Powerfrequency EMFs and Health Risks

This article is separated into 12 sections, each of which can be individually downloaded. It is a 'work in progress' incorporating new information whenever time permits.

Section 7

Light at Night (LAN) and melatonin

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63% of the world population and 99% of the population of the European Union and the United States live in areas where the night sky is brighter than the threshold for light-polluted status set by the International Astronomical Union – that is, the artificial sky brightness is greater than 10% of the natural sky brightness above 45º of elevation.

Both human epidemiological and experimental studies on animals have documented that a potential negative consequence of chronodisruption and nocturnal melatonin inhibition is cancer initiation and growth. In epidemiological studies, the frequency of each of the following cancers has been reportedly increased in individuals who routinely work at night or whose circadian rhythms are disrupted for other reasons (e.g., due to jet lag): breast, prostate, endometrial, and colorectal. Likewise, in experimental animals, cancer growth is exaggerated when the animals are repeatedly phase advanced (as occurs during easterly flights) or exposed to light at night. A variety of mechanisms have been examined to explain how the suppression of melatonin exaggerates cancer risk (Golombek 2013). (S Li 2012) suggests that the decreased level of melatonin secretion and disruption of clock genes expression contribute to the mechanism of carcinogenesis. Mechanistically, how chronodisruption (without a consideration of melatonin suppression) would enhance cancer frequency is less clear. In addition to cancer, there may be other diseases that result from the chronic suppression of melatonin by light at night Reiter 2007).

Al-Naggar & Anil (2016) conclude from a global study that artificial light at night is significantly linked to all forms of cancer as well as lung, breast, colorectal, and prostate cancers (Rybnikova 2016, KY Kim 2017) individually. They recommend that immediate measures should be taken to limit artificial light at night in the main cities around the world and also inside houses.

Disruption of our naturally evolved light and dark cycles can result in a wide range of physiological and behavioural changes with potentially serious medical implications (Fonken & Nelson 2011).

Richard Stevens, a professor and cancer epidemiologist, was part of a study team that used satellite photos to gauge the level of night-time artificial light in 147 communities in Israel, then overlaid the photos with a map detailing the distribution of breast cancer cases (Kloog 2008). The results showed a statistically significant correlation between outdoor artificial light at night and breast cancer, even when controlling for population density, affluence and air pollution. Women living in neighbourhoods where it was bright enough to read a book outside at midnight had a 73% higher risk of developing breast cancer than those residing in areas with the least outdoor artificial lighting. YJ Kim (2015) also reported that artificial light at night might be a risk factor for breast cancer in South Korea, even in rural areas. The same increased risk was found in California, and Georgia, especially among white women (Bauer 2013) with outdoor light at night (Hurley 2014). A further study in Israel by Keshet-Sitton (2016, 2017) looking at breast cancer incidence variability between urban and rural areas suggested that women could influence breast cancer risk and incidence by reducing their exposure to blue light in the evening. This link was confirmed by George Brainard, a professor of neurology. Schwimmer (2013) concluded that exposure to LAN is coincided with a decreased melatonin secretion level, followed by epigenetic modifications which resulted in higher breast cancer tumour growth rate. Further evidence that LAN might induce epigenetic alteration of cancer-relevant microRNAs was reported by Liu (2015).

The increasing use of electricity to light the night, both within the home and outside, in developed and developing countries can disrupt human circadian rhythmicity, affecting melatonin production, sleep (sleep quality in the elderly Obayashi 2014), and the circadian clock (Rahman 2017). The health consequences of circadian disruption may be significant (Takahashi 2008, Sahar & Sassone-Corsi 2009, Stevens 2013).

The circadian control system increases fitness and allows organisms to adapt to their physical and ecological environment controlling several biological processes such as proliferation, cell cycle control and DNA damage repair (de Paula 2008, Borgs 2009, Sancar 2010, Gaddameedhi 2011). Manzella (2015) suggests that ELF-MF may be able to drive circadian physiologic processes by modulating peripheral clock gene expression.

Light at night has markedly increased the growth of human breast cancer transplanted into rats. Evidence for the increased risk of breast cancer as a result of LAN has accumulated in studies investigating shift workers (Dauchy 2014), risk in blind women (Feychting 1998), and the impact of sleep duration on risk. If electric light at night does explain a portion of the breast cancer burden, then there are practical interventions that can be implemented, including more selective use of light and the adoption of recent advances in lighting technology and application (Stevens 2009, 2014).

Stevens (2009) summarises the current view of health effects as a result of light at night. Breast cancer incidence increases rapidly as societies industrialise. Many changes occur during the industrialisation process, one of which is a dramatic alteration in the lighted environment from a sun-based system to an electricity-based system. Based on the fact that light during the night can suppress melatonin and also disrupt the circadian rhythm, it was proposed in 1987 that increasing use of electricity to light the night accounts in part for the rising risk of breast cancer globally. Predictions from the theory include: non-day shift work increases risk, blindness lowers risk, long sleep duration lowers risk, and population level community night-time light level co-distributes with breast cancer incidence. Thus far, studies of these predictions are consistent in support of the theory. Brainard looked at the published data in 1999, and concluded that it was unclear if EMF and electric light exposure are significant risk factors for breast cancer, but further study appears warranted. Given the ubiquitous nature of EMF and artificial light exposure along with the high incidence of breast cancer, even a small risk would have a substantial public health impact. According to Brainard (2001) there is a novel opsin photopigment in the human eye that mediates circadian photoreception, which may explain how people with visual difficulties may not be as affected by LAN. Stevens says (2009) that the molecular genetics of circadian rhythm generation are both advancing rapidly, and will provide for the development of lighting technologies at home and at work that minimise circadian disruption, while maintaining visual efficiency and aesthetics.

The National Institute of Environmental Health Sciences (NIEHS) in 2006 noted that it may not be entirely coincidental that dramatic increases in the risk of breast and prostate cancers, obesity and early-onset diabetes have mirrored the dramatic changes in the amount and pattern of artificial light generated during the night and day in modern societies.

Light at night led to changes in insulin production which can predispose to diabetes (Qian 2013).

When people are exposed, at night to light, a part of the electromagnetic spectrum, studies have shown significant reductions in the amount of melatonin that they have produced (reviewed by Henshaw & Reiter 2005, Grundy 2011).

Melatonin is responsible for many crucial processes in the body, including

- it is one of the most potent anti-cancer substances that the body naturally produces, repairing damaged cells
- it maintains circadian rhythm
- it is responsible for mood control, including depression and suicide
- it maintains the integrity of the immune system
- Other possible roles

Controlled laboratory studies do show that exposure to light during the night can disrupt neuroendocrine physiology, thereby accelerating tumour growth.

Breast cancer incidence is increasing globally (Stevens 2009). A study by O'Leary (2006) found women who switched the light on during sleep hours at home more than twice a week or more than twice a night, had an increased risk of developing breast cancer. Countries in which residents were exposed to more LAN had a higher number of men suffering from prostate cancer (Kloog 2009), though not lung or colon cancers, and women suffering from breast cancer, but not lung cancer (Kloog 2008). Kloog reported that according to the results of the 2011 study, not only should artificial light exposure in the working environment be considered as a potential risk factor for breast cancer, but also LAN in the "sleeping habitat." Prostate and breast cancers are hormone-dependent and thought to be associated with melatonin levels. Blask (2011, 2014) said that experimental evidence in rats and humans indicating that LAN-induced circadian disruption of the nocturnal melatonin signal activates human breast cancer growth or risk (He 2015). Wu (2011) suggested that it accelerated breast tumour growth. Dauchy (2014) found that melatonin made breast tumours more responsive to the anti-cancer drug tamoxifen and to tumour regression. Pauley, in a meta-analysis (2004), suggested that the proper use and colour of indoor lighting is important to the health of humans. Reed (2011) suggested that health care institutions work with occupational health nurses to develop and implement hazard communication and policies concerning shift work, exposure to light at night, and increased risk for negative health outcomes, particularly breast cancer.

A paper by Kloog (2010) found a 30-50% increased risk of breast cancer in countries with the highest versus lowest LAN levels. No such association was found between LAN and incidence of non-hormone-dependent lung, colorectal, larynx or liver cancers in women. Increased LAN may have implications for other lifestyle changes that may be implicated in such an increase, so a straightforward cause/effect relationship cannot be assumed.

Melatonin administered to experimental animals that were cancer-prone and exposed to constant light, significantly reduced the incidence of cancer, though not all animals exposed to constant light had an increased risk of tumours (Anderson 2000). Dauchy (2011) found that even very low levels of LAN in their animal laboratory disrupted circadian rhythms and stimulated cancer growth. Reducing LAN restored these aspects of metabolism. Zubidat (2011) found that LAN was an environmental stressor in voles affecting endocrine responses.

The breast cancer drug, doxorubicin has been shown to be less effective when the patient is exposed to light at night (LAN). LAN reduces the production of melatonin which acts as both a tumour metabolic inhibitor and also establishes the sensitivity of breast tumours to Doxorubicin. The authors of the paper indicate that light at night-induced circadian disruption of nocturnal melatonin production contributes to a complete loss of tumour sensitivity to Dox chemotherapy (Xiang 2015).

Human encroachment on wild animal habitats via night-time lighting may inadvertently compromise animals' immune function and ultimately fitness (Bedrosian 2011).

Vinogradova (2009, 2010) found that constant light exposure from the age of 1-2 months accelerated aging and promoted tumour development in rats. Starting constant light at the age of 14 months, tumour development was accelerated in females, but delayed in males.

Epidemiologic studies suggest increased cancer risk, especially for breast cancer, in night and rotating female shift workers. A consequence of shift work, is likely to be repeated disruption of the circadian system, pineal hormone melatonin suppression by exposure to light at night, sleep-deprivation-caused impairment of the immune system, plus metabolic changes favouring obesity and generation of proinflammatory reactive oxygen species (Haus & Smolensky 2013).

Working night shifts has been acknowledged by the International Agency for Research on Cancer (IARC) as a class IIA carcinogen. That is, that it is a probable cause of cancer. Brudnowska & Peplonska (2011) carried out a literature review on night shift work and cancer risk. In 6 out of 10 studies, a significant association was found between night shift work and risk of breast cancer, though not all studies found this effect (Travis 2016). However, in Travis' study "the baseline age of their women was nearly 70, and they followed their health for only 3 years; those women who reported ever doing shift work, did so probably long ago; current use is associated with significantly increased risk, but after 5 years of quitting, there is no association" said Richard Stevens, who has studied issues of shift work and subsequent melatonin depletion for many years. To do a prospective study with the majority of women aged about 68 years when their natural melatonin levels will have already fallen to very low diurnal levels because of their age is quite pointless. For people with 10-19 years of night-shift work that finished less than 10 years previous to diagnosis (only 52 cases) the relative risk was a significant 1.41.

An increased risk has been reported in nurses, radio-telephone operators, flight attendants and women employed in occupations in which 60% of employees work at night. Gromadzińska (2013) found an association between light-at-night exposure and a reduced level of enzymes in the blood which protect against oxidative damage in female nurses working shifts.

Chronic lymphocytic leukaemia (CLL) has few known modifiable risk factors. Recently, circadian disruption has been proposed as a potential contributor to the development of lymphoid neoplasms. Serum melatonin levels have been found to be significantly lower in CLL subjects compared with healthy controls. Night shift in excess of 20 years, especially among those with rotating shifts was positively associated with CLL (Costas 2016).

There is growing evidence that night shift, and aeroplane flight personnel, which may be considered to be proxies for exposure to light at night, is associated with an increased risk of breast cancer. Some studies show a direct link between light at night and breast cancer. (Davis 2001, Hansen 2001, Rafnsson 2001, Schernhammer 2001,2006, Anisimov 2002, 2003 Blask 2005, Nagata 2008, Viswanathan & Schernhammer 2009, Li 2010, Yang 2014). Other cancers have also been implicated, such as endometrial cancer (Viswanathan 2006), colorectal cancer (Schernhammer 2003), other cancers, and premature aging (Asinimov 2004, 2006).

Rotating night shift is associated with coronary heart disease. Brown (2009) also found a 4% increased risk of ischemic stroke after periods of rotating night shift work.

Fritschi (2011) suggests that multiple factors may be involved in the association between shift work and adverse health consequences (including cancer risk). They suggest phase shift; sleep disruption; lifestyle factors, such as poor quality diets, less physical activity and higher BMI; and lower vitamin D. These (and others) could be included in further studies, to discover which factors may have synergistic effects.

The risk of developing hormone-related cancers, such as breast and prostate cancer is decreased in people who have a visual impairment or who are blind (Verkasalo 1999, Pukkala 2006, Flynn-Evans 2009), supporting the link between light at night, melatonin implications and cancer risk.

The intrinsic period of the human circadian pacemaker averages 24.18 hours in adulthood and does not shorten with age (Czeisler 1999). The 24-hour day/night cycle, known as the circadian clock, affects physiologic processes in almost all organisms. These processes include brain wave patterns, hormone production, cell regulation, and other biologic activities. Disruption of the circadian clock is linked to several medical disorders in humans, including depression, insomnia, cardiovascular disease and cancer, says Paolo Sassone-Corsi, chairman of the Pharmacology Department at the University of California. *"Studies show that the circadian cycle controls from ten to fifteen percent of our genes,"* he explains. Fonken (2009) found that mice exposed to constant light had increased depressive-like and decreased anxiety-like responses. Even dim light at night disturbs the circadian clock and affects molecular mechanisms (Ikeno 2013).

A representative survey revealed that 90% of Americans used some type of electronics at least a few nights per week within 1 h before bedtime. Mounting evidence from countries around the world shows the negative impact of such technology use on sleep. This negative impact on sleep may be due to the short-wavelength-enriched light emitted by these electronic devices, given that artificial-light exposure has been shown experimentally to produce alerting effects, suppress melatonin, and phase-shift the biological clock (Chang 2015). Among a range of technologies, interactive technological devices are most strongly associated with sleep complaints (Gradisar 2013). Adolescents living in brightly illuminated urban districts had a stronger evening-type orientation than adolescents living in darker and more rural municipalities. Time spent on electronic screen media use – a source of indoor light at night – is also correlated with eveningness. Adequate urban development design and parents limiting adolescents' electronic screen media use in the evening could help to adjust adolescents' zeitgeber (an environmental condition that acts to reset an innate biological rhythm) to early school schedules when they provide appropriate lighting conditions for daytime and for nighttime (Vollmer 2012).

The hypothesis that has been accepted is that light at night disrupts the body's circadian rhythm (Stevens & Rea 2001, Stevens 2007, Bedrosian 2012), and the production of melatonin (Blask 2002). Richard Stevens, one of the foremost researchers into the biological effects of light at night said in his 2005 paper *"Lighting during the night of sufficient intensity can disrupt circadian rhythms, including reduction of circulating melatonin levels and resetting of the circadian pacemaker of the suprachiasmatic nuclei. Reduced melatonin may increase breast cancer risk through several mechanisms, including increased estrogen production and altered estrogen receptor function. Epidemiologic studies should consider gene and environment interactions such as circadian gene variants and shift work requirements on the job".*

Buijs (2017) found that the suprachiasmatic nucleus is more than an autonomous clock, and forms an essential component of a larger network controlling homeostasis. An imbalance in this through circadian disruption could be involved in the aetiology of metabolic disorders.

Juutilainen & Kumlin (2006) found that those people who were occupationally exposed to magnetic fields and also had night time light exposure produced significantly lower levels of melatonin. Ghaderi (2014) found that low levels of urinary melatonin resulted in people being susceptible to developing skin cancer. The subjects of the study also had problems with sleep duration.

Blask (2009) concludes *"The mutual reinforcement of interacting circadian rhythms of melatonin production, the sleep/wake cycle and immune function may indicate a new role for undisturbed, high quality sleep, and perhaps even more importantly, uninterrupted darkness, as a previously unappreciated endogenous mechanism of cancer prevention."*

Ohta (2006) found that constant light very early in life (such as in neonatal intensive care units [NICUs]) had both acute and long-term disruptive effects on developing biological clocks and that cyclic lighting conditions are critical for developing circadian clocks to coordinate their molecular circadian mechanisms.

Other studies are implicating over- or underexpression of genes known to be involved in the body's circadian clock. Healthy women showed a lower expression of the CLOCK gene than women with breast cancer (Hoffman 2010). They also found that epigenetic changes – the switching on or off of genes as a result of environmental factors – may play a role. For instance, an epigenetic change called promoter methylation, which turns off expression of CLOCK, was associated with a lower risk of breast cancer. A pilot study by Zhu (2011) found evidence of cancer-relevant epigenetic effects of night shiftwork, affecting breast cancer risk.

Long-term shiftwork may alter methylation patterns at imprinted genes (Jacobs 2012), which may be an important mechanism by which shiftwork has carcinogenic potential.

Melatonin is a hormone known to be involved in mood regulation, and low melatonin levels have been found in people suffering from depression. The intensity, duration and wavelength of lighting seems to be significant (Glickman 2002, Lockley 2003, Hanifin 2006, Jasser 2006) though this has been less researched. Alpert (2009) suggested that it is primarily the blue wavelengths of light that are responsible for loss of melatonin. Blocking the blue wavelengths with amber glasses restores melatonin production. They believe that wearing these type of glasses or using blue-free light bulbs for a few hours before bedtime maximises melatonin production and reduces the risk of breast, ovarian and prostate cancer. Bennett (2009) suggested that these glasses or bulbs may be helpful in preventing postnatal depression in women who get up at night to feed their new-born babies.

A study by Shang (2017) indicated that LED blue-light exposure poses a great risk of retinal injury in awake, task-oriented rod-dominant animals. The wavelength-dependent effect should be considered carefully when switching to LED lighting applications.

College students using computers late at night were investigated to see whether this had an effect on their melatonin levels. It seemed that as long as there were no bright, blue white light present as well, exposure to computer screens had little effect (Figueiro 2011). Clearly, monitors should be adjusted to give the minimum light-exposure that is comfortable to work with in night-time conditions.

The reduction of melatonin has been implicated in the development of Parkinson's disease.

Circadian dysfunction may underlie excessive sleepiness. Approaches aimed to strengthen circadian function, such as timed exposure to bright light and exercise, might serve as complementary therapies for the nonmotor manifestations (Videnovic 2014).

Our exposure to light at night may be having some impact on the excessive weight that is a problem for many people. Fonken (2010, 2013a, 2013b) reports that mice housed in bright or dim light without a dark cycle had significantly increased body mass and reduced glucose tolerance compared with mice who had a normal dark/light cycle, despite equivalent levels of calories and activity. In a review by Fonken and Nelson (2014), the authors suggest that *"The increase in exposure to light at night parallels the global increase in the prevalence of obesity and metabolic disorders."* They further propose that *"exposure to light at night alters metabolic function through disruption of the circadian system."* Tan & Scott (2014) in their mouse studies identified tissue-specific deletion of core clock genes in key metabolic tissues confirming a mechanistic relationship between the circadian clock and the development of metabolic disease. Circadian misalignment increases insulin resistance and decreases pancreatic function. Clock gene polymorphisms or altered expression of clock genes induced by circadian misalignment appear to play a role in the development of obesity and diabetes in humans. Circadian disruption caused by exposure to light at night is associated with lower nocturnal melatonin, which in turn seems to affect glucose metabolism. Potential therapies for circadian misalignment include entraining the central pacemaker with timed light exposure and/or melatonin and restricting food intake to the biological day.

Van Moorsel (2016) suggests that the biological clock drives robust rhythms in human skeletal muscle oxidative metabolism. The authors speculate that disruption of these rhythms contribute to the deterioration of metabolic health associated with circadian misalignment.

Plant, animal and insect effects

Karatsoreos (2011) also reports the weight gain effect, and adds that animals with a chronically disrupted circadian rhythm also showed decreased cognitive flexibility and changes in emotionality.

Artificial light at night has been identified as a major driver of change in timing (a characteristic of melatonin) of daily activity in urban-dwelling songbirds (Dominoni 2014).

Bennie (2015) found that the physiological effects of light at night on a plant species within a diverse plant community can have detectable effects on a specialist herbivore.

In a study on crickets (Jones 2015), melatonin supplementation was able only partially to mitigate the detrimental effects of artificial light at night.

Eggs deposited by nesting female loggerhead **turtles** were permitted to develop in situ either in the natural ambient magnetic field or in a magnetic field distorted by magnets placed around the nest. In orientation experiments, hatchlings that developed in the normal ambient field oriented approximately south when exposed to a field that exists near the northern coast of Portugal, a direction consistent with their migratory route in the northeastern Atlantic. By contrast, hatchlings that developed in a distorted magnetic field had orientation indistinguishable from random when tested in the same north Portugal field. The authors (Fuxjager 2014) suggested that the magnetic environment present during early development can influence the magnetic orientation behaviour of a neonatal migratory animal.

Painter (2013) suggested that characterizing the mechanism(s) of magnetoreception in flies may hold the key to understanding the magnetic sense in a wide array of terrestrial organisms.

The spectacular migration of monarch butterflies partly involves an inclination magnetic compass which is light-dependent utilizing ultraviolet-A/blue light between 380 and 420 nm (Guerra 2014).

A review of the effects of powerfrequency radiation on **birds** was carried out by Fernie & Reynolds (2005). They found that *"most studies indicate that EMF exposure of birds generally changes, but not always consistently in effect or in direction, their behavior, reproductive success, growth and development, physiology and endocrinology, and oxidative stress under EMF conditions."* In a previous study she had reported increased levels of oxidative stress in American kestrels exposed to EMFs (Fernie & Bird 2001). Birds have an ability to sense magnetic fields of the earth to navigate (Hohtola 2016). Wiltschko & Wiltschko (2013) showed there are magnetite-based magnetoreceptors located in birds' upper beak close to the skin. Their natural function appears to be recording magnetic intensity and thus providing one component of the multi-factorial 'navigational map' of birds.

In a study looking at the mortality rates in endangered **raptors** due to power lines (Guil 2011), pylons with cable insulation showed higher electrocution rates than unimproved pylons, both for raptors and eagles. DeGregorio (2014) found that only indigo **buntings** (*Passerina cyanea*) decreased with proximity to power lines, that landscape features are likely to be specific to both the local predators and landscape. Decades after the problem was first identified, power line electrocution continues to be a cause of avian mortality. Currently, several federal laws protect eagles and other migratory birds, meaning that utility companies may be liable for electrocution-related deaths (Kagan 2016).

Gonet (2009) found that magnetic fields had negative reproductive effects on **flies** for three generations from exposure. ELF magnetic field significantly decreases locomotor activity of adult **flies** at all developmental stages (Dimitrijevic 2014).

The **nematode**, Caenorhabditis elegans, orients to the earth's magnetic field during vertical burrowing migrations. Well-fed worms migrated up, while starved worms migrated down, northern- and southern-hemisphere worms displaying opposite migratory preferences (Vidal-Gadea 2015).

Many light thin **bumblebee** hairs respond to the electrical field surrounding a flower. This provides key evidence for electrosensitivity to ecologically relevant electric fields. It is possible that other terrestrial animals use such sensory hairs to detect and respond to electric fields.

Oriental hornet workers build brood combs of hexagonal cells. Magnetic field exposure in oriental hornets caused (a) 35-55% smaller number of cells and fewer eggs in each comb, (b) disrupted symmetry of building, with many deformed and imperfectly hexagonal cells, and (c) more delicate and slender comb stems (Ishay 2007).

Nishimura (2010) found that **lizards** responded to low frequency electromagnetic fields, but that the effects seem to be mediated by light as they stopped when the parietal eye (at the top of the head, photoreceptive and associated with the pineal gland) was covered. This adds further evidence to the protective effect of melatonin which is produced by the pineal gland.

Foxes attack their prey from the north, a case of magnetic alignment (Cerveny 2011). Do the fox victims have reduced sensitivity from some directions? They may use the magnetic fields as a 'range finder' or targeting system to measure distance and increase accuracy. Some of the same team had found that **rodents** (mole-rats) navigate by means of neurons responsive to magnetic stimuli (Burger 2010). As some people can navigate using inbuilt magnetic directions it is difficult to know what biological effects may be triggered by magnetic disturbance.

The discovery means that foxes join migratory animals (**pigeons**, turtles and **whales**) in being able to sense magnetic direction.

The magnetic compass orientation of European **robins** could not be disrupted by any of the relatively strong narrow-band electromagnetic fields employed in a study by Schwarze (2016), but weak broadband field very efficiently disrupted their orientation.

Phillips (2013) reported that mice have a well-developed magnetic compass, which gives further impetus to the question of whether epigeic rodents (e.g., mice and rats) have a photoreceptor-based magnetic compass similar to that found in amphibians and migratory birds.

Aquatic life

The activity and drift of gammarids (a type of tiny crustacean), were affected by bright light. This may have consequences for the fresh water ecology in cities (Perkin 2014).