CELL PHONES AND THE BRAIN

by John D. MacArthur © 2000

John D. MacArthur is a freelance writer (www.getwrite.com) specializing in neuroscience. In 2001, The Franklin Institute Science Museum commissioned him to research and write a comprehensive online section about the human brain (www.fi.edu/brain).

This article was published in the July 2002 issue of the ***Townsend Letter for Doctors & Patients.***

During the past century, electricity has become the driving force of civilization, yet much mystery still surrounds this primal energy. We don't really know to what extent biological processes are influenced by the electromagnetic fields that emanate from everything electrical -- especially the long-term effects on our extraordinarily complex and sensitive brains.

The most immediate concern involves the safety of cellular (mobile) telephones. Conflicting studies and conflicts of interest have led to considerable controversy, but some progress toward a realistic analysis of cell phone safety was finally made with the publication of a major British report -- the most thorough yet undertaken.

Adopting an evidence-based approach, the government-appointed Independent Expert Group on Mobile Phones conducted "a rigorous assessment of existing research." For eight months the panel of 12 scientists consulted widely and heard evidence from experts, members of the public, representatives of government, interest groups, and the industry. On May 11, 2000, the Expert Group presented its report on Mobile Phones and Health. (1) Key findings include:

"First, the balance of the evidence available does not suggest that RF [radiofrequency] radiation from mobile phones or base stations causes cancer or other disease. However, there is now evidence that effects on biological functions, including those of the brain, may be induced by RF radiation at levels comparable to those associated with the use of mobile phones. There is, as yet, no evidence that these biological effects constitute a health hazard but at present only limited data are available.

"We conclude therefore that it is not possible at present to say that exposure to RF radiation, even at levels below national guidelines, is totally without potential adverse health effects.

"We recommend that a precautionary approach to the use of mobile phone technologies be adopted until much more detailed and scientifically robust information on any health effects becomes available . . . These should include the following: effects on brain function, consequences of exposures to pulsed signals, . . . the possible impact on health of sub-cellular and cellular changes induced by RF radiation . . .

"Children may be more vulnerable because of their developing nervous system, the greater absorption of energy in the tissues of the head, and a longer lifetime of exposure . . . We believe that the widespread use of mobile phones by children for non-essential calls should be discouraged."

Cellular Safety

In order to establish a basis for any discussion about the health effects of electromagnetic fields, especially those produced by cell phones, this comprehensive report explores fundamental information about how electricity is known to affect biological processes at the cellular level. Evidence is reviewed here showing that electromagnetic fields can increase free radicals, activate the stress response, and alter enzyme reactions.

Important new findings about the electrical nature of the brain and DNA are discussed. Also mentioned are several recent studies that may represent pieces to the neurodegeneration puzzle.

Current safety guidelines for cell phones assume no harmful effects as long as the microwave radiation they emit does not cause heating of body tissue. Exposure limits are intended to protect us only from excessive temperatures caused by absorption of energy -- a known danger linked to the intensity of radiofrequency microwaves.

But intensity and temperature are not the only considerations. Living cells also respond in non-thermal ways to the low frequency magnetic fields produced by cell phones. Consequently, bioeffects can occur at intensities well below the established safety threshold. Much of the new research is now focusing on these subtler cellular effects.

HOW ELECTRICITY AFFECTS BIOLOGY

Electromagnetic Fields and Free Radicals

The mechanism by which an external electromagnetic field (EMF) interacts with an internal biological process is thought to be through the action of free radicals. These are highly reactive atoms whose unpaired electrons initiate chemical chain reactions that damage cells.

At its most fundamental level, biology is physics. During all biochemical reactions, bonds between atoms are constantly breaking and reforming. The atoms in a chemical bond share a pair of electrons whose opposite spins create a magnetic attraction. When a chemical bond breaks, each atom reclaims its electron and briefly becomes a free radical -- until it pairs up with another atomic partner whose electron has an opposite spin.

The magnetic field component of an external EMF can delay this "recombination rate" of free radical pairs. In other words, magnetic fields cause radicals to stay free longer. Although measured in nanoseconds, this extra time gives them the potential to do more damage.

Ongoing research by a team of chemists at the University of Ottawa has shown that magnetic fields increase the average concentration of free radicals, lengthen their lifetime, and enhance the probability of radical reactions with cellular components. (2)

Although free radicals are a normal part of metabolism and play a vital role in many biochemical processes, the body must keep them under control. An increase in free radicals can affect various cellular and physiological processes, including gene expression, release of calcium from intracellular storage sites, cell growth, and cell death. The actual effects, however, can vary from individual to individual and may depend on one's nutritional status and the availability of dietary antioxidants.

Antioxidants

Because free radicals cause oxidation reactions which damage cells, the body removes them with antioxidants, molecules that readily donate their electrons to neutralize free radicals. These include potent antioxidant enzymes manufactured in the body, as well as vital antioxidants obtained from food.

A major study involving 3,385 Japanese-American men from the Honolulu-Asia Aging Study reinforces the value of antioxidants for the brain. Elderly men who took both vitamin C and E supplements had an 88% reduction in the frequency of vascular dementia, compared with men who

did not take the supplements. The protective effect was substantially greater in men who reported long-term use of both vitamins.

Regarding the mechanism of the protective effect, Dr. Kamal H. Masaki, of the Honolulu Heart Program, and co-authors say that the study results support "hypothesized roles for cellular and molecular oxidative injury in the pathogenesis of brain aging and neurodegenerative diseases, including Alzheimer's dementia and Parkinson's dementia, and vascular dementia." (3)

EMFs and DNA

Several studies by Henry Lai and Narendra Singh at the University of Washington's Bioelectromagnetics Research Laboratory have shed new light on the biological effects of electromagnetic fields. DNA damage (single- and double-strand breaks) was observed in the brain cells of rats exposed for two hours to a 60 Hz (cycles per second) magnetic field -- the kind generated by household electric currents. This same type of DNA damage also occurred after a two-hour exposure to radiofrequency microwaves at power levels considered safe.

The researchers then found that this EMF-induced DNA damage could be blocked by treating the rats with antioxidants, including melatonin, immediately before and after exposure. Melatonin is a hormone secreted from the brain's pineal gland. As a potent antioxidant, it effectively eliminates free radicals inside cells -- suggesting that free radicals may play a role in the genetic damage caused by magnetic fields. (4,5)

The effect of radiofrequency radiation on DNA could conceivably be more significant on neurons than on other cell types, because these nerve cells have a low capability for DNA repair, says Dr. Lai. "Since nerve cells do not divide and are not likely to become cancerous, more likely consequences of DNA damage in nerve cells are changes in functions and cell death, which could either lead to or accelerate the development of neurodegenerative diseases." (Glial cells, however, can become cancerous. These more numerous brain cells protect and support neurons.) (6)

Dr. Lai cautions against applying the existing research results to evaluate the possible health effects of normal cell phone usage. While "it is difficult to deny that radiofrequency at low intensity can affect the nervous system," he says the data available suggest a complex reaction. Other parameters of exposure, "such as frequency, duration, waveform, frequency- and amplitude-modulation, etc., are important determinants of biological responses." More research is needed, but since not much is known on the biological effects of cell phones, "prudent usage should be taken as a logical guideline."(6)

Melatonin Matters

The chemical neurotransmitter dopamine is uniquely vulnerable to free radical damage. Many researchers believe that some diseases of aging -- most notably, Parkinson's disease -- are associated with the loss of dopamine-using neurons. Lorraine Iacovitti, Ph.D., showed in animal experiments that melatonin was effective in blocking the oxidative damage to these brain cells. Her results indicate "melatonin possesses the remarkable ability to rescue dopamine neurons from cell death in several experimental paradigms associated with oxidative stress." (7)

Past research has demonstrated a correlation between EMFs and decreased levels of melatonin in the body, but results have been inconsistent. Numerous factors are involved, including one's natural melatonin levels and the length of exposure. A recent study suggests there may be a"cumulative effect of magnetic field exposure on the stability of individual melatonin measurements over time." (8)

EMFs are characterized by many variables, such as the orientation of the magnetic field and its polarity. In a study of electric utility workers, Dr. Jim Burch of Colorado State University has shown that certain EMF environments have a greater effect on melatonin levels. The key difference may be the polarization of the magnetic field.(9) Burch's preliminary results agree with a series of animal studies by Dr. Masamichi Kato at Hokkaido University School of Medicine, Sapporo, Japan. (10)

DNA Conducts Electricity

Swiss scientists at the University of Basel reported in March 1999 that DNA conducts electricity as well as a good semiconductor. A few months later, a research team from the Georgia Institute of Technology actually observed the complicated process by which an electrical charge moves through DNA.

"It's not at all like a conductor or a wire," said lead author Dr. Gary B. Schuster. He compared the charge transport mechanism to the movement of a Slinky, the large spring used as a toy. When an electrical charge is injected into DNA, the DNA responds by changing its structure to pairs. This creates a local distortion that, just like the compression in a Slinky, can move in the DNA.

The charge transfer stops when it encounters a specific pairing of two chemical bases (guanine), where it then oxidizes the guanine and causes strand breaks that can lead to genetic mutations. (11)

Normally, DNA is capable of efficiently repairing itself. Through a homeostatic mechanism, cells maintain a delicate balance between spontaneous and induced DNA damage. By causing an increase in free radicals, however, EMFs may alter this balance.

Cell Division Errors and Aging

A study published in the March 31, 2000 edition of Science indicates that the source of many, if not all illnesses of aging, may be due to gradual genetic changes. Lead researcher Danith Ly, Ph.D., theorized that genes go awry because they are damaged by free radicals.

"This study suggests that aging is really a disease of quality control. In this case the manufactured product is a new cell," says co-author Richard A. Lerner, M.D., president of The Scripps Research Institute. While the research is not conclusive, Lerner says the process begins slowly in middle age and gradually accelerates as we get older. In tissues throughout the body, an increase in cell division errors leads to altered gene expression which causes the loss of tissue function -- culminating in the diseases and conditions associated with human aging. (12)

In 1999, Swedish researchers exposed mice to EMFs generated by actual outdoor electric transmission power lines (220 kV). After 32 days of exposure, a highly significant change was observed in the animals' brain cells. The researchers said their "data indicate that transmission lines of this type may induce genotoxic effects in mice, seen as changes in the DNA migration."(13)

Heat Shock

The Scripps study also revealed links to specific age-related disorders. In Alzheimer's disease, there was evidence for the overexpression of a small protein associated with heat shock. Other studies have confirmed the presence of alpha B-crystallin and other heat shock proteins in the brains of patients with Alzheimer's as well as in those with Parkinson's disease. Furthermore, the myelin-producing cells (oligodendrocytes) were among those most affected. (14-17)

Swedish researchers at the University of Goteborg have shown an association between Alzheimer's disease and altered lipid composition in myelin, indicating that demyelination is a primary event in late-onset form Alzheimer's disease. (18-19)

In a significant new study titled "Cell biology: Non-thermal heat-shock response to microwaves," worms were continuously exposed to microwave radiation of the sort emitted by cell phones. The researchers showed "that prolonged exposure to low-intensity microwave fields can induce heat-shock responses in the soil nematode Caenorhabditis elegans. This effect appears to be non-thermal, suggesting that current exposure limits set for microwave equipment may need to be reconsidered." (20)

Keeping brain cells from overheating is one of the bloodstream's functions. Blood not only delivers oxygen, glucose, and nutrients, and removes toxins; it also cools the brain. An efficient cerebral vascular system enabled the evolution of intelligence, and healthy blood vessels continue to be necessary for proper cognitive function -- and for protection against neurodegenerative diseases -- especially since both "epidemiologic and pathologic observations suggest that vascular factors may contribute to the development of Alzheimer's disease." (21)

The summer 1999 heat wave in the Midwest revealed another piece to the neurological health puzzle. The U.S. Centers for Disease Control found that psychiatric medicines could make the mentally ill especially vulnerable to death from intense summer heat. This is because antidepressants that target the brain can interfere with the body's thermoregulatory system. (22)

Heat Stress from EMFs

To protect body tissue from being overheated, the Federal Communications Commission (FCC) has set the maximum allowed "specific absorption rate" (SAR) from cell phones at 1.6 W/Kg (watts per kilogram). This is partial-body exposure, as averaged over one gram of tissue. The whole-body threshold is 0.08 W/Kg.

This thermal threshold is itself problematical, because it is based on the body's ability to maintain homeostasis during heating from the radiofrequency radiation. But even if the body's thermoregulatory mechanism succeeds in distributing the heat and maintaining the temperature at the pre-irradiation value, a certain stress still develops.

A pioneer in the bioeffects of electromagnetic fields, Robert O. Becker, M.D., emphasizes the role of EMFs in producing stress. In his landmark 1990 book, Cross Currents: The Perils of Electropollution; The Promise of Electromedicine, he points out that exposure to any abnormal electromagnetic field produces a stress response. After prolonged exposure, the body's stress response system can be exhausted and the immune system compromised. In such a state, animals and humans could become more susceptible to cancer and infectious diseases.

Dr. Becker refers to experiments conducted in the early 1980s by the U.S. Air Force School of Aerospace Medicine that were reported in the September 1986 issue of Scientific American. Test animals were continuously exposed for long periods to microwaves at a power density twenty times lower than the safe thermal level. They developed a fourfold increase in cancers of the pituitary, thyroid, and adrenal glands -- the primary organs through which the body mediates stress.

The cellular stress response is a protective mechanism that enables cells to survive. It is activated by a wide variety of environmental stimuli, such as high temperature, oxygen starvation, and heavy metals, as well as EMFs. Cells essentially perceive man-made electromagnetic fields as potentially harmful.

Thermal vs. Non-Thermal Stress Response
Ongoing research by Columbia University scientists Reba Goodman and Martin Blank has focused on how EMFs cause stress in cells. They found that the "cellular response to low frequency magnetic fields is activated by unusually weak stimuli, and involves pathways only partially associated with heat shock stress." (23)

To provide a more realistic basis for new cell phone safety standards, Goodman and Blank have recently focused on the bioeffects of radiofrequency radiation. They discovered remarkable similarities in the biological responses to both the low and the high frequency fields emanating from cell phones. What's more, preliminary results showed that "the energy required to induce stress proteins with low frequency EM fields is 14 orders of magnitude lower than required by temperature increase." (24)

Not only did they find it possible to differentiate between thermal and non-thermal stress, but the stress proteins induced by low frequency served as "biomarkers" to monitor the early stages of the cellular stress reaction to EMFs -- prior to activation by increased temperature. They believe this will make it is possible to establish a lower, more accurate safety threshold for cell phones and towers.

Electromagnetic Fields and Enzymes
Another pathway by which living organisms are influenced by radiofrequency radiation in a non-thermal way may be through an alteration in the activity of important enzymes. A well-studied example is ornithine decarboxylase (ODC), an enzyme involved in the regulation of cell growth. High ODC activity is characteristic of the unregulated growth of tumor cells, and ODC activity has been shown to be sensitive to both extremely low frequency magnetic fields and to radiofrequency fields. (25,26)

Scientists are learning more and more about intracellular communication pathways. Signals originating at the cell membrane initiate a production sequence of enzyme "cascades" within the cell. These signaling pathways are proving to be sensitive to weak EMFs. (27,28)

In his summary of "Cell and Molecular Biology Associated with Radiation Fields of Mobile Telephones," longtime EMF researcher Dr. W. Ross Adey writes: "Microwave bioeffects at the cellular level support concepts of athermal responses not mediated by tissue heating. A spectrum of these biological responses show dependence on ELF amplitude- or pulse-modulation of the imposed fields. Cell membranes have been identified as the site of transduction of many of these responses, with initiation of enzyme cascades that chemically couple cell surface radiofrequency signals to intracellular systems, including some that reach cell nuclei and regulate processes of cell growth and division." (29)

Programmed-Cell-Death
Dr. Adey also points to evidence that suggests these same enzyme cascades have probable continuing roles in programmed-cell-death (apoptosis), in the promotional phase of tumor formation, and in the pathophysiology of certain neurodegenerative diseases such as Parkinson's and Alzheimer's.

In the process of programmed-cell-death, caspase enzymes are unleashed to destroy cells that are abnormal or are no longer needed. In Lou Gehrig's disease (ALS), scientists believe the process of caspase-mediated apoptosis is misdirected and begins to destroy neurons. (30)

Researchers at Howard Hughes Medical Institute and at Harvard Medical School have identified an enzyme that may be involved in the pathogenesis of Alzheimer's disease. Calpain, a calcium-dependent cysteine protease, appears to be a common mechanistic link between the death of primary cortical neurons and known causes of neurotoxic damage, including oxidative stress, excitotoxic chemicals, and oxygen starvation. (31)

Enzymes and Free Radicals
Reduced activity of a key mitochondrial enzyme complex has been observed in the brains of patients with Alzheimer's disease. Neuroscientists at Cornell University think a reduction in alpha-ketoglutarate dehydrogenase complex (KGDHC) may be responsible for the decreases in brain metabolism characteristic of many neurodegenerative disorders. Their research suggests "KGDHC participates in a deleterious cascade of events related to oxidative stress that are critical in selective neuronal loss in neurodegenerative diseases." (32,33)

Much of this intracellular signaling is mediated by free radicals. Like so many processes, enzyme kinetics re also affected by radical pair recombination rates. Research conducted at Stanford University's Department of Radiation Oncology suggests that although a magnetic field may induce only a very small change in radical pair recombination rate, "the effect on the enzyme reaction rate is considerably larger, for example, by a factor of 1 to 100." (34)

Related research by chemists at the University of Utah found that a decrease in the activity of a vitamin B12-dependent enzyme was likely caused by an applied magnetic field which changed the behavior of free radical pairs. (35)

OUR ELECTRICAL BRAIN AND ENVIRONMENT

Inhibitory Neurons Use Electrical Connections
Until very recently it was thought that neurons can communicate only by using chemical neurotransmitters that travel across the gaps (synapses) between them. In 1999, Brown University researchers discovered a network of inhibitory neurons able to communicate directly with one another through electrical connections -- a previously unknown type of brain circuitry.

According to neuroscience professor Barry Connors, electrical synapses may allow these neurons to generate activity over a large area of the brain. They may be acting as the brain's "pacemaker" by creating some of the brain's rhythmic electrical activity, which can be measured by an electroencephalogram (EEG).

Inhibitory neurons prevent the brain from quickly spinning out of control into hyperexcited states. Their malfunction is involved in autism and ADHD, as well as in memory disorders, neural trauma, and addictions. They also play a role in a wide range of psychiatric conditions, such as depression, obsessive-compulsive disorders, and schizophrenia.

This electric neural network is especially suited to regulating higher brain functions, explains Connors. "Most of the time it is not doing anything, but it becomes active when the brain's activity increases to a high level . . . and may act like the governor on the engine of the cortex, keeping excitability from running away and becoming an epileptic seizure." (36)

Researchers at Israel's Weizmann Institute of Science recently discovered that inhibitory neurons are far more diverse than previously thought and have an extremely sophisticated system of controlling other neurons. They build complex synaptic connections onto thousands of neighboring

neurons. These synapses then act as fast-switching "if-then" filtering gates which allow inhibition to be selectively applied -- at the exact millisecond and to the right degree. This allows a small group of inhibitory neurons to simultaneously give personal attention to the activity of each of the neurons to which they are connected. (37)

Electrical Rhythms in the Thalamus

Another newly recognized electrical aspect of the brain involves the thalamus, a crucial region that helps filter sensory information from the environment. As a communication hub, the thalamus plays a central role in the brain's ability to perceive, interpret, and respond.

Dr. Rodolfo Llinas, a professor of physiology at New York University School of Medicine, has demonstrated that the frequency of brain's electrical system is slower in the thalamus during sleep and much higher when a person is awake. He observed that patients suffering from Parkinson's disease had low frequency oscillations in their brain patterns when awake, instead of the usual high frequency ones. Part of the thalamus' intricate network seemed to be still asleep, causing havoc in the brain's perception of the internal and external environments.

At the October 1999 Society for Neuroscience meeting, Llinas suggested that these abnormal rhythms may be a common thread underlying Parkinson's disease, depression, epilepsy, obsessive-compulsive disorder, chronic pain, and tinnitis. (38)

Our Electromagnetic Environment

From fertilization to final heartbeat, we are electrical beings. Death is even defined as the end of electrical activity in the brain. We have evolved within a narrow range of physical parameters (temperature, pressure, gravity), but more than any other aspect of nature we have altered our electromagnetic environment -- immersing ourselves in a sea of man-made EMFs that only a century ago were unknown to life.

Only now are we beginning to realize how a small increase in global temperature can have complex consequences. We know even less about the true repercussions of the unnatural electromagnetic radiation we are creating. This revolutionary modification of a fundamental aspect of life is untested for long-term safety. Furthermore, epidemiological effects of EMFs are difficult to measure, because few control groups exist. (It's interesting to note that the Amish population has a lower prevalence of dementia.). (39)

Despite industry assurances of safety, an increasing number of scientists and citizens are insisting on caution -- the precautionary principle of prudent avoidance -- until we know much more about the bioeffects of EMFs, especially those associated with cell phones and transmission towers.

Cell Phone Legislation

"It is inappropriate that critical health and safety studies lag behind the vast expansion of cellular telephone marketing." This is the rationale for a new consumer-oriented cellular telephone bill -- the first such legislation in the United States -- introduced by California Senator Tom Hayden in February 2000.

"We think this bill makes a lot of sense," says the executive director of the National Brain Tumor Foundation. "It's just a precautionary measure." Opposing the bill is the Cellular Carriers Association of California, which says the industry was "continuing to look at everything possible to make sure the service was safe."

The editor of *Microwave News*, Louis Slesin, Ph.D., disagrees, noting that spending on safety research has been ridiculously small. "After all, when a device is pumping radiofrequency/microwave energy into a complex electrical system like the brain, it would seem natural to ask if it changes the way that system works. Instead, no cognitive studies of mobile phones were done until the last couple of years, and none has ever been done in the United States." (40)

In May 2000 SB 1699 was approved by the California Senate. If it becomes law, it will require the State Department of Health Services to conduct a review of existing research concerning the health effects of cellular telephones and to report its findings to the Legislature by July 1, 2001. This bill would also require the Director of Health Services to advise the Legislature regarding the need for additional research and legislative action regarding the use of cellular telephones. (41)

Transmission Towers

The most contentious issue surrounding cell phones is the safety of long-term, low-dose irradiation from their transmission towers. People throughout the world are expressing their opposition to the presence of these techno-monuments in their neighborhood. Often it's simply because the towers are ugly and their flashing red lights are annoying. But that's just the tip of the iceberg: what we can see.

Unfortunately, our five senses cannot perceive the bulk of the iceberg: invisible radiation from transmitters atop the towers. Our exquisitely sensitive brains probably can, though, and are capable of responding to wireless radiation in subtle yet significant ways.

The Scottish Parliament's Transport and the Environment Committee reviewed research into the health effects associated with wireless radiation. They listened to the concerns of communities and individuals across Scotland, as well as reviewed testimonies submitted from other parts of England and the world.

In March 2000, the committee recommended that all telecommunication towers, including cell phone transmission towers, should be required to apply for planning permissions, and local authorities should adopt a precautionary approach:

"Based on the evidence received, the Committee considers that there is reasonable doubt about the health risks and recommends that health should be viewed as a material planning consideration and a precautionary approach should be adopted at a national level allowing for local flexibility. The Committee considers that areas such as schools, nurseries, hospitals, and residential areas may be considered sensitive for environmental health reasons." (42)

The Salzburg Resolution

In Austria, on June 7-8, 2000, experts from around the world gathered at a conference on "Cell Tower Siting: Linking Science & Public Health," which was organized on behalf of the government of the federal state of Salzburg. According the Salzburg Resolution on Mobile Telecommunication Base Stations:

"Presently the assessment of biological effects of exposures from base stations in the low-dose range is difficult but indispensable for protection of public health. There is at present evidence of no threshold for adverse health effects.

"Recommendations of specific exposure limits are prone to considerable uncertainties and should be considered preliminary. For the total of all high-frequency irradiation a limit value of 100 mW/m2 (10 µW/cm2) is recommended.

"For preventive public health protection a preliminary guideline level for the sum total of all emissions from ELF pulse modulated high-frequency exposure facilities, such as GSM base stations, of 1 mW/m2 (0.1 µW/cm2) is recommended." 43 [milliwatts per square meter (microwatts per square centimeter)].

Commentary

Cell phones have many functional benefits and despite their downside are likely to be with us for a long time (as the internal partial-combustion engine has been). In the author's opinion, however, they are well on their way to becoming the "cigarettes" of this century. Already banned in some restaurants because of the annoying secondhand sound waves emanating from their users, cell phones may eventually be shunned for much more compelling reasons -- as the bioeffects of their microwaves are better understood.

The way cell phones are practically given away is reminiscent of how cigarettes were introduced into new markets. Eventually, phones too will probably have to carry warning labels that escalate in severity over the years. And, few people will be surprised if it's ultimately revealed that the telecommunications industry knew more about the negative effects of cell phone usage than they let on.

Today, we view classic films with a mixture of amusement and amazement as movie stars constantly smoke cigarettes in the most inappropriate situations, from baby rooms to bomb shelters. In the future, when we look back at today's media celebration of cell phones, will we cringe at the sight of people holding these powerful electronic devices to their brains?

References

1. The British Expert Group report on Mobile Phones and Health (http://www.iegmp.org.uk/IEGMPtxt.htm)

2. Scaiano JC, Cozens FL, McLean J, Model for the rationalization of magnetic field effects in vivo. Application of the radical-pair mechanism to biological systems.Photochem Photobiol 1994 Jun;59(6):585-89.

3. Masaki KM, et al., Vitamins E and C protect against dementia, cognitive decline in elderly men. Neurology 2000;54:1265-72.

4. Lai H, Singh NP, Melatonin and N-tert-butyl-alpha-phenylnitrone block 60-Hz magnetic field-induced DNA single and double strand breaks in rat brain cells. J Pineal Res 1997 Apr;22(3):152-62.

5. Lai H, Singh NP, Melatonin and a spin-trap compound block radiofrequency electromagnetic radiation-induced DNA strand breaks in rat brain cells. Bioelectromagnetics 1997;18:446-54.

6. Lai H, Neurological effects of radiofrequency electromagnetic radiation, Mobile Phones and Health, Symposium, October 25-28, 1998, University of Vienna, Austria. (http://www.emfguru.com/Research/dr-henry.html)

7. Iacovitti L, Stull ND, Johnston K, Melatonin rescues dopamine neurons from cell death in tissue culture models of oxidative stress. Brain Res 1997 Sep 12;768(1-2):317-26.

8. Graham C, Cook MR, Sastre A, Riffle DW, Gerkovich MM, Multi-night exposure to 60 Hz magnetic fields: effects on melatonin and its enzymatic metabolite. J Pineal Res 2000 Jan;28(1):1-8.

9. Burch JB, Reif JS, Noonan CW, Yost MG, Melatonin metabolite levels in workers exposed to 60-Hz magnetic fields: work in substations and with 3-phase conductors. J Occup Environ Med 2000 Feb;42(2):136-42.

10. Kato M, Honma K, Shigemitsu T, Shiga Y, Circularly polarized 50-Hz magnetic field exposure reduces pineal gland and blood melatonin concentrations of Long-Evans rats. Neurosci Lett 1994 Jan 17;166(1):59-62.

11. Henderson PT, Jones D, Hampikian G, Kan Y, Schuster GB, Long-distance charge transport in duplex DNA: the phonon-assisted polaron-like hopping mechanism. Proc Natl Acad Sci U S A 1999 Jul 20;96(15):8353-58.

12. Ly D, Lockhart D, Lerner R, Schultz P, Mitotic misregulation and human aging. Science 2000 Mar 31;287(5462):2486-92.

13. Svedenstal BM, Johanson KJ, Mattsson MO, Paulsson LE, DNA damage, cell kinetics and ODC activities studied in CBA mice exposed to electromagnetic fields generated by transmission lines. In Vivo 1999 Nov-Dec;13(6):507-13.

14. Renkawek K, Stege GJ, Bosman GJ, Dementia, gliosis and expression of the small heat shock proteins hsp27 and alpha B-crystallin in Parkinson's disease. Neuroreport 1999 Aug 2;10(11):2273-76.

15. Renkawek K, Voorter CE, Bosman GJ, van Workum FP, de Jong WW, Expression of alpha B-crystallin in Alzheimer's disease. Acta Neuropathol (Berl) 1994;87(2):155-60.

16. Shinohara H, Inaguma Y, Goto S, Inagaki T, Kato K, Alpha B crystallin and HSP28 are enhanced in the cerebral cortex of patients with Alzheimer's disease. J Neurol Sci 1993 Nov;119(2):203-8.

17. Lowe J, Errington DR, Lennox G, Pike I, Spendlove I, Landon M, Mayer RJ, Ballooned neurons in several neurodegenerative diseases and stroke contain alpha B crystallin. Neuropathol Appl Neurobiol 1992 Aug;18(4):341-50.

18. Wallin A, Gottfries CG, Karlsson I, Svennerholm L, Decreased myelin lipids in Alzheimer's disease and vascular dementia. Acta Neurol Scand 1989 Oct;80(4):319-23.

19. Svennerholm L, Gottfries CG, Membrane lipids, selectively diminished in Alzheimer brains, suggest synapse loss as a primary event in early-onset form (type I) and demyelination in late-onset form (type II). J Neurochem 1994 Mar;62(3):1039-47.

20. de Pomerai D, Daniells C, David H, Allan J, Duce I, Mutwakil M, Thomas D, Sewell P, Tattersall J, Jones D, Candido P, Cell biology: Non-thermal heat-shock response to microwaves. Nature 405:6785 (2000) 417-18.

21. Di Iorio A, Zito M, Lupinetti M, Abate G, Are vascular factors involved in Alzheimer's disease? Facts and theories. Aging (Milano) 1999 Dec;11(6):345-52.

22. Heat Deaths Linked To Medications. Cox News Service, April 17, 2000.

23. Blank M, Goodman R, Electromagnetic fields may act directly on DNA. J Cell Biochem 1999 Dec 1;75(3):369-74.

24. Goodman R, Blank, M, Biologically based safety standards for cell phones: discriminating between heat and magnetic fields. Radiofrequencies and Modulations Applied in Wireless Communication: Biological Effects and Safety Concerns, Bioelectromagnetic Society workshop, February 4, 2000.

25. Byus CV, Pieper SE, Adey WR, The effects of low-energy 60-Hz environmental electromagnetic fields upon the growth-related enzyme ornithine decarboxylase. Carcinogenesis 1987 Oct;8(10):1385-89.

26. Byus CV, Kartun K, Pieper S, Adey WR, Increased ornithine decarboxylase activity in cultured cells exposed to low energy modulated microwave fields and phorbol ester tumor promoters. Cancer Res 1988 Aug 1;48(15):4222-26.

27. Engstrom S, Fitzsimmons R, Five hypotheses to examine the nature of magnetic field transduction in biological systems. Bioelectromagnetics 1999 Oct;20(7):423-30.

28. Adey WR, Biological effects of electromagnetic fields. J Cell Biochem 1993 Apr;51(4):410-16.

29. Adey WR, Cell and molecular biology associated with radiation fields of mobile telephones. Bioelectromagnetics Research, University of California, Riverside. (http://www.electric-words.com/adey/adeyoverview2.html)

30. Li M, Ona VO, Guegan C, Chen M, Jackson-Lewis V, Andrews LJ, Olszewski AJ, Stieg PE, Lee JP, Przedborski S, Friedlander RM, Functional role of caspase-1 and caspase-3 in an ALS transgenic mouse model. Science 2000 Apr 14;288(5464):335-39.

31. Lee MS, Kwon YT, Li M, Peng J, Friedlander RM, Tsai LH, Neurotoxicity induces cleavage of p35 to p25 by calpain. Nature 2000 May 18;405(6784):360-64

32. Gibson GE, Park LC, Zhang H, Sorbi S, Calingasan NY, Oxidative stress and a key metabolic enzyme in Alzheimer brains, cultured cells, and an animal model of chronic oxidative deficits. Ann N Y Acad Sci 1999;893:79-94.

33. Gibson GE, Park LC, Sheu KF, Blass JP, Calingasan NY, The alpha-ketoglutarate dehydrogenase complex in neurodegeneration. Neurochem Int 2000 Feb;36(2):97-112.

34. Eichwald C, Walleczek J, Model for magnetic field effects on radical pair recombination in enzyme kinetics. Biophys J 1996 Aug;71(2):623-31.

35. Harkins TT, Grissom CB, Magnetic field effects on B12 ethanolamine ammonia lyase: evidence for a radical mechanism. Science 1994 Feb 18;263(5149):958-60.

36. Gibson JR, Beierlein M, Connors BW, Two networks of electrically coupled inhibitory neurons in neocortex. Nature 1999 Nov 4;402(6757):75-79.

37. Gupta A, Wang Y, Markram H, Organizing principles for a diversity of GABAergic interneurons and synapses in the neocortex. Science 2000 Jan 14;287(5451):273-78.

38. Llinas RR, Ribary U, Jeanmonod D, Kronberg E, Mitra PP, Thalamocortical dysrhythmia: A neurological and neuropsychiatric syndrome characterized by magnetoencephalography. Proc Natl Acad Sci USA 1999 Dec 21;96(26):15222-27.

39. Holder J, Warren AC, Prevalence of Alzheimer's disease and apolipoprotein E allele frequencies in the Old Order Amish. J Neuropsychiatry Clin Neurosci 1998 Winter;10(1):100-12.

40. Slesin L, Dow 10,000 -- Safety Research 0. Microwave News, March/April 2000.

41. Official California Legislative Information, SB 1699 (http://info.sen.ca.gov/cgi-bin/postquery?bill_number=sb_1699&sess=CUR&house=B&site=sen)

42. Scottish Parliament (http://www.scottish.parliament.uk/official_report/cttee/trans-00/trr00-03-01.htm)

43. Salzburg Resolution on Mobile Telecommunication Base Stations, International Conference on Cell Tower Siting: Linking Science & Public Health, Salzburg, Austria, June 7-8, 2000 (http://www.land-sbg.gv.at/celltower)