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Global electromagnetic toxicity and frequency-induced diseases: Theory and short overview

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Abstract

The development and implementation of electricity in the modern society have facilitated the survival of mankind in the present, modern ages. However, the health consequences of introducing electricity into the society are poorly studied. Studies of artificial light and non-ionizing radiation are generally low priorities on the agenda of public health organizations, and the reported existing data indicate that there are several unanswered questions to whether humans are negatively affected in electrified environments. This article discusses the potential aspects of the impact of electricity on human health and brain function and introduces a hypothesis. The article furthermore discusses the disturbance of sleep patterns caused by electrified environments, and the increasing absence of natural stimuli to the human brain causing chronic 'digital stress' facilitating pathophysiological development. A significant need to study adverse health effects from non-ionizing radiation and synthetic luminous environments from an environmental toxicological perspective is definitely urged.

Keywords: Electromagnetic radiation; Mobile phone radiation; Toxicity; Effects; Adverse; Health; Theory; Faraday

1. Introduction

Long before any knowledge of electricity existed people were aware of shocks from electric fish. Ancient Egyptian texts dating from 2750 BC referred to these fish as the "Thunderer of the Nile". Ancient cultures around the Mediterranean knew that objects, such as rods of amber, could be rubbed with cat's fur to attract light objects like feathers.

Electricity would remain little more than an intellectual curiosity for millennia until 1600, when the English scientist William Gilbert made a careful study of electricity and magnetism. He coined the New Latin word *electricus* ("of amber" or "like amber", from ἤλεκτρον [*elektron*], the Greek word for "amber") to refer to the property of attracting small objects after being rubbed. This association gave rise to the English words "electric" and "electricity", which made their first appearance in print in Thomas Browne's *Pseudodoxia Epidemica* of 1646. Benjamin Franklin conducted extensive research in electricity, selling his possessions to fund his work. In 1752 he is reputed to have attached a metal key to the bottom of a dampened kite string and flown the kite in a storm-threatened sky. A succession of sparks jumping from the key to the back of the hand showed that lightning was indeed electrical in nature.

In 1791, Luigi Galvani published his discovery of bioelectricity, in which the legs of dead frogs were shown to twitch on application of animal electricity, demonstrating that electricity was the medium by which nerve cells passed signals to the muscles. The recognition of electromagnetism, the unity of electric and magnetic phenomena, is due to Hans Christian Ørsted and André-Marie Ampère in 1819–1820. Through such people as Nikola Tesla, Michael Faraday, Thomas Edison, Ottó Bláthy, Ànyos Jedlik, Sir Charles Parsons, George Westinghouse, Ernst Werner von Siemens, Alexander Graham Bell and Lord Kelvin, electricity was turned from a scientific curiosity into an essential tool for modern life, becoming a driving force for the Second Industrial Revolution.

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The implementation of electricity into our society started fully toward the end of the 19th century, and was soon spread out through Europe and USA as a central medium for sustaining pivotal life functions of the society. The popular culture of the time accordingly often depicts it as a mysterious, quasi-magical force that can slay the living, revive the dead or otherwise bend the laws of nature!

With the inventions from Nikola Tesla, Thomas Edison, Lord Kelvin, Alessandro Volta, Luigi Galvani, and many others, the electrification of society became possible through the use of electrical engines, the electrical telegraph and the supply of electricity to households. Meanwhile society has grown exponentially in the 20th century – and continues to grow in the 21th century – and electricity has supplied it for its necessary needs. The implementation of electricity has gradually made it possible to use radio, TV, and various other media, which has been crucial for the emergence of yet novel technologies.

With the further implementation of electricity, the microchip, which is a highly dense electrical circuit, was invented in the early 1960s and grew gradually into becoming the central component that would be applied to drive the high-technological era. This era started fully in the 1980s, with its preparation in the 1970s when the microchip went through major transformations in engineering feats and design. These revolutions in design triggered the ingenuity of many major corporations, including Apple and Microsoft, to begin their travel into "serving society" with revolutionary inventions, the computer and the operating systems. With the condensation of high-speed electronics into computers, the development went even further, where cybernetics experienced a break-through in the last years with hybrid systems where computers communicates with neurons through the brain-computer interface (neuron-chip interface) [1]. This gradual evolvement and implementation of electricity from the 18th century's Luigi Galvani into communication with biosystems have, however, a dark side which has been poorly discussed and evaluated in modern medicine and health science.

In Sweden, already when the new electricity was introduced on a larger scale at the end of the 19th century, certain persons actually started to claim adverse health effects. Anecdotal reports are early found indicating the presence of the functional impairment electrohypersensitivity. This was further strengthened by the introduction of amateur DX radio. One of the first scientific studies to attract serious health interest came in 1979 following the work of epidemiologist Nancy Wertheimer, who was looking for possible causes for a number of childhood leukemia cases in the Denver metropolitan area. Her research, performed with physicist Ed Leeper, found that children with leukemia were more than twice as likely to have lived in homes near high current power lines, where the electromagnetic fields were stronger.

In "Historical evidence that the electrification caused the 20th century epidemic of diseases of civilization", Dr Milham introduces a number of very interesting hypotheses on the connection between electricity and life-style diseases which will be further discussed here [2]. Studies from the US show a statistical correlation between the emergence of childhood leukemia mortality (at age 2–4) in the US in the 1930s and the spread of residential electrification. The data furthermore show a 49% higher cancer rate for urban areas as compared to rural ones. Both urban and rural cancer rates where lower for low electrification states [2]. Additional findings reveal that rates of coronary disease are 49% higher in US urban areas, and that all cancers are 21% higher for urban cases. Diabetes has a 66% higher rate in urban areas in US [2]. A second and interesting aspect is that the suicide prevalence peaks to a 30% higher level for electrified urban areas compared to non-electrified rural areas [2]. Of course, a number of possible confounders should not be overlooked, but for the sake of the argument, below we will concentrate on the possibility that electrification is, at least, one of the factors behind these differences.

2. A hypothesis

If electricity was the sole factor and prime stimulus to the "civilization epidemic", as described by Dr Milham [2], then the tendency of increased disease rates in electrified parts can be correlated to, among very many, two hypothesized aspects: (1) the lack and reduced level of sleep as a result of increased stimulus to amygdala activity in the human brain by increased presence of electricity and artificial light in the society or/and (2) the lack of the positive effects of natural acoustic and visionary impulses exerted from nature on the individual, which are replaced by significant levels of environmental noise and auditory distractions from the surroundings, such as those present in cities [3].

The first point, if proven, builds on the way the human body reacts to sleep, where the brains ability to reduce amygdala stress signals is observed [4]. The reduction of amygdala stress affects the release of corticosteroid hormones, which restores bodily homeostasis and normalize brain processing in the aftermath of stress from the daily activities [5]. If stress, however, still increases as a time-/dose-dependent factor in urbanized electrified environments, the effects of stress on the sleep patterns become negative [6], and the beneficiary effect of sleep – such as increased neocortex plasticity and increased learning abilities – on brain function is reduced [7]. Once the brain function is reduced and homeostasis imbalanced, negative effects on the appetite, digestion, disturbances of cholesterol levels in the blood and depression often results [8,9]. Depression becomes quickly a source of chronic stress and affects the stress-reactive hypothalamic-pituitary–adrenal (HPA) axis [10]. This negative response from lack of sleep to depression has, in its turn, effects on the levels of basal cortisol [11].

In this way, sleep problems may affect health significantly. The effects from sleep problems are in turn observed on melatonin levels amongst other factors, and given its role on sleep

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[12] the reported findings between electrified environments and melatonin levels and sleep quality find support in several studies of the detrimental causes of electrified environments on sleep [13–20]. A study from 2001 showed that melatonin levels in women living near power lines were lower than melatonin levels in women living away from any power lines [12]. Melatonin is a central component in circadian rhythms and the deficient/disturbed expression of it is also reported to be potentially involved in carcinogenesis and reproduction problems [13–15]. Three other studies recently report on the existence of a sensitive response in humans to various electromagnetic fields, and how this can be affected and in turn modulate estrogen and melatonin metabolites in women who live near radio and television broadcasting transmitters. The same effect on melatonin metabolism has been observed from cellular phones, thus delineating a connection between brain function, electromagnetic fields and biochemical and neurochemical responses [21–23].

The fashion in which these artificially triggered signals affect the body is a potential source of biochemical imbalance, given the non-linearity of the brain in its reaction to electromagnetic field impulses [24]. The non-linear EEG-activation was first introduced by Marino and co-workers [24] who showed that a magnetosensory reaction mechanism is activated by the brain upon exposure to magnetic fields. Upon interaction with the neurochemical system, the magnetosensory mechanism may thus introduce a series of stress impulses and thus contribute or represent the main cause to the neurochemical imbalances mentioned [21–23], as also showed in a recent very interesting study by Finnish scientists [25].

The mechanisms of electrified environments on melatonin levels may therefore hereby introduce the theory on that the negative effects from electrified environments are primarily an electromagnetic disturbance on brain function and interneuronal communication affecting sleep and other neurochemical responses. The first point of interest is founded on that the brain operates at a particular frequency during sleep [7]. Given that the brain's interneuronal communication is exerted through bioelectric signals, the effects of the degree of radiation on neuron communication can be hypothesized through the Faraday cage principle [26].

The Faraday cage principle states that the Faraday cage blocks external electromagnetic fields from redistributing the electrical charges inside the cage's interior [26]. Analogously, *but with poor if not absent Faraday cage properties*, the skull acts as a cage to the brains electric activities but without insulating the brains electrical properties from exterior electromagnetic fields. The exterior's electromagnetic properties affect therefore, in contrast to the Faraday cage principle, the internal electrical charge distribution among neurons to a very significant extent. The Faraday cage principle, being absent in the case of the skull, may be the central aspect to disturbance of neurochemical responses such in the cases observed near high-power lines and in other situations within significantly electrified environments [2,12,19–36]. This is observed in that the autonomous properties of interneuronal communication are originally primarily dependent on the individuals' health and condition and that these result in a highly individual pattern of neuronal activity.

In the case of electrification, these individual interneuronal communication patterns are potentially affected by external electromagnetic signals altering neurochemical responses, such as altering melatonin levels. The postulated alteration of the charge distribution explained by the Faraday cage principle, which in it's turn affects the brains neurochemical patterns, may therefore during long-term exposure affect the signaling system from the brain to the body via the autonomic nervous system (ANS), giving rise to complications at the physiological level such as diabetes [27], biological effects of adverse nature [27,28], and in turn be the foundation of the patterns of childhood leukemia observed in various studies [30–33]. These very mechanisms may be accounted through a more frequent generation of reactive nitrogen and oxygen species which through its generation from electromagnetic fields induces mutations and affecting cell cycle mechanisms [34].

Nevertheless, in an attempt to elucidate the possible effects posed by electricity on human health [2,19–37], the level of intensity of the radiation may naturally be of central importance. However, the *time-dependent exposure* to the weak radiation from electrified environments may be even more important. These points can be clarified either through long cohort studies, genetic studies of several generations or through highly detailed molecular studies, where the possible effects of electromagnetic radiation on e.g. the brain are quantified. Conclusively, for the first point postulated, the connection between electrified surroundings, sleep activity and brain sensitivity, related to endocrine and psychological effects and health impacts, lacks more data to be proven. A series of investigations in this field is therefore strongly encouraged, particularly when just very recently, Sonmez et al. [28] found even a decrease in Purkinje cell number in the adult female rat cerebellum following exposure to 900 MHz electromagnetic field pointing, in addition, to effects on balance, coordination and motor activity in addition to the reported effects of electromagnetic fields [19–37].

3. Environmental impulses, electrified environments and artificial light

From a historical and evolutionary perspective, man-made electromagnetic fields are very significantly different from the natural background ones which the brain was naturally evolved in, from the earlier ages before electrification. The background radiation levels are synthetically increased by human activities through electrification, electrification, digitalization, and so forth (see Fig. 1) and do introduce immediate altered physical surroundings for the brain's evolutionary development/adaptation. The effects of the introduction of a different background electromagnetic

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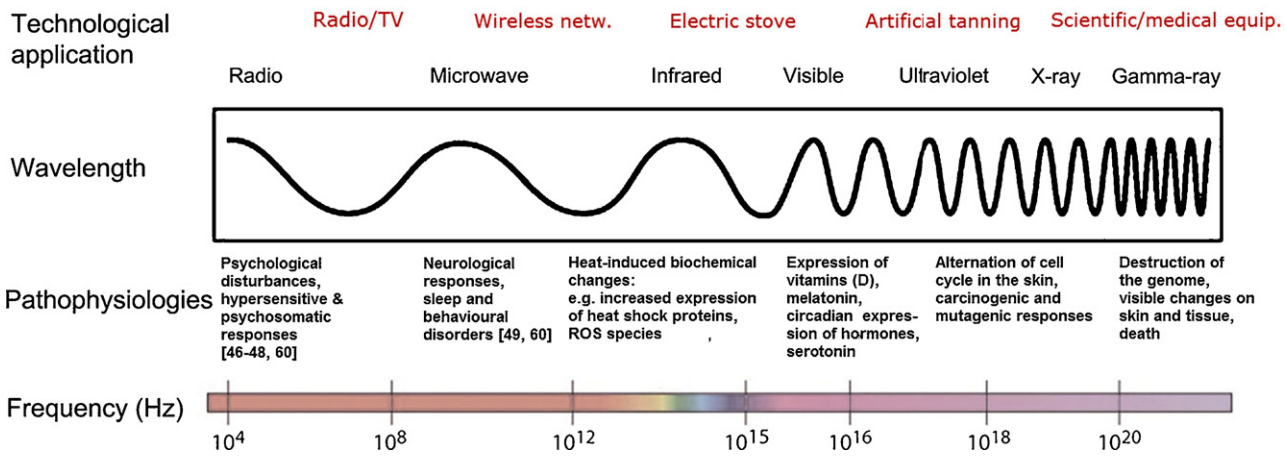

Fig. 1. A pattern of reaction chart (POR). The POR shows the relationship between electromagnetic field frequencies and type of stress/damage induced on the physiome (i.e. the description of an individual's functional behavior). Sub-classifications not shown in the figure are for instance: Electromagnetic fields at 1–3 Hz are known to affect heart electric signal and cardiac function [59]. Effects from electromagnetic field frequencies on brain function are also sub-classified in responses upon awake or sleep state. Further damage and stress induced by electromagnetic fields at other frequencies are reported in the figure.

base for brain development and function may therefore be discussed further based on the observations posed by Dr Milham [2], but from a different angle, i.e. point two in the earlier paragraph: interneuronal communication.

The second point with relevance to the electrification of society is more subtle and less identifiable than the first. Based on the presumption that electricity and electromagnetic fields *are* the primary cause for psychological and medical disorders such as reported [2,19–37], the correlation may be to a lack of natural impulses in the daily activities in urban and electrified surroundings and the impact of artificial light [38–44]. The lack of natural impulses may be argued to be pleasant, or not, based on the subject experiencing it, however natural (or near-natural) environments are the prime destination choices for holidays and relaxation purposes. Of particular interest is that peaceful impulses and philosophies are used to relieve and calm traumatized and dying patients [45]. This interesting aspect of such a tranquillizing effect on the brain by sources from natural surroundings may be related to reduction of amygdala stress (cf. above) and the undisturbed circadian expression of melatonin. Amygdala stress has also interestingly recently been connected to systemic inflammation [46], and correlates well with mouse studies which show inflammatory stress and DNA damage on mice exposed to electromagnetic fields from transmission lines [47].

To discuss the inverse of this point, environmental disturbance and noise affects increasingly the prefrontal cortex [3], and the presence of artificial light has been demonstrated to affect negatively breeding habits of birds [39], and to be involved with the incidence of cancer [40–44]. The second possibility of a correlation between the electrified civilization and emergence as well as increase, respectively, of diseases relies therefore on aspects of research that relate habits, life styles and health, and may also be difficult to examine without prolonged studies on various groups exposed to different environments. As a second point to the theory, research in this field is also required, and the statistics presented [2,19–44] remain still to be debated.

4. Psychological disorders

Related to the neurochemical disturbances mentioned above, the psychological disorders induced by electromagnetic fields may be even more ubiquitous and difficult to show, particularly those which blend with minute aspects of human evolution (decades of detrimental activities which show no immediate or intangible effects on the populations, but post-dose effects in the subsequent generations). There has thus been a series of attempts to depict the negative psychological effects by electromagnetic fields. The phenomenon on psychological disorders induced by radiation was investigated by a German group of scientists recently [48]. In their study, Thomas and colleagues demonstrated a statistically significant effect from electromagnetic radiation from wireless and mobile telephone networks on the behavior of adolescents and children. There were 1498 children and 1524 adolescents in the experimental group, which were tested using a SDQ (Strengths and Difficulties Questionnaire). The results showed that adolescents were more prone to behavioral problems as affected by mobile telephone frequencies GSM 900, GSM 1800, Universal Mobile Telecommunication System (UMTS 2100), Digital Enhanced Cordless Telecommunications (DECT) and Wireless Local Area Network (WLAN 2400) frequencies (Fig. 1). Seven percent of the adolescents showed behavioral problems, while 5% of the children. The results related the observed effect from the dosed exposure to the radiation applied at controlled intervals, and among possible explanations, the still developing nervous system in adolescent and the effect on it by radiation was postulated. Also in the children group, the sensitivity of the nervous system to radiation was mentioned, as also earlier

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reported [49,50] and the effects were also behavioral disorders. The cognitive system seems on the short-term not to be affected according to a study [51], however the opposite was documented in another study [52] and explained by the modulating effect of mobile phone radiation on the response patterns in human brain activity [53]. Furthermore this may be connected to that preparatory slow-brain potentials have been documented to be affected by electromagnetic fields with particular emphasis on the temporo-parieto-occipital brain regions, but not on the frontal one [54]. This may partly be the explanation to that no significant effects where observed in another study, regarding electromagnetic field effects on human brain activity and sleep variables [55]. Correlated with the findings from Johansson et al. [56], the cognitive character of electrohypersensitive individuals can therefore play a pivotal role in explaining the disagreements between studies. In the study by Johansson et al. the electrohypersensitive persons reacted more intensively to the effects by radiation, thereby accounting for the differences. In the study by Johansson et al. the emotional aspects following exposure to radiation were also reported, where depression, anxiety and exhaustion were reported for a group tested on exposure to electromagnetic radiation. In this study, the electrohypersensitive individuals reacted indeed more intensively to electromagnetic fields. Similarly to the investigation by Thomas et al. [48], sleep disturbances, tiredness, stress, anxiety and concentration difficulties were also reported in a study performed by a Swedish group among a group of adolescents [57]. Yet convincing, a study by Huber et al. demonstrated that electromagnetic fields including signals from mobile telephone networks do alter the cerebral blood flow and sleep and waking EEG [58].

The observed mechanisms of reaction to radiation may be summarized in a pattern of reaction (POR) where the frequency of radiation may be associated with types of pathology. In the POR we postulate that a dose-dependent response to radiation may be summarized as follows (see Fig. 1).

5. Perspectives and conclusions

The historical perspective of our society and civilization presents certain interesting clues. It is known from the middle ages that the human sleeping pattern was quite different than today's modernized society, when it was common to retire earlier in the evening and rising earlier in the morning, and, for people in the far north, hibernating in the winter and working long hours in the summer, assumingly given the absence of artificial light as also observed recently [61]. From a public health point of view, maybe it was a pity that Thomas Alva Edison did invent the light bulb?

Even more interestingly, in the modern society, with the increasing presence of electrical tools and increase of media in households through internet, cellular telephones, entertainment tools and other gadgets, the sleeping disorders observed in society [62–64] may be connected to the overwhelming levels of impulses to the still old-fashioned human brain. However, still just as a hypothesis, the evolution of diseases – such as those presented after the electrification of the society [2,19–36] – brings artificial light and non-ionizing radiation from electrified surroundings onto the public health research agenda, and definitely should be investigated more.

Ultimately, and of equal interest, the development of "civilization diseases" vs. electrification should also be included in the study of society's health, given that most evidence-based medicine is conducted on short time-frames using mice and rats, or cohort studies focusing on the exposure to more tangible pollutants such as air and water pollution. Since the relation between population density and development of diseases already is on the agenda [39,65] the exposure to man-made electromagnetic sources should be more rigorously considered. Living in unnatural radiation backgrounds may imprint damage on health on a longer time scale, and may be of high relevance to modern medical science. However uncertain, the relation between radiation and disease, the consequences of studying all aspects related to large populations may therefore aid in the search for better therapeutic alternatives, not only restricted to medical solutions but also to activities and re-orientation of negative habits in the modern society. *Thus, to step back may be to step forward*!

This article has discussed the need to investigate public health focusing on environmental toxicological aspects of man-made electromagnetic fields in order to understand better the interaction between the human body and artificial background radiation. The potential of such an approach is to aid public health research programs to generate better public safety routines as well as general public health knowledge.

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References

[1] J. Clausen, Man, machine and in between, Nature 457 (2009) 1080.
[2] S. Milham, Historical evidence that electrification cause the 20th century epidemic of "diseases of civilization", Medical Hypotheses 74 (2009) 337–345.
[3] T. Falk, M. Guirgis, S. Power, T. Chau, Taking NIRS-BCIs outside the lab: towards achieving robustness against environment noise, IEEE Transactions on Neural Systems and Rehabilitation Engineering 19 (2) (2011) 136–146.
[4] A.V. Kalinchuk, R.W. McCarley, T. Porkka-Heiskanen, R. Basheer, Sleep deprivation triggers inducible nitric oxide-dependent nitric oxide

production in wake-active basal forebrain neurons, Journal of Neuroscience 30 (2010) 13254–13264.
[5] M.J. Henckens, G.A. van Wingen, M. Joëls, G. Fernández, Time-dependent effects of corticosteroids on human amygdala processing, Journal of Neuroscience 22 (30) (2010) 12725–12732.
[6] P. Hegde, K. Singh, S. Chaplot, B.S. Shankaranarayana Rao, S. Chattarji, B.M. Kutty, T.R. Laxmi, Stress-induced changes in sleep and associated neuronal activity in rat hippocampus and amygdala, Neuroscience 153 (2008) 20–30.
[7] J.E. Gangwisch, D. Malaspina, L.A. Babiss, M.G. Opler, K. Posner, S. Shen, J.B. Turner, G.K. Zammit, H.N. Ginsberg, Short sleep duration as a risk factor for hypercholesterolemia: analyses of the National Longitudinal Study of Adolescent Health, Sleep 33 (2010) 956–961.
[8] H. Miyamoto, H. Katagiri, T. Hensch, Experience-dependent slow-wave sleep development, Nature Neuroscience 6 (2003) 553–554.
[9] A. Steiger, M. Kimura, Wake and sleep EEG provide biomarkers in depression, Journal of Psychiatric Research 44 (2010) 242–252.
[10] L.C. Solberg, N. Ahmadiyeh, A.E. Baum, M.H. Vitaterna, J.S. Takahashi, F.W. Turek, E.E. Redei, Depressive-like behavior and stress reactivity are independent traits in a Wistar Kyoto × Fisher 344 cross, Molecular Psychiatry 8 (2003) 423–433.
[11] P.W. Gold, M.L. Wong, G.P. Chrousos, J. Licinio, Stress system abnormalities in melancholic and atypical depression: molecular, pathophysiological, and therapeutic implications, Molecular Psychiatry 1 (1996) 257–264.
[12] J. Barchas, F. DaCosta, S. Spector, Acute pharmacology of melatonin, Nature 214 (1967) 919–920.
[13] P. Levallois, M. Dumont, Y. Touitou, S. Gingras, B. Mâsse, D. Gauvin, E. Kröger, M. Bourdages, P. Douville, Effects of electric and magnetic fields from high-power lines on female urinary excretion of 6-sulfatoxymelatonin, American Journal of Epidemiology 154 (2001) 601–609.
[14] D.E. Blask, Systemic, cellular, and molecular aspects of melatonin-action on experimental breast carcinogenis, in: R.G. Stevens, B.W. Wilson, L.E. Anderson (Eds.), The Melatonin Hypothesis: Breast Cancer and Use of Electric Power, Battelle Press, Columbus, OH, 1997, pp. 189–230.
[15] R.J. Reiter, Melatonin and human reproduction, Annals of Medicine 30 (1998) 103–108.
[16] A. Compte, R. Reig, V.F. Descalzo, M.A. Harvey, G.D. Puccini, M.V. Sanchez-Vives, Spontaneous high-frequency (10–80 Hz) oscillations during up states in the cerebral cortex in vitro, Journal of Neuroscience 8 (2008) 13828–13844.
[17] L. Sher, The effects of natural and man-made electromagnetic fields on mood and behavior: the role of sleep disturbances, Medical Hypotheses 54 (2000) 630–633.
[18] A.A. Borbély, R. Huber, T. Graf, B. Fuchs, E. Gallmann, P. Achermann, Pulsed high-frequency electromagnetic field affects human sleep and sleep electroencephalogram, Neuroscience Letters 275 (1999) 207–210.
[19] S.P. Loughran, A.W. Wood, J.M. Barton, R.J. Croft, B. Thompson, C. Stough, The effect of electromagnetic fields emitted by mobile phones on human sleep, Neuroreport 16 (2002) 1973–1976.
[20] C.Y. Li, P.C. Chen, F.C. Sung, R.S. Lin, Residential exposure to power frequency magnetic field and sleep disorders among women in an urban community of northern Taiwan, Sleep 25 (2002) 428–432.
[21] S. Carrubba, C. Frilot, F.X. Hart, A.L. Chesson, A.A. Marino, The electric field is a sufficient physical determinant of the human magnetic sense, International Journal of Radiation Biology 85 (7) (2009) 622–632.
[22] M.L. Clark, J.B. Burch, M.G. Yost, Y. Zhai, A.M. Bachand, C.T. Fitzpatrick, J. Ramaprasad, L.A. Cragin, J.S. Reif, Biomonitoring of estrogen and melatonin metabolites among women residing near radio and television broadcasting transmitters, Journal of Occupational and Environmental Medicine 49 (2007) 1149–1156.
[23] J.B. Burch, J.S. Reif, C.W. Noonan, T. Ichinose, A.M. Bachand, T.L. Koleber, M.G. Yost, Melatonin metabolite excretion among cellular telephone users, International Journal of Radiation Biology 78 (2002) 1029–1036.
[24] S. Carrubba, C. Frilot, A.L. Chesson, A.A. Marino, Nonlinear EEG activation evoked by low-strength low-frequency magnetic fields, Neuroscience Letters 417 (2007) 212–216.
[25] T. Lipping, M. Rorarius, V. Jäntti, K. Annala, A. Mennander, R. Ferenets, T. Toivonen, T. Toivo, A. Värri, L. Korpinen, Using the nonlinear control of anaesthesia-induced hypersensitivity of EEG at burst suppression level to test the effects of radiofrequency radiation on brain function, Nonlinear Biomedical Physics 3 (1) (2009) 5 Jul 18.
[26] Faraday Cage, http://en.wikipedia.org/wiki/Faraday_cage.
[27] M. Havas, Dirty electricity elevates blood sugar among electrically sensitive diabetics and may explain brittle diabetes, Electromagnetic Biology and Medicine 27 (2008) 135–146.
[28] O.F. Sonmez, E. Odaci, O. Bas, S. Kaplan, Purkinje cell number decreases in the adult female rat cerebellum following exposure to 900 MHz electromagnetic field, Brain Research 14 (1356) (2010) 95–101.
[29] M.A. Navakatikian, I.A. Tomaschevskaya, Phasic behaviour of endocrine effects of microwaves of nonthermal intensity, in: D.O. Carpenter (Ed.), Biological Effects of Magnetic Fields, vol. 1, Academic Press, San Diego, CA, 1994, pp. 333–342.
[30] Assessment of health effects from exposure to power-line frequency electric and magnetic fields, in: C.J. Portier, M.S. Wolfe (Eds.), National Institute of Environmental Health Sciences Working Group Report of the National Instates of Health, No. 98-3981, NIH Publication, Research Triangle Park, NC, 1998, p. 508.
[31] A.B. Miller, T. To, D.A. Agnew, C. Wall, L.M. Green, Leukemia following occupational exposure to 60 Hz electric and magnetic fields among Ontario electricity utility workers, American Journal of Epidemiology 144 (1996) 150–160.
[32] A. Ahlbom, N. Day, M. Feychting, E. Roman, J. Skinner, J. Dockerty, M. Linet, M. McBride, J. Michaelis, J.H. Olsen, T. Tynes, P.K. Verkasalo, A pooled analysis of magnetic fields and childhood leukaemia, British Journal of Cancer 83 (2000) 692–698.
[33] S. Milham, L.L. Morgan, A new electromagnetic exposure metric: high frequency voltage transients associated with increased cancer incidence in teachers in a California school, American Journal of Industrial Medicine 51 (2008) 579–586.
[34] H. Okano, Effects of static magnetic fields in biology: role of free radicals, Frontiers in Bioscience 13 (2008) 6106–6125.
[35] M. Havas, A. Olstad, Power quality affects teacher wellbeing and student behavior in three Minnesota Schools, Science of the Total Environment 402 (September (2–3)) (2008) 157–162.
[36] M. Havas, Electromagnetic hypersensitivity: biological effects of dirty electricity with emphasis on diabetes and multiple sclerosis, Electromagnetic Biology and Medicine 25 (4) (2006) 259–268.
[37] M. Havas, Intensity of electric and magnetic fields from power lines within the business district of 60 Ontario communities, Science of the Total Environment 298 (October (1–3)) (2002) 183–206.
[38] B. Kempenaers, P. Borgström, P. Loës, E. Schlicht, M. Valcu, Artificial night lighting affects dawn song, extra-pair siring success, and lay date in songbirds, Current Biology 20 (2010) 1735–1739.
[39] C. Rich, T. Longcore (Eds.), Ecological Consequences of Artificial Night Lighting, Island Press, Washington, DC, 2006.
[40] R.G. Stevens, Working against our endogenous circadian clock: breast cancer and electric lighting in the modern world, Mutation Research 680 (2009) 106–108 (Review).
[41] R.G. Stevens, Light-at-night, circadian disruption and breast cancer: assessment of existing evidence, International Journal of Epidemiology 38 (2009) 963–970.
[42] R. Chepesiuk, Missing the dark: health effects of light pollution, Environmental Health Perspectives 117 (2009) A20–A27.
[43] I. Kloog, A. Haim, R.G. Stevens, B.A. Portnov, Global co-distribution of light at night (LAN) and cancers of prostate, colon, and lung in men, Chronobiology International 26 (2009) 108–125.

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[44] R.J. Reiter, D.X. Tan, A. Korkmaz, T.C. Erren, C. Piekarski, H. Tamura, L.C. Manchester, Light at night, chronodisruption, melatonin suppression, and cancer risk: a review, Critical Reviews in Oncogenesis 13 (2007) 303–328.

[45] W. Kongsuwan, K. Keller, T. Touhy, S. Schoenhofer, Thai Buddhist intensive care unit nurses' perspective of a peaceful death: an empirical study, International Journal of Palliative Nursing 16 (2010) 241–247.

[46] H. Engler, R. Doenlen, A. Engler, C. Riether, G. Prager, M.B. Niemi, G. Pacheco-López, U. Krügel, M. Schedlowski, Acute amygdaloid response to systemic inflammation, Brain, Behavior, and Immunity 25 (2011) 1384–1392.

[47] B.M. Svedenstål, K.J. Johanson, M.O. Mattsson, L.E. Paulsson, DNA damage, cell kinetics and ODC activities studied in CBA mice exposed to electromagnetic fields generated by transmission lines, In Vivo 13 (1999) 507–513.

[48] S. Thomas, S. Heinrich, R. von Kries, K. Radon, Exposure to radio-frequency electromagnetic fields and behavioural problems in Bavarian children and adolescents, European Journal of Epidemiology 25 (2010) 135–141.

[49] L. Kheifets, M. Repacholi, R. Saunders, E. van Deventer, The sensitivity of children to electromagnetic fields, Pediatrics 116 (2005) e303–e313.

[50] N. Leitgeb, Mobile phones: are children at higher risk? Wiener Medizinische Wochenschrift 158 (2008) 36–41.

[51] C. Haarala, M. Bergman, M. Laine, A. Revensuo, M. Koivisto, H. Hämäläinen, Electromagnetic field emitted by 902 MHz mobile phones shows no effects on children's cognitive function, Bioelectromagnetics 7 (2005) 144–150.

[52] N. Edelstyn, A. Oldershaw, The acute effects of exposure to the electromagnetic field emitted by mobile phones on human attention, Neuroreport 13 (2002) 119–121.

[53] C. Eulitz, P. Ullsperger, G. Freude, T. Elbert, Mobile phones modulate response patterns of human brain activity, Neuroreport 9 (14) (1998) 3229–3232.

[54] G. Freude, P. Ullsperger, S. Eggert, I. Ruppe, Effects of microwaves emitted by cellular phones on human slow brain potentials, Bioelectromagnetics 19 (1998) 384–387.

[55] D.L. Hamblin, A.W. Wood, Effects of mobile phone emissions on human brain activity and sleep variables, International Journal of Radiation Biology 78 (8) (2002) 659–669.

[56] A. Johansson, S. Nordin, M. Heiden, M. Sandström, Symptoms, personality traits, and stress in people with mobile phone-related symptoms and electromagnetic hypersensitivity, Journal of Psychosomatic Research 68 (2010) 37–45.

[57] F. Söderqvist, M. Carlberg, L. Hardell, Use of wireless telephones and self-reported health symptoms: a population-based study among Swedish adolescents aged 15–19 years, Environmental Health 7 (2008) 18.

[58] P. Huber, V. Treyer, A.A. Borbely, J. Schudere, J.M. Gottselig, H.P. Landolt, E. Werth, T. Berthold, N. Kuster, A. Buck, P. Achermann, Electromagnetic fields, such as those from mobile phones, alter regional cerebral blood flow and sleep and waking EEG, Journal of Sleep Research 11 (4) (2002) 289–295.

[59] P. Paredi, S.A. Kharitonov, T. Hanazawa, P.J. Barnes, Local vasodilator response to mobile phones, Laryngoscope 111 (2001) 159–162.

[60] N. Leitgeb, J. Schröttner, R. Cech, Perception of ELF electromagnetic fields: excitation thresholds and inter-individual variability, Health Physics 92 (6) (2007) 591–595.

[61] C.A. Peixoto, A.G. da Silva, M.A. Carskadon, F.M. Louzada, Adolescents living in homes without electric lighting have earlier sleep times, Behavioral Sleep Medicine 7 (2009) 73–80.

[62] D. Bluestein, C.M. Rutledge, A.C. Healey, Psychosocial correlates of insomnia severity in primary care, Journal of American Board Family Medicine 23 (2010) 204–211.

[63] R. Santos-Silva, L.R. Bittencourt, M.L. Pires, M.T. de Mello, J.A. Taddei, A.A. Benedito-Silva, C. Pompeia, S. Tufik, Increasing trends of sleep complaints in the city of Sao Paulo, Brazil, Sleep Medicine 11 (2010) 520–524.

[64] A. Lowden, T. Akerstedt, M. Ingre, C. Wiholm, L. Hillert, N. Kuster, J.P. Nilsson, B. Arnetz, Sleep after mobile phone exposure in subjects with mobile phone-related symptoms, Bioelectromagnetics 32 (2011) 4–14.

[65] H.L. Howe, J.E. Keller, M. Lehnherr, The relation of population density and cancer incidence. Illinois 1986–1990, American Journal of Epidemiology 138 (1993) 29–36.

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