V/m)

[An in depth description of the briefly presented mechanism can be found in[19,20].]

For electric power fields ($\nu=50$ Hz), Condition 27 becomes,

$$E_0 \geq 0.005\text{V/m} \tag{28}$$

Thus, power frequency EMFs with intensities exceeding 5 mV/m are potentially able to disrupt cell function. For N number of EMF-sources of the same polarization (e.g. N number of parallel power lines) the last value is divided by N (according to Eq. 19) at the locations of constructive interference, and thus even more decreased. Such minimum power frequency field intensity values are abundant in urban daily environments, and even more close to high-voltage power transmission lines[7].

For pulsed fields the second part of Condition 27 is divided by 2, and becomes:

$$E_0 \geq 0.5\nu \times 10^{-4} \tag{29}$$

(ν in Hz, E_0 in V/m).

For digital mobile telephony fields/radiation emitting ELF pulses with a pulse repetition frequency $\nu=217$ Hz (among other ELF frequencies they transmit)[33], Condition 29 becomes:

$$E_0 \geq 0.01\text{V/m} \tag{30}$$

For the pulse repetition frequency of $\nu=8.34$ Hz (also included in mobile telephony signals)[33,34], Condition 29 becomes:

$$E_0 \geq 0.0004\text{V/m} \tag{31}$$

As is evident from the described mechanism, the field does not gate the channel by forces exerted directly on the channel sensors. It would take a field on the order of the transmembrane field (10^6–10^7 V/m) for that. It is the mediation of the oscillating free ions in close proximity to the S4 channel sensors that allows such weak fields to be able to exert the necessary forces to gate the channel.

Thus, ELF electric fields emitted by mobile phones and base stations stronger than 0.0004 V/m are also potentially able to disrupt the function of any living cell. This ELF intensity value is emitted by regular cell phones at distances up to a few meters and base stations at distances up to a few hundred meters[6,34,35]. For N number of mobile telephony antennas vertically oriented, the last value is divided by N (according to Eq. 19) at locations of constructive interference.

We do not distinguish between externally applied EMFs and internally induced ones within living tissue, especially in the case of ELF for the following reasons: 1. Living tissue is not metal to shield from electric fields and certainly is not ferromagnetic metal (Fe, Co, Ni) to shield from magnetic fields. Moreover, it is known that especially ELF fields cannot be easily shielded even by Faraday cages and in order to significantly minimize them it is recommended to totally enclose them in closed metal boxes[6]. Thus, ELF electric fields penetrate living tissue with certain degree of attenuation, and magnetic fields penetrate with zero attenuation. 2. Even in case that the ELF fields are significantly attenuated in the inner tissues of a living body, the eyes, the brain, the skin cells, or the myriads of nerve fiber terminals that end up on the outer epidermis, are directly exposed to the field intensities measured externally on the surface of the living tissue.

It has been shown that tissue preparations (such as bovine fibroblasts or chicken tendons) respond to externally applied pulsed or sinusoidal ELF electric fields (by changes in DNA or protein synthesis rates, proliferation rates, alignment with respect to the field direction, etc), at very low thresholds ~10^{-3} V/m[1,36–38]. These thresholds are very close to those predicted by the present study.

Except for direct electric field exposure by an external field, there can be an electric field within tissues induced by an externally applied oscillating magnetic one, which as explained penetrates living tissue with zero attenuation. Tuor *et al.*[34] measured ELF magnetic fields from cell phones on the order of 1 G ($=10^{-4}$ T) at 217 Hz. This can induce electric fields on the order of ~0.1 V/m within the human body, as can be shown by application of Maxwell's law of electromagnetic induction:

$$\oint_l \vec{E}_{ind} \cdot d\vec{l} = -\frac{d}{dt}\int_S \vec{B} \cdot \vec{u}_N dS \tag{32}$$

($\bar{B}$, $\bar{E}_{ind}$, the magnetic and the induced electric field intensities respectively, $d\vec{l}$ an incremental length along a closed path l of induced electric field circulation enclosing a surface S. $\vec{u}_N$ is the unit vector vertical to the surface S).

Assuming $\bar{E}_{ind}$ parallel to and independent of l, $\bar{B}$ vertical to and independent of S, and l a circular path of radius α including the surface S, Eq. 32 becomes:

$$E_{ind} \oint_l dl = -\frac{dB}{dt} \int_S dS$$

which gives:

$$E_{ind} = 0.5\alpha \frac{dB}{dt} \tag{33}$$

(E_{ind} in V/m, B in T, α in m).

By replacing in the last equation $\alpha = 0.20$ m (a reasonably large radius for a circumference within an adult human body), and $\frac{dB}{dt} = 1\mathrm{T/s}$, [according to Tuor *et al.*[34]], we get $E_{ind} \sim 0.1$ V/m. This is the induced electric field intensity within a human body by the 217 Hz pulses of mobile telephony, and it is about ten times larger than the minimum estimated value able to initiate biological effects at this frequency according to Condition 30.

Discussion

In the present study we showed that polarized EMFs/EMR, such as every type of man-made EMF, have the ability to create interference effects and amplify their field intensities at specific locations where constructive interference occurs, and that this phenomenon cannot occur with natural EMFs/EMR which are not polarized.

Any location at equal distances from identical sources (antennas), in other words any location along the midperpendicular to the distance d between the two sources, is a location of constructive interference and increased field and wave intensities. As the number of sources (e.g. antennas) increases, the amplification of the resultant field intensities (E, B) at certain locations increases too (Eq. 19), and for a large number of sources field intensities may become very sharp. This explains theoretically the detected "hot spots" from mobile telephony base stations in urban environments[21]. The result of field superposition at those locations are standing waves (i.e. they do not change with time) when the two or more sources of the same polarization are in addition coherent (i.e. same frequency, same phase difference). Within biological tissue, at those locations of constructive interference we can have increased biological activity due to the polarized EMFs.

The most usual case is, when the multiple incident fields/waves are of the same polarization but not coherent (i.e. different frequency and/or varying phase difference), as e.g. the waves from all different radio, television, and mobile telephony antennas vertically oriented. Then, the resultant fields/waves are not standing but timely varying, creating momentary constructive interference at unpredictably different locations each moment. This fact may represent an extraordinary ability of man-made/polarized EMFs to trigger biological effects.

Using the forced-oscillation mechanism[19,20] we showed that the resultant force exerted on the S4 sensors of electrosensitive ion channels on cell membranes by several ions forced to oscillate on parallel planes and in phase by an applied polarized EMF (and even more by constructively superimposed fields from several polarized EMF-sources), is able to irregularly gate these channels. The result can then be the disruption of the cell's electrochemical balance, leading to a variety of biological/health effects[28]. This is in contrast to the null force exerted by any number of ions oscillating on non-parallel random planes and with different phases from each other due to any number of non-polarized applied EMFs, and in contrast to the null force exerted by the random thermal movement of the same ions[20,26].

In experiments testing the role of different polarization types on the biological activity of RF EMR, exposure of E. coli to 51.76 GHz radiation resulted in inhibition of DNA repair when linear or right-handed circularly polarized radiation was used, while left-handed circularly polarized radiation caused no effects. Exposure to 41.32 GHz similar EMR was reported to reverse the effect: In this case, only linear or left-handed circularly polarized radiation inhibited the DNA repair[39]. In both frequencies, the right-handed or the left-handed circularly polarized radiation induced a greater effect than the linearly polarized radiation. When the structure of the DNA was altered by ethidium bromide intercalation, a change in intensity of the effect of polarization was reported[40]. Chromatin condensation (a sign of cell death) was induced by elliptically polarized 36.65 GHz microwave radiation. The effect increased with intensity. Right-handed polarization induced a stronger effect than left-handed[41]. These experiments show that not only linear but circular and elliptical polarizations are important parameters for the biological action of EMR, and that molecular structure of biomolecules may be important for the interaction between polarized EMF and the biological tissue. In all these studies there was no comparison with unpolarised field of identical other parameters, but only comparison between different types of

polarization. Again, it is important to note that circularly and elliptically polarized 50–60 Hz EMFs are formed around 3-phase power transmission lines.

Experiments with non-polarized and polarized EMFs/EMR of identical other characteristics (intensity, frequency, waveform, etc) on certain biological models should be performed to test the validity of the present theoretical study. This should be the subject of a future experimental study.

The present theoretical analysis shows that polarized man-made EMFs/EMR can trigger biological effects while much stronger and of higher energy (frequency) unpolarized EMFs/Non-Ionizing EMR (e.g. heat, or natural light) cannot.

This is the reason why polarized microwave radiation of maximum power 1 W emitted by a mobile phone can damage DNA and cause adverse health effects[2,3,5,6,35], while non-polarized infrared, visible, and ultraviolet radiation from a 100 W light bulb, or ~400 W infrared and visible EMR from a human body[14,16], cannot. Similarly with solar EMR the intensity of which incident on a human body (~8–24 mW/cm^2) is hundreds of times higher than radiation intensity incident from e.g. a cell phone on a user's head/body during a usual phone-conversation with the handset in touch with the head (less than 0.2 mW/cm^2), or incident intensities from other RF, ELF sources of human technology[6,7,12,13]. The total daily duration of human exposure to the sunlight is also much longer normally than the total daily duration of cell phone exposure during conversations[5,6,12,13]. Moreover the frequency (energy) of sunlight is also significantly larger than any man-made RF or ELF frequencies. Yet, there are no adverse biological effects due to normal/non-excessive exposure to sunlight. On the contrary, it is beneficial and vital/necessary for human/animal health, in contrast to cell phone radiation. Similarly, there are no adverse biological effects due to exposure (mainly in the infrared and visible regions) from one human body to another (with an incident intensity ~20 mW/cm^2)[16]. Although all animals on Earth have adapted throughout evolution to exposures to EMFs from the sun and the earth, these fields are non-polarized (even though natural light may become partially polarized in a small average degree due to atmospheric scattering or reflections). Moreover, terrestrial electric and magnetic fields are mainly static, emitting very weak non-polarized ELF radiation due to slight variations in their intensities. However, larger variations on the order of 20% of their normal intensities due to solar activity with a periodicity of about 11 years result in increase of human/animal health incidents[15]. Therefore, living organisms on Earth are adapted to natural (non-polarized or even partially polarized) EMFs since the beginning of life, but not to variations in their normal intensities on the order of 20%, and thus we would not expect them to adapt to man-made (totally polarized) EMFs/EMR. The present study explained how this difference in polarization results in corresponding differences in biological activity between natural and man-made EMFs.

Increased biological activity does not necessarily result in observable biological/health effects, since there are adaptive mechanisms operating at cellular-tissue-organism levels in response to ever occurring changes. However, these mechanisms may not always be totally effective, especially when the organism is under additional stress or increased metabolic needs (e.g. sickness, childhood/development, old age, etc.). Then exposure to polarized (man-made) EMFs may considerably increase the probability for the initiation of adverse health effects. The effect of polarized EMF-exposure may even be beneficial in certain cases of applied static or pulsed electric or magnetic fields of specified orientation and intensities that enhance the action of endogenous physiological fields within living cells/organisms e.g. during development, wound healing, bone fracture healing etc.[38,42].

The role of polarization in the ability of EMFs/non-ionizing EMR to induce biological effects, as described in the present study, is - up to today - largely underestimated in the EMF-bioeffects literature. Thus, we believe that the present study contributes significantly towards a better understanding of the mechanisms underlying EMF-bioeffects.

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Author Contributions

Analyzed the data: D.J.P., O.J. and G.L.C. Wrote and reviewed the paper: D.J.P., O.J. and G.L.C. Conceived and designed the study: D.J.P. Wrote equations and Performed calculations: D.J.P.

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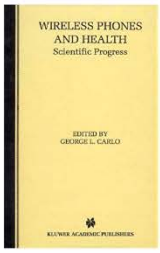

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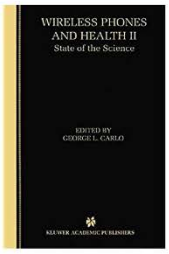

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