REVIEW ARTICLE MAGNETIC FIELD EFFECT ON BIOLOGICAL SYSTEM
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ABSTRACT
The magnetic field is a mathematical means of representing the magnetic force. Electric and magnetic fields arise from many natural sources. They appear throughout nature and in all living things. Animal systems have been examined under a range of electric and magnetic field intensities and for varied exposure conditions and durations. Historically, the animal experiments began by looking for general effects rather than by formulating and testing hypotheses because there was no indication about what system or function, if any, is most likely to be affected by fields. However, now there is a very large number of scientific findings based on experiments with animals and people which suggested that low frequency magnetic fields can interact with, and produce changes in biological system.

KEYWORDS: Biological system, magnetic field, physiology, hematology, reproduction, pineal gland.

Our senses tell us what we need to know about our environment. They help to keep us out of danger and enable us to find food and shelter. As humans, our senses include sight, sound, taste, smell, and touch. But other animals need different information about the world to survive than we do. They may have senses like eolocation, infrared vision, electric sense, magnetic sense etc [klappenbach, 2009]. Toothed whales, bats, and some shrews use eolocation to navigate their surroundings. Each of these animals emits high-frequency sound pulses and, in turn, detects the echoes produced by those sounds [klappenbach, 2009]. Rattle snakes and other pit vipers use their eyes to see during the day, but at night they use infrared sensory organs to detect and hunt warm-blooded prey [klappenbach, 2009]. Electric fields are also used in numerous ways by animals. Electric eels and some rays have modified muscle cells that produce an electric charge strong enough to shock and sometimes kill their prey. Other fish use weaker electric fields to navigate murky waters or to monitor their surroundings [Klappenbach, 2009]. In addition, all organisms have a biologic sensitivity to the earth’s magnetic field [Internet source, 2008].

MAGNETIC SENSITIVITY
The magnetic field is a form of energy to which all plants and animals are exposed. However, its influence on living systems is not well understood (Internet source A, 2009). The flow of molten material in the earth's core and the flow of ions in the atmosphere generate a magnetic field that surrounds the earth (Klappenbach, 2009). All points on the earth’s surface are characterized by the presence of a static geomagnetic field (Bochert and Zettler, 2004).

Earth's magnetism is very weak, from 0.3 gauss at the Equator to 0.7 gauss at the Poles. This magnetosphere of the earth affects the life of most creatures on Earth (Anitei, 2008). Since the earth has a magnetic field, any conducting medium moving through it induces an electric field. For an electro sensory animal, two potential mechanisms are available to perceive the magnetic fields: a passive detection of gradients from water currents or an active detection of gradients set up by swimming movements (Wilkening and Hafmann, 2004). Magnetic fields interact directly with magnetically anisotropic or ferromagnetic materials, and with moving charges (Repacholi and Greenbaum, 1999). Static magnetic fields may interact with living systems through magnetic induction (forces on moving ions in solution), magneto-mechanical effects (torques on molecules and ferromagnetic material) and electronic interactions (altering of energy levels and spin orientation of electrons) (Repacholi and Greenbaum, 1999).

Scientists and biologists have long been fascinated by the ability of some fish to use electricity and magnetism to navigate and find prey. It is known that all fish have some reaction to electric stimulus in the water (Internet source B, 2010). Further, the magnetic field is known to exert its influence on both adult and juvenile fishes, as well as the embryos. The effects are diversified and pertain.
but CitC differs in various groups of fishes. Some fish have been noted on several occasions (Wilkens et al., 2004). It has also been learned that many fish have the capability to sense the electrical impulses given off by other fish and some can even sense the tiny voltage gradients created by ocean currents and river water movements in the presence of the earth’s magnetic field (Internet source B, 2010). All fish have a reaction to an electrical field but it differs in various groups of fishes. Some fish are attracted to the field, some are frightened by it and attempt to hide and some may appear to be immobilized by it. Interestingly, however, all of these groups react towards the positive charge and away from the negative. Even fish that are frightened and attempt to hide, move in the direction of the positive anode (Internet source B, 2010). Some fish may have special cells on their body surface that are electro receptors. These nerve cells have the specific capability of reading electric signals. Sharks, rays, sturgeon and catfish are some of the better known species of this type. Not only they are attracted by an anode reaction but they use their electro receptors to find prey hidden or buried in the mud or sand. They can sense the electrical nerve discharges of their target (Internet source B, 2010). Studies on trout have linked their response to electrical fields to metabolism. Active fish like trout have a higher rate of metabolism and demonstrate more electrical sensitivity (Internet source B, 2010).

Catfish are long known for their sensitivity to metallic objects (Parker and Heusen, 1917). Depending on the size and kind of metal used, catfish either show avoidance reactions or are attracted and show various feeding behaviors. Since nonmetallic objects are ineffective, it was suggested that catfish respond to the electric fields caused by the electrochemical potential of metals. This was confirmed by using batteries as stimuli, which give better control over the intensity of the electric field (Uzuka, 1934). The responses obtained in that way range from barbel movements, approach and nibbling to avoidance and escape. In general, weaker stimuli resulted in approach and stronger stimuli in avoidance. The high sensitivity in catfish to electric fields was also thought to be a possible explanation for the earthquake predictions by these fish. The unusual behavior of catfish preceding earthquake has been noted on several occasions (Wilkens and Michael, 2004). Catfish are able to detect electric fields with their electroreceptor organs. It goes without saying that the electro detection threshold depends on the sensitivity of the electroreceptor organs. The sensitivity in turn depends on a variety of extrinsic factors such as water temperature, conductivity and electric field frequency (Lonneke et al., 2001).

Behavioral experiments show that elasmobranch fishes (sharks, skates, and rays) can detect changes in the geomagnetic field (Andrianov et al., 1974; Meyer et al., 2005; Murray, 1962), and studies of migration (Klimley, 1993; Bonfil et al., 2005) give strong evidence that several species can navigate over long distances in environments where the geomagnetic field is the only plausible reference (Montgomery and Walker, 2001). Both direct magnetoreception and induction-based electroreception have been proposed as mechanisms for this ability to orient to the geomagnetic field or “compass sense” (Molteno and Kennedy, 2009). All elasmobranch fishes can detect electric fields using small pit organs in their snouts, the ampullae of Lorenzini (Kalmijn, 1966). The ampullae permits detection of both small local electric fields produced by other biological organisms, and large uniform electric fields, such as the earth’s magnetic field (Tricas, 2001). This electric sense is known to play a role in many behaviour observed in elasmobranches. It has been suggested that geomagnetic induction of electric current could play a role in orientation behaviour (Kalmijn, 1978, 1982; Paulin, 1995).

Several species of sharks have demonstrated the ability to sense magnetic fields (Kalmijn, 1978; Klimley, 1993, 2002). Whales and dolphins were found to use Earth’s electromagnetism in their long migrations (Anitei, 2008). Sharks moving through the terrestrial magnetic field generate an electric field whose value depends on their position of the magnetic field captured by the electroreceptors. In an aquarium, sharks always swim around the walls. If the magnetic field is cancelled or impaired, they start swimming randomly (Anitei, 2008). Fish have a thin line of sensitive cells on their sides which sense movement or vibration in the direction of the current (Internet source, C).

Further, it has been discovered that magnetic
bacteria living in the ponds and lakes, those located in the Northern Hemisphere swim in the direction of the magnetic north, while those from the Southern Hemisphere swim in the direction of the magnetic south (Anitei, 2008). Plant seeds do not germinate in cosmos, as they must feel the terrestrial magnetic field so their cells can be activated. When seeds are put in a more powerful magnetic field than that of the earth, a 15% increase of the production was caused. If bees are subjected to a magnetic field ten times more powerful than the terrestrial one, they are completely disoriented, and the combs get unusual forms and orientations (Anitei, 2008).

Salamanders, frogs use the magnetic field for orientation when they have to find the direction of the nearest shore quickly. Migratory birds use magnetic clues (in addition to light polarization, star signs, position of the sun) to find their way south in fall and north in spring (Internet source D, 2007).

It has been suggested that each of these animals has deposits of magnetite in their nervous systems. Magnetite, small magnet-like crystals, align themselves with magnetic fields and might act like microscopic compass needles. These crystals may be the key to revealing how animals sense magnetic fields (Klappenbach, 2009).

The tiny deposits of magnetite were discovered in the beaks of pigeons and bobolink. If a small magnet impairs their reception of the earth's magnetism or the area has a natural disturbance of the terrestrial magnetism, pigeons get disoriented and cannot find the way back on long distance (Anitei, 2008).

Birds and many non-mammal magnetic sensitive animals are known to perceive the inclination, using the Earth's magnetic field inclination to assess relative latitude. A bird species, Arctic Tern, use this information to make annual journeys from the North Pole to the South Pole and back (Anitei, 2008).

Marine turtles use to return to the same breeding beach, often located thousands of kilometers off the feeding places, making the return with no visual landmarks but relies on detecting the earth's magnetic field, against the deflection induced by the ocean currents (Anitei, 2008). If a powerful magnet attached on the turtles' heads impairs the detection of the earth's magnetism, the turtles decrease their navigational sense (Anitei, 2008).

The magnetic compass, using the terrestrial magnetism, is also used by moles, rats, fish and amphibians. Bats also have the ability to detect the difference between north and south. They use the terrestrial magnetism for long-distance navigation and foraging abilities.

Lab mice that had formed the conditional reflex of pressing a flap to get food any time they wanted to eat lost their reflex after being kept for 10 days in a room where the terrestrial magnetism was impaired (Anitei, 2008).

Although the use of the geomagnetic field for directional information is well established experimentally, it is not known by which biophysical mechanism magnetoreception is achieved (Internet source D, 2007).

How does the animal brain process magnetic information? Past studies have shown that some species have particular brain areas that respond to magnetic information. These areas may also have nerve cells that detect changes in the magnetic field. And the presence of the naturally magnetic mineral magnetite in the brains of some animals triggers magnetoreception (i.e. the ability to detect a magnetic field, to perceive direction, altitude or location) (Internet source E, 2009).

The effects of various types of magnetic fields on living organisms has been a subject of increasing interest in recent years for both theoretical and practical reasons. "Basically, the magnetic field, being a form of energy, just as are light, heat and sound, impinges upon all living organisms whether plants or animals. The question as to its effect on living matter is what we are seeking to learn. Is it an active or passive process? How will an organism react to an environment that is devoid of a magnetic field? Further, what will happen if the field is altered or distorted (Caldwell and Russo, 1968).

Therefore, in the present study, it was aimed to examine the effect of pulsed and continuous magnetic field exposure on metabolic and physiological activities of catfish, *Clarias batrachus*.
and *Clarias gariepinus*.

**Effect of magnetic field exposure on biological system**

Living systems are very sensitive to magnetic fields and the magnetic effect reaches every cell in the body on account of the highly pervasive character of magnetism. (Internet source F, 2009). Magnetism is a force that acts at a distance and is caused by a magnetic field (Kurtus, 2006). Our body’s natural magnetic field is created by the flow of electrically charge ions in and out of cells and the transmission of electric impulses through membranes (Internet source G, 2009). Many biological processes are affected by electromagnetic fields. Magnetic fields interact with biological systems through forces on the electrical currents associated with physiological functions and through the torques exerted on the magnetic moments of biologically important molecules (Adair, 2000). Bioelectrical phenomena, underlying all vital functions of living organisms are determined by metabolism controlling mechanisms. The interactions between external fields (including the terrestrial magnetic field) and internal electromagnetic ones results in release of the so called activation energy of potential substrates, making them ready to enter into reactions. The mechanisms may be regulated by means of specific external electromagnetic fields, thus affecting life functions (Milewski et al., 2001).

When a magnet is applied to the body, magnetic waves pass through the tissues and secondary currents are induced. When these currents clash with magnetic waves, they produce impacting heats on the electrons in the body cell (Bansal, 2006). Earlier reports suggested that magnetic field affects the living body by various ways (Milewski et al., 2001).

The pineal gland in the center of our head controls hormones, enzymes and immune function, and is itself magnetic organ containing magnetic crystals. It is acutely sensitive to magnetic energy and produces it’s most important and characteristic substance, the sleep hormone melatonin, almost entirely during the night when the earth’s negative field is dominant (Phillpott, 2006). Therefore, there is evidence that the pineal gland is a “Magnetosensor” in the brain, since experimental animals exposure to external magnetic fields alters the firing rate of pineal cells and induces inhibition of melatonin secretion (Sandyk, 1993).

Further, it has been unequivocally accepted that pineal organ acts as a neurochemical transducer of photoperiodic information and linked to several physiologic processes in various vertebrate species including fishes (De vlaming and Olcese, 1981; McNulty, 1984; Burns, 1972; Delahunty et al., 1978; Innocenti et al., 1993; Shedpure and pati, 1995).

During the last 50 years, the nature and scope of the magnetic field and its effect on living organisms have been studied. Thousands of experiments on bacteria, flies, mice, birds, fish, pigeons and rabbits as well as on the plants and tissue cultures have been conducted and astonishing facts revealed (Internet source, F, 2010).

**PLANTS**

In general, earlier studies on plants suggested a beneficial effect of magnetic field exposure on plant growth and production [Internet source H, 2000]. Exposure of magnetic field has been suggested to increased sprouting and growth of seedlings and fast fruit and vegetable ripening Internet source H, 2000.

It has been discovered that plants kept, within the magnetic field grow faster and give far better results in the form of greenery and fruits [Internet source F, 2010].

**MICROORGANISMS**

Effect of magnet has also been seen on the activity of certain bacteria specially those which are harmful and produce diseases in human beings. One such organism studied by the scientists is *Staphylococcus aureus* which produces skin troubles, stomach disorders and in certain troubles in human beings. These bacteria when incubated in the magnetic fields of 15 kilo-gauss showed complete inhibition of their development after 6 hours. Similarly, *Serratia marcescens* and *Eschirichia coli* which produce intestinal disorders in human beings and animals, have been shown to exhibit partial or complete inhibition of their growth under magnetic field (Internet source H, 2000).

However, magnetic field exposure of
nutritional medium of microorganism has been found to increase the growth rate, biomass accumulation and biosynthetic activity of microorganisms (Erygin et al., 1988). In addition, decrease in growth rate of unicellular organisms, i.e. paramecium [Elahee and Poinapen, 2006] and Fusarium culmorum (Albertini et al., 2003) have been suggested by exposure under magnetic field.

**ANIMAL BEHAVIOUR**

It has been suggested that behavioral responses of living organisms are greatly dependent on the ambient magnetic fields (Tenforde, 1979; Blank, 1993; Wiltshchko et al., 1995a). An inhomogeneous, static magnetic field has been documented to reduce the flying activity of bees (Martin et al., 1989). Magnetic fields has been found to affect the selection of migration direction and navigation of numerous fish species. Such responses were found in salmonids such as smolts and juveniles of sockeye salmon Oncorhynchus nerka (Quinn et al., 1981; Quinn & Brannon, 1982) Chum Salmon (O. keta) [Yano et al., 1997], Rainbow trout (O. mykiss) (Walker et al., 1997; Chew et al., 1989) Atlantic salmon (Salmo salar) (Rommel et al., 1973; Varanelli et al., 1974), European eel (Anguilla) (Tesch et al., 1992), American eel (Arostrata) (Rommel et al., 1973; Mc Cleave et al., 1978) yellowfin tuna (Thunnus albacares) [Walker, 1984] as well as sharks and rays (Kalmijn, 1982).

It has been documented that the fish are capable of developing conditional responses to magnetic fields [Walker, 1984; Kalmijn, 1978; Formicki et al., 2006]. The artificially generated constant magnetic fields were found to induce significantly stronger orientation responses in fish embryo compared to those elicited by the geomagnetic field alone. (Tanski et al., 2005).

Anadromous rainbow trout has been found to align along an external magnetic field, but become disoriented in a null magnetic field [Chew and Brown, 1989]. It can discriminate between superimposed magnetic field, but only when the conditional response allows movement and when the magnetic fields are spatially distinctive [Walker et al., 1997]. Experiments with yellow fin Tuna (Thunnus albacares) showed that they reacted to differences in intensity of magnetic field but not to differences in direction [Walker, 1984].

In mice, static magnetic field exposure has been shown to reduce the activity of mating behaviour (Zimmerman and Hentschel, 1987). In deer mice, increase of spatial learning by magnetic field exposure has been documented (Kavaliers et al., 2004).

**HEMATOLOGY**

Magnetic energy has a beneficial effect on blood circulation, lymph flow, hormone production, nerves and muscles (Warnke, 2006). Movement of hemoglobin in blood vessels is accelerated due to presence of ferric ions while calcium and cholesterol deposits in blood are decreased (Bansal, 2006). Even the other unwanted materials adhered to the inner side of blood vessels, which provoke high blood pressure, are decreased and made to vanish. The blood is cleansed and circulation is increased. Most often it is used to bring the blood back to its natural healing polarity. Increase blood flow, bringing in more oxygen and nutrients and flushing away waste products have also been reported by magnetic field exposure (Johnston, 2006).

Magnetic field exposure has been reported to increase the immature and mature erythrocytes in mice (Svedenst and Johanson, 1998). It has been reported that the exposure of rats 1 hour/day for 13 consecutive days to static magnetic field induced an increase in hematocrit level, hemoglobin concentration and LDH levels (Chater et al., 2006). In mice, exposure of extremely low frequency magnetic field has been suggested to cause leucopenia (Carbrales et al., 2001; Picazo et al., 1995a; Picazo et al., 1994; Vallejo et al., 2001). However, contrary reports are available, i.e., red cell number, hemoglobin content and hematocrit have been reported to decrease in mice exposed under extremely low frequency magnetic field (Picazo et al., 1995a; Cabrales et al., 2001).

In rats, electromagnetic field (EMF) exposed water has been suggested to cause leukocytosis and thrombocytosis on 30 days, and leucopenia and thrombopenia on 60 days (Singh et al., 1995). It has been reported that chronic exposure to a 0.2-6.6- µT magnetic field can lead to decreased total lymphocytes in humans and mice (Bonhomme-Faivre
Bonhomme-faiivre and his coworkers, 1995 have also reported decline in number of leukocytes, lymphocytes, monocytes and eosinophils in mice depending on the duration of exposure to magnetic field. In contrast, in human, exposure under electromagnetic field has been reported to cause an increase in the white blood cells (Marino, 1995).

An earlier report on guinea pig suggested a decrease in platelet count and an increase in platelet aggregation after exposure under magnetic field [Gorczynska and Wegrzynowicz, 1983]. Results (Jain, 2010) emerged from our laboratory suggested that pulsed magnetic field exposure may cause beneficial effect on hemopoietic variables and may be advantageous for body weight gain in C. batrachus, irrespective of photoperiod and phase of the annual reproductive cycle.

PHYSIOLOGICAL AND BIOCHEMICAL ACTIVITIES

Artificial magnetic fields have been reported to influence some physiological processes in bees. (Martin et al., 1989). Magnetic field has been reported to alter the acidity or alkalinity of body fluids and cell chromosome alignment, enzyme activity and other biochemical processes, such as the production of ATP molecule (Johnston, 2006).

Static magnetic field exposure has been reported to cause significant disruption in the carbohydrate, lipid and protein metabolism reflected by altered blood glucose levels and accelerated glycolysis and glycogenolysis in rats (Day, 1999; Salem et al., 2005; Picazo I 1995a; Sert et al., 2000; Al-Akhras et al., 2001). An increased blood glucose and decreased insulin release, by exposure to static magnetic field in rats (Chater et al., 2006).

Milewski et al., [2001] have studied that pulsed electromagnetic field stimulation may cause increase in intensity of lipid metabolism in sheep. Pulsed electromagnetic exposure has been reported to alter the dynamics of intracellular calcium in astrocytoma cells in human (Pessina et al., 2001). Basal calcium ion level and levels of interleukin-6 in astrocytoma cell increased after exposure under pulsed magnetic field exposure in human (Aldinucci et al., 2000). Movement of calcium ion increased in lymphocytes in human after receiving electromagnetic field (Aldinucci et al., 2003). An increase of Na and K content in urine in mice by exposure under magnetic field has also

Exposure of mice under static magnetic field has been reported to cause an increase in endochondral ossification on chondrocytes (Okazaki et al., 2001). Frequency of magnet dependent effect of magnetic field was documented on degeneration of cancer cells in mice (Internet source H, 2000).

Varying reports on the effect of magnetic field exposure on sciatic nerve regeneration are also available. An increase in sciatic nerve regeneration was documented by pulsed magnetic field exposure in rats (Kanje et al., 1993; Rusovan et al., 1992). However, no effect on sciatic nerve regeneration by pulsed magnetic field exposure in rat has also been documented by Guven et al., [2005]. An intensity of magnet independent effect of magnetic field exposure on thrombolytic process has been documented in rabbit. An increase in liquefaction of clot by constant magnetic field in rabbit has been reported (Gorczynska, 1986). Magnetic field exposure has been found to produce time of exposure dependent effect on body weight in mice (Svedenstal and Johanson, 1995; Forlen et al., 1993). Body weight loss was reported after postnatal exposure to static magnetic field of mice (Barnothy, 1964; Nagakawa, 1979). However, no significant differences in body weight gain of mice and rat were reported by electromagnetic field exposure (Bellosi et al., 1984). An earlier work conducted in our laboratory suggested that Continuous magnetic field exposure may be helpful in increasing the content of protein in muscle in Clarias batrachus (Jain, 2010).

IMMUNE SYSTEM AND AGING

Exposure to power-frequency fields produced changes in the immune system (Malagoli et al., 2003). The normal life span has been reported to increase by exposure under the magnetic field in mice (Internet source I, 2009) and bees (Martin, 1989). Several scientists (Internet source I, 2009) have carried out experiments with different poles of magnets and have come out with a positive assertion that cancer cannot exist in a magnetic field. With the application of the north pole of the magnet, it was found that the cancerous tumours gradually shrunk in
size and ultimately disappeared totally. But the exact opposite effect was noticed when the south pole was applied (Internet source I, 2009), the tumours increased rapidly and killed the mice. The life of the houseflies doubled by prolonged feeding of magnetized sugar (Internet source I, 2009).

DEVELOPMENT AND REPRODUCTION

Pulsed low frequency electromagnetic field exposure has been reported to accelerate the development of sea urchin (Falugi et al., 1987). However, another report (Zimmerman et al., 1990) on sea urchin has suggested delayed development by exposure under extremely low frequency electromagnetic field. Cleavage plane has been found to altered in frog by exposure under strong static magnetic field (Denegre et al., 1998). In rainbow trout, enhancement of fertilization has been reported by exposure under magnetic field (Strand et al., 2005). Similarly, in sea trout magnetic field exposure has been reported to increase the percentage of egg fertilization (Formicki et al., 1991).

Extremely low frequency magnetic field has been found to produce varying effect i.e. no effect (Maffeo et al., 1984), inhibitory effect (Delgado et al., 1982), and time of exposure dependent effect [Ubeda et al., 1983] on chick embryogenesis. Early hatching in fertile hen’s egg has been documented by short period exposure to magnetic field (Internet source H, 2000).

No change in testicular weight in mouse (Tablado et al., 1996) and rat (Chapin et al., 1984) by magnetic field exposure has been reported. However, extremely low frequency electromagnetic field exposure has been reported to cause an increase in testicular weight in rat (Ossenkopp et al., 1972). Further, no effect of magnetic field on reproduction and embryo fetal development has been documented in rat (Negichi et al., 2002) and mice (Ohnishi et al., 2002). Exposure under high static magnetic field has been reported to decline the mating in mice (Zimmermann and Hentschel, 1987).

The exposure time dependent effect of magnetically pregenerated water was noticed on oestrous cycles and body weight changes in cycling female albino mice (Pandey et al., 1996).

ENDOCRINE SYSTEM

Magnetic field have been found to promote the secretion of different hormones (Johnston, 2006). It has been suggested that electromagnetic field is able to change the serum levels of ACTH, cortisol and glucose (Zare et al., 2005). A time of exposure dependent effect of magnetic field has been suggested on the level of cortisol in guinea pigs by Zare and his coworkers [Zare et al., 2005]. An increase in the level of ACTH has also been reported in guinea pig by exposure under magnetic field (Zare et al., 2005; Lymangrover et al., 1986).

The magnet has been reported to cause effect on the adrenal gland and its hormone aldosterone (Internet source H, 2000). Coincident nonlinear changes in the endocrine and immune systems due to low-frequency magnetic fields have been observed in mice (Andrew, 2001) been reported (Internet source H, 2000). Further, in mouse decrease of Ca ion concentration in skeletal muscle has been reported by magnetic field exposure (Picazo et al., 1995b).

PINEAL ACTIVITY

The pineal gland and its main hormone, melatonin, have been widely reported sensitive to electromagnetic field exposure (Reiter, 1994; Yellon, 1994; Rosen et al., 1998; Lerchl et al., 1998; Karasek et al., 1998; Reiter et al., 1998). Exposure to low frequency electromagnetic field may supress the synthesis of the idoleamine hormone melatonin in the pineal gland of some species (Reiter, 1993; Kato et al., 1994; Yellon, 1994).

In a teleost fish, brook trout (Salvelinus fontinalis) significant increase in night-time pineal and serum melatonin level was noticed after exposure under magnetic field (Lerchl et al., 1998). Magnetic field has been shown to affect hormone production of pineal gland, which initiates a cascade of biological effects (Johnston, 2006). In mammalian species magnetic field exposure has been reported to decrease the melatonin secretion from pineal gland and the night time peak of melatonin (Touitou et al., 2002; Repacholi and Greeenebaum, 1999; Kato et al., 1991; Bonhomme-Faiver et al., 1998; Wilson et al., 1999). An alteration in normal circadian rhythm of melatonin synthesis has also been reported in animals and humans by (Wilson et al., 1989). However, in human no effect has been suggested on the level of
Further, it has been suggested that the effect of electromagnetic field exposure on pineal function is similar to that of light which is the main environmental cue mediating the response to photoperiod in mammals and birds (Reiter, 1980).

**LIGHT DEPENDENT MAGNETORECEPTION**

In terrestrial organisms, magnetic orientation appears to be mediated by more than one type of mechanisms (for reviews, see Wiltschko and Wiltschko, 1995a; Phillips and Deutschlander, 1997; Deutschlander et al., 1999a; Lohmann and Johnsen, 2000). In some cases, the underlying magnetoreception mechanism appears to be independent of light, e.g. in the subterranean mole rat (*Cryptomys sp.*) (Burda et al., 1990; Marhold and Wiltschko, 1997). In contrast, magnetic compass orientation has been shown to be sensitive to the wavelength and/or intensity of light in the eastern red-spotted newt (*Notophthalmus viridescens*) (Phillips and Borland, 1992a; Deutschlander et al., 1999a; Deutschlander et al., 1999b), bullfrog (Rana catesbeiana; M. J. Freake, S. C. Borland and J.B. Phillips, manuscript in preparation and unpublished data), fruit fly (*Drosophila melanogaster*) (Phillips and Sayeed, 1993), homing pigeon (*Columba livia*) (Wiltschko and Wiltschko, 1998) and several species of migratory bird (Wiltschko et al., 1993; Wiltschko et al., 2000a; Wiltschko et al., 2000b; Wiltschko and Wiltschko, 1995b; Wiltschko and Wiltschko, 1999; Rappl et al., 2000). Pineal complex of lizards and anuran amphibians exhibit spectral properties that are consistent with the behavioral responses in the newt (Eldred and Nolte, 1978; Solessio and Engbretson, 1993).

The role of the pineal gland as a neuroendocrine transducer in mammals is now well established. It exhibits circadian rhythmic activities, responds to photoperiodic stimuli, and transmits these stimuli to modulate the functional status of many other endocrine glands (Quay, 1974; Wurtman, 1980; Reiter, 1980; Banerji et al., 1980). The pineal gland is also known to have an anti-gonadal effect in mammals. The existence of pineal’s anti-gonadal effects in some sub-mammalian species, especially those characterized by a defined annual reproductive cycle, has also been reported (Maitra and Dey, 1994a, 1994, 1996).

While the pineal is a discrete endocrine gland present dorsally in the epithalamic area of the brain in mammals, in lower vertebrates the pineal organ has been reported to show a wide range of structural variabilities (Van de Kamer, 1965; Vollrath, 1979). From an evolutionary perspective, it becomes readily apparent that the structure and function of the pineal gland have undergone a clear transformation from being primarily a sensory organ in lower vertebrates to an important endocrine gland in mammals. It is noteworthy that the pineal organ in some lower vertebrates exhibits both sensory as well as secretory functions (Falcon et al., 1992; Gern et al., 1992; Okimoto and Stetson, 1999). Evidence has also been presented that the pineal organ in some lower vertebrates is directly photosensitive (Ekstrom and Meissl, 1997). The teleostean pineal organ has been suggested to serve as an important component of the photo-neuroendocrine system transmitting and transducing photic signals into neuroendocrine messages (De Vlaming and Olcese, 1981; McNulty, 1981, 1984; Korf et al., 1998).

The effect of light on magnetic orientation responses (e.g. shifts in the direction of orientation or disorientation) and the wavelength dependence of these effects vary considerably among newts, bees and birds. In addition, several animals are able to orient using magnetic cues in the absence of light (Arendse, 1978; Lohmann, 1991; Lohmann and Lohmann, 1993; Marhold and Wiltschko, 1997) and numerous experiments have provided evidence for a non-light dependent mechanism of magnetoreception involving permanently magnetic material, possibly biogenic magnetite (Kirschvink et al., 1993; Wiltschko et al., 1994; Beason et al., 1995; Walker et al., 1997).

Further, application of a magnetic field has the virtues of simplicity, freedom from danger and low cost. Electromagnetism and its effects on the body may be one of the most exciting scientific breakthroughs in current research and needs to be worked out thoroughly.

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