Journal of Bodywork and Movement Therapies (2005) **9**, 3–15

Journal of
Bodywork and
Movement Therapies

www.intl.elsevierhealth.com/journals/jbmt

ENERGY MEDICINE: OVERVIEW

Energy and the healing response

James L. Oschman*

Nature's Own Research Association, PMB 170, P.O. Box. 5101 827, Central Avenue, Dover, NH 03820 2506, USA

Received 1 August 2003; received in revised form 1 September 2003; accepted 1 September 2003

KEYWORDS
Subtle energy;
Energy medicine;
Healing response;
Homeostasis;
Frequency/power window

Abstract The healing response is the vital means by which an organism marshals its diverse repair strategies in reaction to injury or disease. This article discusses the question of how much energy may be necessary to stimulate or 'jump start' the repair of injuries, or to reverse disease processes. The question obviously is of major clinical importance. Clinical and behavioral research validates the 'less is more' principle of energetic interactions. Convincing evidence came in 1975, when a number of scientists confirmed that extremely weak low frequency electric fields can have significant effects on important regulatory processes in the brain. These findings led to the concept of the power/frequency window, the narrow range of signal properties that will produce a maximum biological effect. This was a turning point in a lingering controversy over beneficial vs harmful environmental field effects on physiology and behavior and the applications of subtle energies in healing.

> Don't use a sledgehammer when a feather will do the job.
> Robert James (2003).

Introduction: the healing response

The healing response is a fundamental and important biological process. It is the vital means by which an organism marshals its diverse repair strategies in reaction to injury or disease. It is a life-saving response for all organisms, from protozoa to *Homo sapiens*. Many medical philosophies, down through the ages, have emphasized the importance of facilitating the body's built-in restorative systems.

> ...injury has...left it's imprint in our tissues, even in our cells, in the form of built-in, life-saving reactions, ready to be triggered at an instant's notice. And myriads of wounds have become stepping stones to one of man's greatest creations—the art of healing (Majno, 1975).

Modern biomedical research is elucidating at least some of the cellular and molecular processes involved in the healing response (Marchesi, 1985; Miyake and McNeil, 2003; Lin and Hopf, 2003). How many more remain to be discovered is an open question. In terms of biology and biomedicine, study of the healing response involves vital topics such as self-organization (Kauffman, 1993), intercommunication (Ho et al., 1994), immunity (Ayala et al., 2003), systems theory

*Tel.: +1-603-742-3789; fax: +1-603-742-4695.
E-mail address: joschman@aol.com (J.L. Oschman).

1360-8592/$ - see front matter © 2003 Elsevier Ltd. All rights reserved.
doi:10.1016/S1360-8592(03)00092-5

(Weinberg, 2001), and the role of consciousness (Ho, 1997). To understand the healing response we obviously need to understand how the healthy body is formed, how it functions, and the nature of conscious experience. And studies of the healing response, in turn, shed light on the origins of structure, function, and consciousness.

Study of the healing response from all perspectives is an urgent topic because the most costly, debilitating, and painful chronic and degenerative diseases occur when the natural healing response is compromised, for whatever reasons. Fortunately progress is taking place in this area, due to advances in both complementary medicine and in clinical research as to the nature of the energetic signals that can 'jump start' the healing process when it has been slowed or stalled, for whatever reasons. New insights in this area have emerged when there is integration, or synthesis, of data and concepts from the best of both conventional and complementary medical theory and practice.

Virtually all medical interventions involve energy of one kind or another. One can categorize clinical methods as "energy medicine" when they involve diagnostic procedures that measure energy fields produced by the body in health and disease. These diagnostic procedures include important methods such as the electrocardiogram, electroencephalogram, electromyogram, electroretinogram, or electropneumogram, and their magnetic counterparts, the magnetocardiogram, magnetoencephalogram, magnetomyogram, magnetoretinogram, or magnetopneumogram, to name just a few. Likewise, many treatments involve application of different forms of energy to the body, such as electricity, magnetism, light, heat, cold or pressure (hands-on). While some may regard this as obvious and trivial, it is becoming apparent that a close look at the energetics involved in *any* clinical procedure can lead to conceptual and practical breakthroughs. So "energy medicine" includes a long-neglected medical perspective, with major implications for patient care.

Every therapist knows that, within limits, the body has remarkable capacities to restore diseased or injured tissues. As documented in Weil's best-selling *Spontaneous Healing*, physicians sometimes observe extremely rapid recoveries from seemingly hopeless injuries or diseases (Weil, 1995). We would obviously like to know how this happens, with the goal of 'reverse engineering' the process, to be able to trigger "spontaneous healing" when it is needed.

Less is, indeed, more

Some practitioners apply greater force in situations or conditions that seem unresponsive to light interventions. 'If what you are doing is not working, push harder' seems to be a widely accepted principle. This applies in medicine, as we treat the most serious diseases, such as cancer, with our most powerful 'weapons,' such as surgery, radiation, and chemotherapy. In contrast, a variety of complementary therapies utilize interventions that are so subtle that skeptics cannot see how any effect can possibly be produced (take Therapeutic touch and homeopathy as examples).

Much evidence suggests that the human body, in its responses to subtle therapeutic interventions, validates the 'small is powerful' or 'less is more' concept, that is the hallmark of various energetic approaches. Basic and clinical research seems to confirm this profound principle (see below). However, much of this research is not widely appreciated, for a variety of reasons.

This article summarizes an appreciation of the energetics of the healing process that emerges from research done some 25 years ago. Since then, a number of important discoveries seem to have been obfuscated by statements that suggest the operation of vested interests. The discovery of the exquisite sensitivity of living matter to energies of all kinds has been overshadowed by unnecessary controversy and confusion.

The historical perspective

This essay is based on both the published literature, as well as on conversations with some of the key players in the inquiry. It is because of these personal contacts that the author can fill in some of the gaps in the story that are not to be found in books and journals. We often forget that others who have not been steeped in this subject for the past 20 years or so may simply not know how the various controversies unfolded, and how widely accepted opinions were found to be erroneous.

This is not a comprehensive review article citing all of the literature on this subject. The intention is to paint with a broad brush, to provide an overview of a multidisciplinary topic. The reader is advised to consult the references at the end of the paper for further details (Oschman, 2003).

A major reason for looking at the question of therapeutic signal intensity from the historical perspective is that there are seemingly convincing statements in the literature, from prominent scientists, that have subsequently been proven to be incorrect. Some of these statements are based on simple and obvious logic that, upon closer examination and testing, has proven to be false. The scholar new to this field of inquiry can therefore become confused without some reference to the history of the subject.

The subject of subtle energy effects has been controversial and confusing because opinions and discussions may have been influenced by political and economic issues that should not be a part of biological and medical research. There are also professional "skeptics" who appear to have the peculiar and disruptive goal of maintaining controversy and confusion. Understanding the subject therefore requires an historical perspective that deals with the sources of the controversies and confusions, as well as with the pressures that sustain them. This article is intended to resolve some of these confusions.

To understand the fundamental discoveries in this field, and their clinical significance, their emergence along several fronts will be followed in chronological order, involving animal behavior, biomedicine, and complementary medicine. In discussing these discoveries certain physical principles and terminology will be referred to with which some readers may not be familiar. An appendix describes the essential concepts, and those who wish to explore this further are urged to review texts on physics and electrical engineering (see Appendix A).

Animal behavior

For centuries, naturalists have noticed behavioral changes in plants and animals that seemed to be correlated with extremely small environmental influences such as variations in electrical, magnetic, and electromagnetic fields, including visible and near visible light. In the older literature the observed sensitivities of organisms were reported in an anecdotal fashion, and seemed improbable to many non-biologists. Some well-documented sensitivities are so mind-boggling that scientists tended to dismiss them as artifacts: errors in experimental design or in data analysis. These sensitivities are much less bewildering to those naturalists who understand that there is a huge evolutionary and survival pressure for sophisticated biosensors, that operate at the limits set by physical considerations such as quantum mechanics. The sensitivities observed by naturalists evolved to enable organisms to find prey, avoid predators, navigate, sense approaching weather patterns, and adjust their activities and metabolism to harmonize with the larger rhythms of nature, such as tides and other diurnal influences. In some parts of the world, the behavior of animals is used to predict earthquakes.

Behavioral responses to the environment are summarized in the introduction to a 1961 book entitled *The Orientation of Animals* by Gottfried S (Fraenkel and Gunn, 1961):

> Generally speaking, the position normally adopted by an animal in relation to its surroundings is not completely haphazard. There is a posture and an orientation which can properly be regarded as normal. We include under the term *orientation* not only those reactions which guide the animal into its normal stance (primary orientations) but also reactions which guide it into its normal habitat, or into other situations which are of importance to it (secondary orientations). Primary orientations provide the basic position from which other reactions start, and they are most commonly concerned with the inclination of the vertical axis of the animal. Secondary orientations are usually not simply concerned with the direction in which the horizontal axis of the body points—as if it were a compass needle, for example—but they involve locomotion. There is a large body of information, gained mainly during the last half century, about both primary and secondary orientations of animals, particularly in relation to the external factors which direct these reactions.

For instance, some animals have a magnetic compass that they use for navigation. The classic example is the homing pigeon, which has a magnetic compass that the bird uses to navigate on cloudy days when the sun is not visible (Keeton, 1971, 1974; Wiltschko and Wiltschko, 1995). Brown (1971) found that mudsnails have a directional sense that has peak sensitivity at approximately the intensity of the magnetic field of the earth. Brown tried to disorient the mudsnails by applying much stronger fields, but there was no effect. His results are shown in Fig. 1 and exemplify the situation found repeatedly by biologists: peak sensitivities coincide with the environmental field strengths that are present in the environment and that are most important to survival.

Understandings of the mechanisms by which biosensors operate have emerged from multidisciplinary biophysical investigations of which many scientists are simply unaware. We shall see that skepticism has given way to acceptance because of careful studies carried out in a variety of species. Credibility has been firmly established by irrefutable data from well-replicated and well-controlled studies.

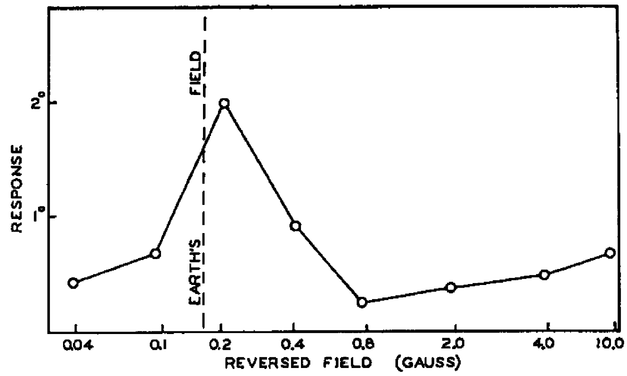

Figure 1 Effects of magnetic fields of various signal strengths on disorienting the paths of mudsnails. The fields were abruptly reversed in six 30-day experiments (Brown, 1971) Reproduced by permission of the New York Academy of Sciences.

Biomedicine

Like many historic controversies, the confusion swirling around the topic of energy medicine had a turning point. Careful research demonstrated that, contrary to widespread belief, very tiny energy fields can have profound clinical significance. A few scientists must be credited with this historic development. Their names are on the publications that will be cited in the next few paragraphs.

An orthopedic surgeon, J. Wolff, noticed over 100 years ago that bones respond to stress by changing their shape. (Stedman's, 1976) Bones are continually remodeling according to loads imposed upon the musculoskeletal system. Robert O. Becker, MD summarizes the situation.

> When a bone is bent, one side is compressed and the other side is stretched. When it's bent consistently in one direction, extra bone grows to shore up the compressed side, and some is absorbed from the stretched side. It's as though a bridge could sense that most of its traffic was in one lane and could put up extra beams and cables on that side while dismantling them from the other. As a result, a tennis player or baseball pitcher has heavier and differently contoured bones in the racket arm or pitching arm, than in the other one (Becker and Selden, 1985).

This discovery answers a profound biomedical/biomechanical question: what is the mechanism that enables a bone (or any other tissue, for that matter) to adjust its structure in relation to the way it is used? It is obvious that such adjustments take place, otherwise training for an athletic or artistic performance would not stimulate the body to change its structure in the most appropriate way to accommodate the desired performance. Wolf's Law provides one of the key mechanisms that couples repeated practice with changes in body structure and function that are essential for peak performance (Stedman's, 1976).

In *The Body Electric*, Becker and Selden (1985) describes what happened when this information was discussed at an orthopedic conference in 1961. Several people came up on the stage to ask Becker questions. One of them was Andrew Bassett, a young orthopedic surgeon who was doing research at Columbia University. This was the beginning of a collaboration that led to a shift in consciousness in terms of the topic of this paper. The outcome of the collaboration between Becker and Bassett was one of the first electromagnetic healing technologies to be incorporated into modern clinical medicine. The first stage in the process was the confirmation of earlier work that showed that passing a current through a bone fracture stimulated repair. The currents were passed through electrodes implanted into the bone on either side of the fracture site. Becker (1967) demonstrated that bone cell function could be altered with implanted electrodes providing a current of $100\,\mu A$–$50\,\mu A/cm^2$.

A key breakthrough was the realization that magnetic fields applied from the outside of the body could induce electric currents within cells and tissues (Manning, 1975). In relation to bone healing, this discovery meant that it was no longer necessary to insert electrodes into the bone itself, in order to pass a current through a fracture site. A comparable current could be magnetically induced to flow through the fracture site using coils placed outside of the skin. That magnetic fields in the environment can induce currents deep within the body has now been well documented by medical researchers using pulsing magnetic field therapy to induce current flows through bone fractures that fail to heal. For example, a 10 V field introduced into a coil of wire adjacent to the body will induce 1 mV/cm or more electric field that can be measured with electrodes inserted into the bone (Rubin et al., 1989).

During the 1980s, further research by Bassett and colleagues led to the acceptance of magnetic field therapies for stimulating the repair of bone fracture non-unions. A comparable breakthrough in pain management was the development of transcutaneous electrical nerve stimulation (TENS) (Shealy et al., 1970). Thus, after half a century of academic neglect, the use of electrotherapies and magnetotherapies began to return to clinical medicine. The inductive method for bone repair is now known to all orthopedic surgeons and has been prescribed by most of them (Bassett, 1995). These developments marked the return of energetic therapies to standard medical care. The subsequent resurgence of interest in energy therapies has taken place with much better theoretical grounding than a century ago, when electric and magnetic therapies were banned for lack of a plausible scientific basis.

Research has revealed the cellular and molecular basis for the effects of currents induced to stimulate healing. And the research on bone healing was gradually extended to other tissues. It was discovered that each type of cell and tissue responds to a particular frequency of stimulation (Siskin and Walker, 1995). One of the first discoveries in this field was that the best results are often obtained with very small inputs of energy—they are 'low field' effects (Rubin et al., 1989).

Neurons as another example

The genesis of the action potential in a neuron is based on the depolarization of the cell membrane. For many years it was accepted that the only important electrical field related to neuronal excitation is a signal capable of depolarizing the 0.070 V/cm electrical field across the cell membrane. A field of some 20 mV is required for this to happen. The very much smaller potentials produced by the spontaneous weak oscillating electric gradients, as seen in the electroencephalogram (EEG), were not considered generally relevant to brain functioning. Hence no functional role was accepted for intrinsic field oscillations in cerebral tissue, although there were hints of relations between EEG patterning and behavioral states. For example, there were indications that action potentials do not explain the intricate operations of the brain in memory, learning, and behavior. Hence, in 1973, the neurophysiologist, Hydén (1973), prophetically began to focus on electric field effects on the microenvironment of proteins:

> Among macromolecules, proteins seem to me to be likely candidates as executive molecules in learning and memory mechanisms: they undergo conformational changes, they have sites for absolute recognition and they can be incorporated in the membranes of nerve cells, synapses, and glia, thereby enabling recognition in a vast number of neurons simultaneously. In addition, because they can react rapidly and significantly to changes in the micro-environment caused by alteration in electric field, they may constitute the mechanism whereby electrical charges are transformed into molecular and cellular effects (Hydén, 1973).

The challenge to neuroscientists is to find ways to measure electrical properties at a much smaller and more subtle scale than nerve impulses. For example:

> Much of the higher activity of the brain eludes detection by conventional electrophysiological methods...remembering, learning, and thinking may be sub-served by phenomena that are electrically silent to those instruments. Memory will be found in giant macromolecular polymers such as proteins, RNA and DNA (Schmitt, 1961).

Complementary medicine

At the same time that energy-based diagnostic and treatment methods were cautiously becoming accepted by physicians, the popularity of a variety of complementary therapies began to increase rapidly. These methods include Acupuncture, Aromatherapy, Jin Shin Jyutsu, Homeopathy, Massage, Cranial Sacral, Healing Touch, Therapeutic Touch, Polarity Therapy, Reiki, Structural Integration, Zero Balancing, and so on. One theory that could explain some of the effects of all of these methods is that the energy field of one person can interact with that of another, producing (or inducing, as we shall see below) specific beneficial energetic signals within a patient. Evidence for such effects is accumulating (reviewed by McCraty et al., 1998).

Most therapeutic schools have pioneers, some of whom continue to develop and improve the effectiveness of their methods. The trend is toward lighter and gentler techniques that produce rapid and profound change. The behavioral observations, the recent acceptance of the therapeutic benefits from low-level energy fields in biomedicine, and the effectiveness of some complementary therapies using mild interventions, support a common theme: living processes are extremely sensitive to energy fields. One explanation is that subtle energy fields in the vicinity of an organism can produce or induce electrical and magnetic fields within the organism, and that these signals have the appropriate characteristics to activate or enhance or suppress cellular and molecular processes. We shall see that direct effects on cell surface receptors, enzymes, and reaction kinetics have been documented. Given the evidence from basic science and clinical practice, one wonders what logical arguments can be used to maintain the controversy and confusion that has surrounded this subject?

A logical but incorrect assumption

It is intuitively obvious, but incorrect, to state that if a very strong field does not affect living processes, then much weaker fields will also have no effect. For example, a way of proving that 50/60 cycle electrical fields from the power grid cannot possibly have harmful effects on humans (such as causing cancer, for example) is to place rats in a cage that is electrified with a high voltage 60-cycle field. It has been repeatedly demonstrated that the rats can survive in such a situation, and reproduce over several generations. The obvious but erroneous conclusion: 60 cycle fields cannot have biological effects.

A quote from an article (Farley, 2003) using this kind of logic: "The magnetic fields from power lines are rather small. Typically they are about 2 mG. By comparison, the earth's field is typically 300–500 mG, with the exact value depending on the location on the surface of the earth. Magnetic fields from power lines are therefore hundreds of times smaller than the magnetic field from the earth. If the relatively weak magnetic fields from power lines had significant adverse health effects, you would expect the much stronger magnetic field from earth to be devastating. Yet no such effect has ever been found. In experiments on animals, mice have lived for several generations in 60 Hz magnetic fields as high as 10,000 mG, thousands of times higher than typical power line fields, without any adverse effects."

Brown's experiments (see Fig. 1), and many others that have followed, prove the fallacy of this logic. Organisms, and the cells and molecules they are composed of, are more sensitive to tiny fields than they are to strong fields. This sensitivity has arisen during evolution as part of survival mechanisms used to locate food, identify predators, and navigate. Moreover, organisms "tune-in" to the subtle variations in the earth's field to set their biological clocks (e.g. Gauguelin, 1974; Wever, 1974). The intensity of the variation of the earth's field is far lower than the larger field that causes the compass needle to point towards the North Pole. These important but subtle variations, and the biosensors that monitor them, are interfered with by various man-made electrical and electronic technologies.

Table 1 lists some of the remarkable sensitivities animals have that have been documented in well-controlled studies. Box 1, from the work of Showalter (2003) documents some of the biological sensitivities found in birds.

The confusion and controversy around the issue of sensitivity to energy fields has been costly in terms of the public health. The obfuscation extends far beyond the controversy about overhead power lines and cell phones. For half a century, potentially valuable diagnostic and treatment methods, employing low energy levels, were overlooked or dismissed. The academic atmosphere did not encourage scientists who could pursue research in this direction.

Physicists have been skeptical

The sensitivities observed by naturalists have been regarded with suspicion by physicists. There is no

Table 1 Electrical fields in various systems ($1\,\mu V = 10^{-6}\,V$).

Resting cell membrane potential	15,000 V/cm
Brain wave oscillations—extracellular	0.001–0.01 V/cm
Brain wave oscillations—cellular dimensions	0.000001 V/cm
Human and bird circadian rhythms	0.025 V/cm
Time perception in monkeys	0.07 V/cm
Weak electric fish	0.000002 V/cm
Escape response of sharks and rays	0.000001 V/cm
Eyelid response in sharks	0.0000001 V/cm
Slowing of heartbeat in rays	0.00000001 V/cm
Other responses of marine vertebrates	0.000000001 V/cm

For references, see Adey and Bawin (1977).

Box 1

It has been demonstrated that birds rely on several different cues—visual landmarks, geomagnetic field, solar compass, skylight polarization pattern/stars, and olfaction—for their orientation and navigation across vast stretches of land and sea.

Schlicte and Schmidt-Koenig (1972) fitted well-trained homing pigeons with frosted contact lenses that limited image formation beyond 3 m. The blind birds flew over 170 km directly back to their lofts. Of course some crashed into the loft and some missed the loft altogether!

Emmlen, (1969) took Adelie Penguins from their coastal breeding rookeries to interior Antarctica and released them. On cloudy days the penguins wandered about randomly. However, when the sun was shining they headed north-northeast towards the coast, compensating for the sun's counterclockwise movement in the Southern Hemisphere by correcting their orientation $15^\circ\,h^{-1}$ clockwise relative to the sun's position. By the way the sun changes continuously by $15^\circ\,h^{-1}$.

Sauer and Sauer (1960) demonstrated the use of stars for navigation by birds. By caging Garden Warblers in a Planetarium, the Sauers showed birds oriented north in the "spring" and south in the "fall" under simulated night skies. When the stars were turned off in the Planetarium, the birds became disoriented. When the Sauers rotated the north–south axis of the planetarium 180° the warblers also reversed their compass headings.

Merkel and Wiltschko (1965) showed European Robins could orient in solid steel cages without celestial cues. They also demonstrated that the robins reversed their orientation when the magnetic field imposed on the cage was reversed.

Continuing the magnetism work, Keeton (1971) demonstrated that free flying homing pigeons wearing bar magnets often did not orient properly on cloudy days vs. control pigeons wearing brass bars. Keeton concluded that the pigeons use the sun preferentially to the earth's magnetic field on sunny days.

Walcott and Green (1974) fitted homing pigeons with electric caps that produced a magnetic field through the bird's heads. Under overcast skies, reversing the field's direction by reversing the current in the cap caused free-flying pigeons to fly in the direction opposite their original course.

From Birds in the Classroom, by Chris Showalter, http://fsc.fernbank.edu/birding/classroom/htm.

question that physics has a deep understanding of electrical and magnetic forces. Using established physical laws (see Appendix A) and making some simplifying assumptions, the physicist can predict the currents that will be induced in conductive components of living tissues by an energy source a known distance away. On the basis of these calculated energy flows, physicists make statements as to how these currents may affect, or not affect, the body. This is where the problems arise.

Organisms, and the molecules they are composed of, must be contrasted with the behavior of the non-living matter that is commonly studied in the physics laboratory. Many physicists and electrical engineers have given "expert" statements and testimony on this subject, particularly in relation to the controversy over the health effects of power lines, household electricity, and cell phones (for example: Adair, 1991; Campion, 1997; Day, 1999; Macklis, 1993; National Research Council, 1997; Linet et al., 1997). Various "blue-ribbon panels" and skeptical groups have used such testimony to influence public policy. Some interests would like to see a complete halt to research on the health effects of environmental fields.

For an understanding of the ways living matter is affected by energy fields we must rely on multidisciplinary research in biophysics. We shall see that it is the biophysicists who have the clearest perspective on this subject.

There are at least three basic problems with the physics/electrical engineering approach. First, physicists do know a lot about the behavior of electric and magnetic fields in a physics laboratory. Bring a living organism into the picture, however, and their calculations, and particularly the conclusions they draw from them, no longer apply. For example, physicists have determined that the signals induced within tissues are very much smaller than the random noise produced by thermal vibrations and endogenous biological rhythms. The problem is that physics treats conductive tissues as though they are metallic wires. Molecules, molecular sheets, and molecular arrays are better described as semiconductors than as conductors. Metallic conductors have a virtually infinite capacity to pick up noise energy whereas this is not so for tissues. And semiconductors are far more sensitive to magnetic fields than conductors. This sensitivity is described as the well-established Hall effect, which was discovered in 1879.

Secondly, at a fundamental level, neither physicists nor anyone else knows what a magnetic or electrical field really is. Nor do we know what a gravitational field is.

The confusion around this issue has been costly, for medical science has given little attention to important field interactions that have been well researched and documented.

Finally, a physical and neurophysiological trick known as stochastic resonance obviates the noise problem.

Stochastic resonance

It is intuitively obvious that noise degrades any signal. However, living systems and certain electronic circuits employ a phenomenon known as stochastic resonance that enables weak signals to be extracted in a noisy environment (Benzi et al., 1981; Bulsara and Gammaitoni, 1996). The method actually takes advantage of noise and uses its energy to boost the strength of a weak signal. This is accomplished through an intricate nonlinear cooperation between the system and detector. This effect is known to operate in neurons, lasers, and tunnel diodes. The noise fluctuations can be stochastic (meaning totally random) but the detection of a desired signal is maximized by *tuning* the noise. A vivid demonstration of how the brain can employ this phenomenon for visual perception has been published on the World Wide Web (Simonotto, 2002). Recent research has led to improvements in the method, helping to explain how sensory systems such as touch or hearing can pick out faint signals (Gammaitoni et al., 1999).

The discovery of power/frequency windows

Controversy and confusion about subtle energy effects came to a head (literally) because of a famous neuroscientist, W. Ross Adey. Professor Adey assumed, as did virtually every other neuroscientist, that weak electric and magnetic fields have no effect whatsoever on the nervous system. As mentioned above, the tiny potentials produced by the spontaneous weak oscillating electric gradients, as seen in the *electroencephalogram*, were not considered generally relevant to brain functioning. These oscillations were often viewed as sort of "artifacts" or byproducts of nerve functioning, with no physiological importance whatsoever.

Alexander Mauro at the Rockefeller Institute (now Rockefeller University), thought he had proved the point by putting the sciatic nerve of a frog between the poles of the strongest magnet in the world, then at the Brookhaven National Laboratories on Long Island (Mauro, 1972, personal communication). The nerve conducted measurable action potentials; the magnet was switched on; nerve conduction did not change. Magnetic fields therefore have no effect on the nervous system. Interesting experiment, wrong conclusion! We now know that both electric and magnetic fields do have effects on consciousness.

Adey had a graduate student named Hamer. The student was young and inexperienced and did not know that electric and magnetic fields do not affect the nervous system. He therefore conducted a very naive experiment. He studied the effects of an electric field on reaction time. In the experiment, a light came on and the subject pressed a button as soon as possible. The time between *light on* and *button press* is the reaction time. Hamer placed electrical plates adjacent to the heads of his subjects and pulsed weak electric fields of different frequencies into the plates. Low frequency pulsing fields changed the reaction time.

He described the study to his mentor, Adey. Of course, Adey knew there had to be a mistake, so he repeated Hamer's experiment himself to find out what had gone wrong. The experiment worked for Adey. Nothing was wrong with Hamer's results. Hamer published his results in two papers (Hamer, 1968, 1969).

This was a turning point in the history of this whole affair, because Adey brought the observations to the attention of the entire scientific community. He did this with the support of his distinguished colleague, Francis O. Schmitt at the Massachusetts Institute of Technology. Schmitt had set up a prestigious organization called the Neurosciences Research Program. Schmitt convened a gathering of leading scientists to discuss the results from Adey's laboratory in relation to other research taking place at the time. The result was an historic publication that has largely gone unnoticed (Adey and Bawin, 1977).

Following on Hamer's studies further research was conducted by Bawin et al. (1975) and Blackman et al. (1979), involving the effects of electromagnetic fields on calcium efflux from tissue taken from the forebrain of the chick. It was discovered that maximum sensitivity occurred at a frequency between 6 and 20 Hz, and an intensity of 10^{-7} V/cm.

This level is comparable with that involved in navigation and prey detection in marine vertebrates and with control of human biological rhythms. The signal giving the strongest effects was found to fall within a range in terms of both frequency and intensity. This range came to be called a "frequency-power window." This was dramatic and reliable evidence that extremely low-level, non-thermal and non-ionizing, energy fields could have an important biological effect. "Subtle energy" effects are neither supernatural, nor do they require a revision of physics. Energy fields are an important language of biocommunication; they go to the foundation of life (Smith, 1994).

A shift in consensus

If the history of science has a lesson for us, it is that 'consensus among the experts' can undergo rapid change:

- A few decades ago the suggestion that organisms have energy fields around them, and that these fields can produce meaningful interactions between organisms, had little scientific credibility.
- The repeated observation of naturalists that geophysical and celestial rhythms influence plant and animal behavior seemed utterly preposterous to all but a few scientists.
- Healing with natural or artificial energy fields had the same scientific acceptance as voodoo, levitation, and UFOs.
- When concern arose about possible health effects of exposure to electromagnetic fields from appliances and other technologies, many experts stated that these energies are far too weak to have any biological effects.

Intense research into these subjects has led to a complete reversal of opinion. Key to the process has been collaborations between the physical, biological, and molecular sciences. Current opinions:

- There is...a growing scientific consensus on the cell and molecular biology mediating interactions with environmental electromagnetic fields. Beyond the chemistry of molecules that form the exquisite fabric of living tissues, we now discern a new frontier in biological organization...based on physical processes at the atomic level, rather than in chemical reactions between biomolecules...these physical processes may powerfully regulate the products of biochemical reactions (Adey, 1996).
- In the last decade, evidence has accumulated that supports the hypothesis that exposure to low energy non-ionizing radiation can induce and/or modulate events within biological tissues (Goodman and Henderson, 1987).
- There is now convincing evidence from a large number of laboratories, that exposure to extremely low frequency (ELF) magnetic and electric fields produces biological responses in animals (Anderson, 1996).
- There is general agreement that exogenous electric and electromagnetic fields influence and modulate the properties of biological systems (Blank and Findl, 1987).
- Many of the leading researchers in the field of bioelectrochemistry/biomagnetics agree that exogenous fields modify cellular calcium ion transport (Findl, 1987).
- Enzymatic processes themselves are field-sensitive (Westerhoff et al., 1987).
- Weak electric fields can change the probability that molecules of the reacting materials will encounter each other (Barnes, 1996).
- By amplification we are referring to a situation in which a tiny field, far too weak to power any cellular activity, triggers a change at the regulatory level, which then leads to a substantial physiological response that is carried out using the energy of cell metabolism (Pilla et al., 1987).
- Recent progress in the application of electromagnetic energy has revolutionized many areas of medicine (Chandos et al., 1996).

Scientific consensus has gone from a certainty that weak environmental energies can have no influence on living systems (the behaviorists must be deluded) to agreement that such influences are extremely important and deserving of thorough study to determine the precise mechanisms involved.

The emerging concepts do not require us to abandon our sophisticated understandings of physiology, biochemistry or molecular biology. Instead, they extend our picture of living processes, and of healing, to finer levels of structure and function. Our definition of living matter is being expanded to incorporate the physics and chemistry of the solid state, including semiconduction, quantum mechanics, liquid crystals, and biological coherence.

Collectively, the discoveries of modern biomedical researchers tell a story of biological sensitivity that coincides with the daily experiences of energy therapists ranging from medical doctors using PEMF techniques to Acupuncturists to Polarity Therapists, Reiki practitioners and so on.

Conclusions

Studies of the sensitivity of physiological processes to external energy fields is key to understanding the various complementary therapies such as Acupuncture, Jin Shin Jyutsu, Massage, Healing Touch, Therapeutic Touch, Polarity Therapy, Reiki, Structural Integration, Zero Balancing, and so on. And knowing the best signal for stimulating healing is obviously vital to the design of energy medicine healing devices. Information on the mechanisms by which energies of various kinds affect the organism is of significance for regulatory and legislative bodies, and for those proposing or evaluating research involving energetic therapies of all kinds. Finally, the findings help us understand the potential harmful effects of using modern electromagnetic technologies such as appliances, computers, and cellular telephones.

Valuable information about the sensitivities of organisms to external energy fields has been ignored for many years at the same time that various "experts" have published conclusions based on erroneous logic or lack of appreciation of subtle aspects of biological systems. This has resulted in a lot of confusion that has been costly to medical progress. There is no reason for this situation to continue. All who have an interest in the advancement of energetic therapies need to look at the classic 1977 paper of Adey and Bawin on brain interactions with weak electric and magnetic fields, published in the Neurosciences Research Program Bulletin. This paper was instrumental in resolving a long-standing controversy:

> ...a striking range of biological interactions has been described in experiments where control procedures have been adequately considered...The existence of biological effects of very weak electromagnetic fields suggests an extraordinarily efficient mechanism for detecting these fields and discriminating them from much higher levels of noise (Adey and Bawin, 1977).

Acknowledgements

I thank Karen Prestwood, MD for asking the question that led to this essay. I am grateful to K. Leigh for very helpful comments on the manuscript.

Appendix A. Physical considerations in measuring fields

This appendix is provided to clarify the units of measurement and the physical principles involved in the study of electric, magnetic, and electromagnetic field interactions with living tissues. For more details, see basic texts on physics and electrical engineering.

Measurements

In discussing field strengths we refer to different kinds of measurements, including voltage, current, power, magnetic field strength, and magnetic flux density. The units of measure for these characteristics are, respectively, Volts, Amperes, Watts, Tesla or Gauss, and Oersteds. Each of these units is named for a leading figure in the history of physics.

In some cases effects on temperature are important, and these are measured in small fractions of degrees. And the energy, work, or force exerted may be measured in Dynes, Joules, or Newtons. Because the levels involved are small, the values are often expressed in various sub-multiples, and these are given in Table 2.

Table 2 Sub-multiples used in measurements.

Centi—c	10^{-2}
Milli—m	10^{-3}
Micro—μ	10^{-6}
Nano—η	10^{-9}
Pico—p	10^{-12}
Femto—f	10^{-18}

Physical principles

A pair of reciprocal physical principles provides the basis for energetic interactions between organisms and their environment and vice versa. These principles provide the basis for many technologies such as electric motors and generators. The following briefly states these principles and their implications for living systems (Table 3).

Magnetism from electricity

In 1820, the Danish scientist, Hans Christian Oersted noticed that a current flowing through a wire would cause a nearby compass needle to move. Between 1820 and 1825, Ampére quantified this phenomenon, leading to *Ampére's Law*, or

Laplace's Law, which is a fundamental law of electromagnetism (see Fig. 2A).

A consequence of this law is that currents set up within organisms, as by the beating of the heart (electrocardiograms), contraction of other muscles (electromyograms), or nerve impulses in the brain (electroencephalograms), must produce magnetic fields both within the body and in the spaces around the body. There is no barrier at the surface of the organism that prevents magnetic fields from leaving or entering the body. The magnetic permeabilities of the various tissues are all about the same, approximately 1, as in a vacuum.

Until a few decades ago, the consensus among experts was that such magnetic fields, if they existed at all, would be far too weak to have any physiological significance. Not only have scientists documented the presence of such fields, but they have also learned how these fields are generated and how they are altered in disease processes.

Table 3 Signal features.

Frequency
Intensity
pulse width
intrapulse interval
pulse shape
energy distribution
repetition rate
current density
Phase
Coherence

Biomagnetism

The magnetic fields produced by living organisms are called biomagnetic fields. They are readily measured with magnetometers such as the superconducting quantum interference device (SQUID). So reliable are these measurements that biomagnetic fields called *magnetocardiograms*, *magnetomyograms*, and *magnetoencephalograms* are being used by physicians to make medical decisions at a variety of medical centers around the world (e.g. van Leeuwen et al., 1999).

Electricity from magnetism

In 1831, Michael Faraday in England demonstrated that moving a magnet near a coil of wire induces a measurable current flow through the wire. *Faraday's Law of Induction* is another basic law of electromagnetism (see Fig. 2B). Note that for a current to be induced the magnet must *move* relative to the wire, or the magnetic field strength must change over time, so that the magnetic flux is changing. A stationary permanent magnet will not induce a continuous current flow in a stationary wire.

A consequence of Faraday's law is that moving or oscillating magnetic fields in an organism's environment must induce current flows within the conducting tissues of the body.

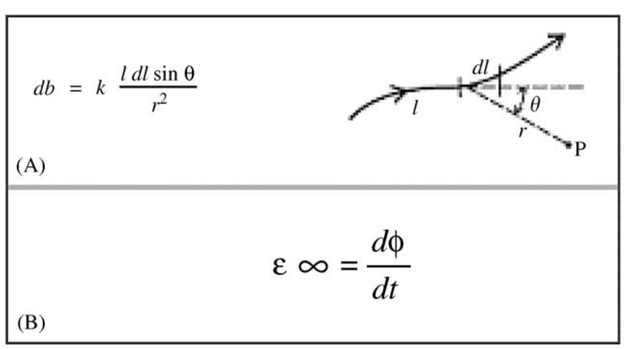

Figure 2 (A) The equation devised by Ampère, expressing the magnetic density B at a point P at a distance r from a current flow I of a particular length l, and at a particular angle ø between the current element and the line joining the element to the point. This is known as Ampère's Law or Laplace's Law, and is a fundamental law of electromagnetism. This law requires that electrical currents, such as those produced within the body by the activities of the heart, brain, muscles, and other organs, produce magnetic fields in the space around the body (Parker, 1993). Reproduced by permission of McGraw-Hill Inc., New York. (B) Faraday's Law of Induction. The induced electromagnetic field in a circuit is equal to the negative rate at which the flux through the circuit is changing. This is another basic law of electromagnetism. The biological and medical significance of this law is that moving or time-varying magnetic fields in the space around the body must induce current flows within the tissues (Halliday and Resnick, 1970). Reproduced by permission of Wiley, New York.

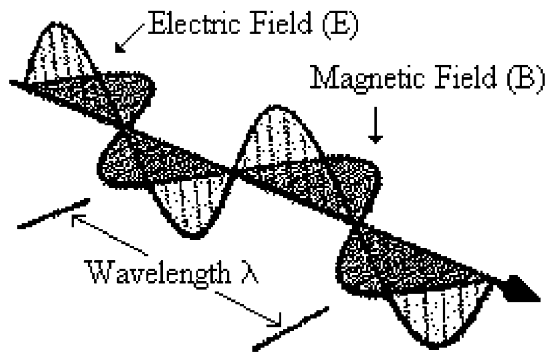

Figure 3 The electromagnetic field has an oscillating electrical aspect and an oscillating magnetic aspect, and these are perpendicular to each other.

Electromagnetism

Electromagnetic fields result from the oscillations of electrical charges. All of the electrical rhythms in the living organism will produce electromagnetic fields that are propagated into the surrounding space. Likewise, appliances, cell phones, radar, power lines, and other technologies generate electromagnetic fields that penetrate into the body. The electromagnetic field has an oscillating electrical aspect and an oscillating magnetic aspect, and these are perpendicular to each other, as shown in Fig. 3.

The extent to which an electromagnetic field will penetrate into an organism is a complex question. The two aspects of the electromagnetic field, the electric and magnetic components, may have different depths of penetration, and these depths are frequency specific. Hence it is generally thought that electric oscillations will not penetrate cell membranes whereas magnetic oscillations readily enter the cell. This is an over-simplification, however, particularly because our traditional understandings of the properties of cell membranes is being brought into question (Pollack, 2001).

References

Adair, R.K., 1991. Constraints on biological effects of weak extremely low-frequency electromagnetic fields. Physics Review A43, 1039–1048.

Adey, W.R., 1996. A growing scientific consensus on the cell and molecular biology mediating interactions with environmental electromagnetic fields. In: Ueno, S. (Ed.), Biological Effects of Magnetic and Electromagnetic Fields. Plenum Press, New York, pp. 45–62 (Chapter 4).

Adey, W.R., Bawin, S.M., 1977. Brain interactions with weak electric and magnetic fields. Neurosciences Research Program Bulletin 15 (1), 1–129.

Anderson, L.E., 1996. Investigation of exposure to extremely low frequency (ELF) magnetic and electric fields: status of laboratory animal studies. In: Ueno, S. (Ed.), Biological Effects of Magnetic and Electromagnetic Fields. Plenum Press, New York, pp. 131–138 (Chapter 9).

Ayala, A., Chung, C.S., Grutkoski, P.S., Song, G.Y., 2003. Mechanisms of immune resolution. Critical Care Medicine 31 (8), S558–571.

Barnes, F.S., 1996. In: Ueno, S. (Ed.), The Effects of ELF on Chemical Reaction Rates in Biological Systems. Biological effects of magnetic and electromagnetic fields. Plenum Press, New York, pp. 37–44 (Chapter. 3).

Bassett, C.A.L., 1995. Bioelectromagnetics in the service of medicine. In: Blank, .M. (Ed.), Electromagnetic Fields: Biological Interactions and Mechanisms. Advances in Chemistry Series 250. American Chemical Society, Washington, DC, pp. 261–275.

Bawin, W.M., Kaczmarek, L.K., Adey, W.R., 1975. Effects of modulated very high frequency fields on specific brain rhythms in cats. Brain Research 58, 365–384.

Becker, R., 1967. The electrical control of growth processes. Medical Times 95, 657–669.

Becker, R.O., Selden, G., 1985. The Body Electric: Electromagnetism and the Foundation of Life. William Morrow, New York.

Benzi, R., Sutera, A., Vulpiani, A., 1981. The mechanism of stochastic resonance. Journal of Physics A 14, L453–L457.

Blackman, C.F., Elder, J.A., Weil, C.M., Benane, S.G., Eichinger, D.C., Hose, D.E., 1979. Induction of calcium-ion efflux from brain tissue by radio-frequency from brain tissue by radio-frequency radiation: effects of modulation frequency and field strength. Radio Science 14 (6S), 93–98.

Blank, M., Findl, E., 1987. Preface to Mechanistic Approaches to Interactions of Electric and Electromagnetic Fields with Living Systems. Plenum Press, New York.

Brown, F.A.J.R., 1971. Some orientational influences of non-visual, terrestrial electromagnetic fields. Annals of the New York Academy of Sciences 188, 224–241.

Bulsara, A.R., Gammaitoni, L., 1996. Tuning in to noise. Physics Today 49, 39–45.

Campion, E.W., 1997. Power lines, cancer, and fear. New England Journal of Medicine 337, 44–46.

Chandos, B., Khan, A., Lai, H., Lin, J.C., 1996. The application of electromagnetic energy to the treatment of neurological and psychiatric diseases. In: Ueno, S. (Ed.), Biological Effects of Magnetic and Electromagnetic Fields. Plenum Press, New York, pp. 161–170 (Chapter 12).

Day, N., 1999. Exposure to power-frequency magnetic fields and the risk of childhood cancer. Lancet 354, 1925–1931.

Emmlen, S.T., 1969. Bird migration: influence of physiological state upon celestial orientation. Science 165, 716–718.

Farley, J.W., 2003. Power lines and cancer: Nothing to fear. On the web at: http://www.quackwatch.org/01QuackeryRelatedTopics/emf.html.

Findl, E., 1987. Membrane transduction of low energy level fields and the Ca^{++} hypothesis. In: Blank, M., Findl, E. (Eds.), Mechanistic Approaches to Interactions of Electric and Electromagnetic Fields with Living Systems. Plenum Press, New York, pp. 15–38.

Fraenkel, S., Gunn, D.L., 1961. The Orientation of Animals, Kineses, Taxes and Compass Reactions. Dover Publications, Mineola, NY.

Gammaitoni, L., Löcher, M.A., Hänggi, .P., Neff, J., Wiesenfeld, K., Ditto, W., Inchiosa M, E., 1999. Controlling stochastic resonance. Physical Review Letters 82 (23), 4574–4577.

Gauguelin, M., 1974. The Cosmic Clocks. Avon Books, New York.

Goodman, R., Henderson, A.S., 1987. Patterns of transcription and translation in cells exposed to EM fields: a review.

In: Blank, M., Findl, E. (Eds.), Mechanistic Approaches to Interactions of Electric and Electromagnetic Fields with Living Systems. Plenum Press, New York, pp. 217–230.
Halliday, D., Resnick, R., 1970. Fundamentals of Physics. Wiley, New York.
Hamer, J.R., 1968. Effects of low level, low frequency electric fields on human time. Communication and Behavior in Biology 2 (A), 217–222.
Hamer, J.R., 1969. Effects of low level, low frequency electric fields on human time judgment. In: Tromp, S.W., Weihe, W.H. (Eds.), Fifth Internatioinal Biometerological Congress, Montreux, Switzerland (Published as a Supplement to Vol. 14 of the International Journal of Biometeorology, 1970, Swets and Zeitlinger, Amsterdam).
Ho, M.-W., 1997. Quantum coherence and conscious experience. Kybernetes 26, 265–276.
Ho, M.-W., Popp, F.-A., Warnke, U., 1994. Bioelectrodynamics and Biocommunication. World Scientific, Singapore.
Hydén, H., 1973. Changes in brain protein during learning. In: Ansell, G.B., Bradley, P.B. (Eds.), Macromolecules and Behaviour. Macmillan, London, pp. 3–26.
Kauffman, S.A., 1993. The Origins of Order: Self-Organization and Selection in Evolution. Oxford University Press, Oxford.
Keeton, W.T., 1971. Magnets interfere with pigeon homing. Proceedings of the National Academy of Sciences 68, 102.
Keeton, W.T., 1974. The mystery of pigeon homing. Scientific American 231 (6), 96–107.
Lin, L.H., Hopf, H.W., 2003. Paradigm of the injury-repair continuum during critical illness. Critical Care Medicine 31 (8), S493–495.
Linet, M.S., Hatch, E.E., Kleinerman, R.A., Robison, L.L., Kaune, W.T., Friedman, D.R., Severson, R.K., Haines, C.M., Hartsock, C.T., Niwa, S., Wacholder, S., Tarone, R.E., 1997. Residential exposure to magnetic fields and acute lymphoblastic leukemia in children. New England Journal of Medicine 337, 1–7.
Macklis, R.M., 1993. Magnetic Healing, Quackery, and the Debate About the Health Effects of Electromagnetic Fields. Annals of Internal Medicine 118 (5), 376–383.
Majno, G., 1975. The Healing Hand. Man and Wound in the Ancient World. Harvard University Press, Cambridge.
Manning, M.R., 1975. Bioelectrochemical regenerator and stimulator devices and methods for applying electrical energy to cells and/or tissue in a living body. United States Patent, 3,893,462.
Marchesi, V.T., 1985. Inflammation and healing. In: Kissans, J.M., Anderson, W.A.D. (Eds.), Anderson's Pathology, 8th Edition. CV Mosby, St. Louis, pp. 22–60 (Chapter 2).
Mauro, 1972. Personal communication.
McCraty, R., Atkinson, M., Tomasino, D., Tiller, W.A., 1998. The Electricity of Touch: Detection and measurement of cardiac energy exchange between people. In: Pribram, K.H. (Ed.), Brain and Values: Is a Biological Science of Values Possible. Lawrence Erlbaum Associates, Publishers, Mahwah, NJ, 1998, pp. 359–379.
Merkel, F.W., Wilschko, W., 1965. Magnetismus and Richtungsfinden zugunruhiger Rotkehlchen (*Erithacus rubecula*). Vogelwarte 23, 71–77.
Miyake, K., McNeil, P.L., 2003. Mechanical injury and repair of cells. Critical Care Medicine 31 (8), S496–501.
National Research Council, 1997. National Research Council Committee on the Possible Effects of Electromagnetic Fields on Biologic Systems. Possible Health Effects of Exposure to Residential Electric and Magnetic Fields. Washington, DC: National Academy Press, 1997.
Oschman, J.L., 2003. Energy Medicine in Therapeutics and Human Performance. Butterworth Heinemann, Oxford.
Parker, S. (Ed), 1993. McGraw-Hill Encyclopedia of Physics, 2nd Edition. McGraw-Hill Inc., New York.
Pilla, A.A., Kaufman, J.J., Ryaby, J.T., 1987. Electrochemical kinetics at the cell membrane: a physicochemical link for electromagnetic bioeffects. In: Blank, M., Findl, E. (Eds.), Mechanistic Approaches to Interactions of Electric and Electromagnetic Fields with Living Systems. Plenum Press, New York, pp. 39–62.
Pollack, G.H., 2001. Cells, Gels and the Engines of Life. Ebner and Sons, Seattle.
Rubin, C.T., McLeod, K.J., Lanyon, L.E., 1989. Prevention of osteoporosis by pulsed electromagnetic fields. Journal of Bone and Joint Surgery 71-A (3), 411–417.
Sauer, E.G.F., Sauer, E.M., 1960. Star navigation of nocturnal migrating birds. Cold Spring Harbor Symposia on Quantative Biology 25, 463–473.
Schlicte, H.J., Schmidt-Koenig, K., 1972. Homing in pigeons with impaired vision. Proceedings of the National Academy of Sciences USA 69 (9), 2446–2447.
Schmitt, F.O., 1961. Molecule-cell, component-system reciprocal control as exemplified in psychophysical research. The Robert A. Welch Foundation Conferences on Chemical Research. V. Molecular Structure and Biochemical Reactions, Houston, Texas, December 4–6, pp. 33–37.
Shealy, C.N., Mortimer, J.T., Hagfors, N.R., 1970. Dorsal column electroanalgesia. Journal of Neurosurgery 32, 560–564.
Showalter, C., 2003. Birds in the Classroom. On the World Wide Web at: http://fsc.fernbank.edu/birding/migration/migratin/htm.
Simonotto, E., 2002. On the World Wide Web at: http://neurodyn.umsl.edu/sr/.
Siskin, B.F., Walker, J., 1995. Therapeutic aspects of electromagnetic fields for soft-tissue healing. In: Blank, M. (Ed.), Electromagnetic Fields: Biological Interactions and Mechanisms. Advances in Chemistry Series 250. American Chemical Society, Washington, DC, pp. 277–285.
Smith, C.W., 1994. Biological effects of weak electromagnetic fields. In: Ho, M.-W., Popp, F.-A., Warnke, U. (Eds.), Bioelectrodynamics and Biocommunication. World Scientific, Singapore, pp. 81–107 (Chapter 3).
Stedman's Medical Dictionary, 1976, 23rd Edition. William and Wilkins Baltimore.
van Leeuwen, P., Hailer, B., Bader, W., Geissler, J., Trowitzsch, E., Gronemeyer, D.H., 1999. Magnetocardiography in the diagnosis of fetal arrhythmia. British Journal of Obstetrics and Gynaecology. 106 (11), 1200–1208.
Walcott, C., Green, R., 1974. Orientation of homing pigeons altered by a change in the direction of an applied magnetic field. Science 184, 180–182.
Weil, A., 1995. Spontaneous Healing: How to Discover and Enhance Your Body's Natural Ability to Maintain and Heal Itself. Knopf, New York.
Weinberg, G.M., 2001. An Introduction to General Systems Thinking. Dorset House, New York.
Westerhoff, H.V., Kamp, F., Tsong, T.Y., Astumian, R.D., 1987. Interactions Between Enzyme Catalysis and Non-Stationary Electric Fields. In: Blank, M., Findl, E. (Eds.), Mechanistic Approaches to Interactions of Electromagnetic Fields with Living Systems. Plenum Press, New York, pp. 203–215.
Wever, R., 1974. ELF-effects on human circadian rhythms. In: Persinger, M.A. (Ed.), ELF and VLF Electromagnetic Field Effects. Plenum Press, New York, pp. 101–144.
Wiltschko, R., Wiltschko, W., 1995. . Magnetic Orientation in Animals. Zoophysiology, Vol. 33. Springer, Berlin.