Electromagnetic Fields and Melatonin & Serotonin: an Investigation into EMF Effects on Associated Neuroendocrine Functions

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Abstract

Melatonin and serotonin are two very important chemicals in the body. Melatonin is a hormone and antioxidant that regulates sleep and also plays roles in depression and anxiety. Serotonin is a neurotransmitter that plays large roles in mood, sleep, and memory. In this paper, I investigate the effects of electromagnetic fields on melatonin and serotonin levels, then investigate the effects of EMFs on the functions these two chemicals play in the body, looking specifically at effects on sleep, mood, cognitive function, and cancer.

Biological Effects of Melatonin and Serotonin

Melatonin in a hormone secreted by the pineal gland that plays major roles in maintaining circadian rhythms [1]. The pineal gland responds to changes in light levels, traditionally from daytime, and is only active at night or in darkness [1]. This is because the pineal gland is stimulated by photoreceptors in the retinas of the eye that detect light levels, meaning darkness sends a stimulating signal to the gland, while light sends an inhibitory signal. Consequently, melatonin levels vary based on the time of day, being high at night and barely detectible during the day [1].

Melatonin plays a variety of roles throughout the body. It is a known antioxidant and plays a role in regulating sleep [1, 2]. Melatonin is thus thought to be a major factor in sleep disorders and sleep quality, and due to its antioxidant properties, a possible factor in cancer. It may also play a role in dementia, depression, fatigue, headaches, anxiety, and many other disorders and diseases [2].

Serotonin is a neurotransmitter used throughout the body, but playing primarily large functions in the brain [3]. Serotonin regulates mood and emotions, sleep, anxiety, appetite, and memory, and its specific role is determined by the location in the brain in which it is operating [3, 4]. Thus, serotonin and melatonin are very related in the effects they have on the body. Serotonin levels also tend to vary over the course of a day, though much less noticeably so than melatonin levels.

Effects of EMFs on Melatonin

Because melatonin is naturally regulated by light, the question arises whether other non-visible electromagnetic fields affect melatonin levels.

Research shows that artificial light, or electromagnetic waves in the visible spectrum, cause significant decreases in nighttime melatonin levels, even if the exposure is brief [5]. The brightness and wavelength within the visual range have both been shown to affect the response, which is also highly species specific [5]. For example, nocturnal animals have been found to be the most sensitive to brightness, needing very low levels of light to decrease melatonin levels, while diurnal species have slightly higher tolerances before disruptions occur [5].

Studies on non-visible EMFs on melatonin levels have produced varying results. Many studies and experiments have found that exposure to electromagnetic fields during sleep resulted or were correlated with decreased plasma, pineal, and serum melatonin levels during the night [5, 6, 7, 8, 9, 10, 15]. Investigations into the mechanisms of such findings suggest that EMFs disturb melatonin at the cellular level, rather than chemical level [10].

When investigating the type of electromagnetic field that could produce such a decrease in melatonin, it was found that rapidly inverted DC fields, pulsed EMFs, and sinusoidal fields produced a decrease in melatonin, but constant fields resulted in no significant difference [6, 8]. The decrease in melatonin due to magnetic fields was found in all cases to be lower in magnitude than the drop caused by visible light [6].

The frequency of the electromagnetic field also significantly impacts the effect of the EMF on melatonin. One study found that frequency Ku band exposure significantly decreased melatonin levels, while X band exposure decreased melatonin levels only slightly, not enough to be statistically significant [7].

A study done on kestrels indicated that sex may play a role in the relationship between EMFs and melatonin. The study found that male kestrels and fledglings experienced a decrease in melatonin levels, while females experienced no effect [9]. It suggested that the sexual dimorphism of the kestrel species predisposed males to be more sensitive to electromagnetic fields than females, since males have higher melatonin levels to start, making any fluctuations more noticeable and consequently more statistically significant [9].

It has been found, however, that some factors of EMF exposure do not affect melatonin levels. Strength of the wave above a certain detection threshold, length of exposure time, and time subjects spent in darkness before exposure were all found to have no significant impact on melatonin levels, with all exposure conditions producing a very similar drop in melatonin levels with exposure to pulsed DC magnetic fields [8].

A couple experiments found no effect on melatonin. An experiment done on humans found that both 50 Hz magnetic fields and intermittent fields had no effect on melatonin levels [11]. This result could indicate that human melatonin may be less sensitive to electromagnetic fields or that the 50 Hz frequency does not affect melatonin, since other studies have shown frequency dependence. Another experiment on mice found no statistically significant decrease in melatonin, though the authors acknowledged that this could have been due to sample size [13].

It should be noted that there are difficulties and confounding factors in all of the experiments involving EMFs and melatonin. One of the big challenges is that each experiment tends to be significantly distinct from the next, using a different species, different wavelength, etc., so it becomes difficult to compare experiments and draw conclusions across them [12]. Confounding factors that experiments face include melatonin's role as a circadian clock (such as circadian phase), adjustment to experimental environment, and light exposure during sampling. Any of these factors could cause inconsistent or incorrect results.

Effects of EMFs on Serotonin

The effect EMFs have on serotonin is much more consistent. Experiments have found that exposure to electromagnetic fields increases serotonin levels [6, 7, 13, 14, 15, 16]. Though most experiments were performed using frequencies near to cell phone frequencies, one study investigated two frequency bands, finding that Ku band exposure was associated with significantly higher serotonin levels than X band, which was elevated but not statistically significantly so [7]. This suggests that response may be frequency dependent, making it difficult to extend the findings of the many studies in the cell phone range to all EMFs.

Multiple mechanisms have been proposed to explain this phenomenon. One proposal is that the EMF induces currents in the brain, leading to changes in chemical functions, but this theory is yet to be tested [13]. Another hypothesis is that increased serotonin and decreased melatonin are directly related; serotonin levels increase because it isn't being metabolized to melatonin as much [6]. While this hypothesis seems possible, it may be showing false causation between serotonin and melatonin. A final hypothesis is that EMFs induce the inactive state of the serotonin receptor, leading to decreased bonding of serotonin to its receptor, which then causes the release of more serotonin in an attempt to compensate [16]. This hypothesis has actually been tested, finding that EMFs did induce the inactive receptor state, leading to decreased binding and increased serotonin release [16]. However, the other mechanisms proposed may also play a role in overall serotonin levels and should still be investigated further.

EMFs and Sleep

Melatonin and serotonin play major roles in sleep regulation, so changes in the levels of these chemicals should affect sleep. Since experimentation and studies up to this point strongly suggest that EMFs affect melatonin and serotonin, one would expect EMFs to affect sleep as well, presumably through the mechanism of changes in melatonin and serotonin levels.

Studies on EMFs and sleep have produced inconsistent and conflicting results; well designed and executed studies and experiments have concluded both that EMFs do affect sleep and that they have no effect. I will look first at the studies claiming an effect.

The most frequently observed effect is an increase in EEG spectral power during sleep, and has been noted by different experiments to occur in nearly all stages of sleep [17, 18, 21, 22]. This increase in spectral EEG power was found as a result of radiofrequency EMFs and pulsed magnetic fields. Regel et al. found a dose-response relationship, meaning that more exposure to the EMF had a greater effect on EEG power [22]. However, none of these studies found an adverse effect on health from this increased EEG power.

Another significant effect noted by multiple studies was changes in REM sleep, which is thought to be the most important type of sleep [17, 18]. Loughran et al found that EMF exposure before sleep resulted in a decrease in REM latency [17], and Schmid et al. found a slight decrease in the duration of REM sleep [18]. These findings would suggest that exposure may lead to a poorer quality of sleep due to REM sleep's important resting functions.

Indeed, there are studies that claim exposure causes or is correlated with negative, qualitative aspects of sleep. Studies suggest that EMF exposure is correlated with lowered sleep quality, sleep disturbances, and insomnia [19, 23]. A study done by Huss et al. found that only high levels of EMF exposure was associated with decreased sleep duration and decreased parasomnias [20]. They also found that increased cell phone usage was correlated with increased sleep onset delay, increased sleep duration, and increased parasomnias [20]. These different findings at different frequencies suggest a frequency-dependent relationship.

In contrast, there are many studies that claim that sleep is not affected by EMF exposure [24, 25, 26]. When looking at the qualitative variables of sleep, these studies found that there was no association between EMF exposure and sleep disturbances, poor sleep quality, and daytime sleepiness [21, 25, 26]. One study found no effect on the sleep cycle (percentages of time spent in each sleep stage), as well as no effect on the sleep EEG [25]. All of these studies looked only at cell phone frequency EMFs, and thus other frequencies could still cause some effect.

Overall, it is unclear whether EMFs are associated with negative effects on sleep, and more research needs to be done in this area, especially at more frequency ranges, to determine the relationship.

EMFs and Cognitive Function

Melatonin and serotonin are known to play a role in cognitive functioning, such as memory, attention, reaction time, and perception. Thus, as with sleep, it should be investigated whether EMFs affect cognitive functioning.

Research into the relationship between EMFs and cognitive functions is more difficult to quantify, and thus the most commonly used cognitive functions to investigate and draw conclusions from are reaction time, attention, and memory.

Multiple experiments have found that EMF exposure either before or during a cognitive task has no effect on reaction time, both simple and choice types [27, 28, 29, 30]. Perception of time has also been observed to be not effected by EMF exposure [27].

Studies have found conflicting results regarding an effect on attention and memory. Two experiments by Sauter et al. found EMF exposure at two different frequencies to have no effect on both selective and divided attention, as well as no effect on working memory [28, 30]. However, an experiment done by Sienkiewicz et al. found a decrease in attention and memory with exposure [29].

With cognition, speed and accuracy to complete cognitive tasks must also be taken into consideration, since these are common signs of impaired cognition. One experiment by Regel et al. found that speed of completing cognitive tasks decreased with exposure, and that it did so with a dose-response relationship, meaning more exposure resulted in slower completion of tasks [22]. This study found no effect on accuracy, however. In contrast, the experiment done by Sienkiewicz et al. found no change in speed, but a significant decrease in accuracy [29]. Though conflicting results, these both indicate some cognitive impairment from EMF exposure.

The difficulty in quantifying cognition is likely the biggest confounding factor in attempting to draw conclusions from these studies. Except for the two studies done by the same researchers (28, 30), each of these experiments likely uses different scales, thresholds, and statistical analysis methods to quantify the qualitative variables of memory and attention, which is likely why these aspects of cognition show the least consistency across experiments. For example, reaction time, which is easily quantifiable, showed a very consistent lack of effect compared to the inconsistent results of memory and attention.

As with sleep, it is still unclear whether or not exposure to electromagnetic fields has any effect on cognition, and it may be too difficult to do so until standardized methods for quantifying cognition are established.

EMFs and Cancer

Melatonin is extremely important as an antioxidant in the body, working to boost the immune system and fight cancer. Low melatonin levels are thought to play a possible role in cancer formation, progression, or incidence, though no concrete conclusion supporting or refuting this claim can be made with the information and research currently available, especially since cancer is already known to have many contributing factors. It should be investigated whether EMFs contribute to cancer by lowering melatonin levels.

In a chapter of *The Handbook of Biological Effects of Electromagnetic Fields: Biological and Medical Aspects of Electromagnetic Fields*, David McCormick overviews many studies that investigate cancer and tumor incidence with and without exposure to various magnetic and electromagnetic fields. Nearly all of the studies come to the same conclusion: electromagnetic field exposure does not have any statistically significant effect on cancer in rodents, in both chronic and multistage studies and even in genetically modified rodents [31]. It is very clear that EMF exposure does not affect the risk of cancer in rodents.

However, because of ethical reasons and long lifespan, no experiments have yet been done on humans, so we cannot determine if EMFs play a role in human cancer risk. We can only postulate that the effect, or lack of effect, observed in rodents is likely to extend to humans as well, due to similarities in cancer formation and progression between the species, but no conclusions about humans can be drawn.

EMFs and Mood

Melatonin and especially serotonin are both known to affect mood, so much so that serotonin is often known as the "happy" neurotransmitter. High levels of serotonin cause a feeling of happiness, while low levels of serotonin or serotonin deficiencies lead to depressed mood and many mood disorders, such as bipolar depressive disorder, major depressive disorder, and seasonal affective disorder. Thus, EMFs pose a unique possibility to treat depressive disorders and improve mood by increasing serotonin.

Many studies support the claim that EMFs can treat depression improve mood. Various forms of electromagnetic exposure have been investigated as possible treatments for depressive disorders. Rohan et al. found that low field magnetic stimulation produced an increase in mood in patients with bipolar depression or major depressive disorder [32]. Experimentation by Triggs et al. demonstrated that prefrontal rapid transcranial magnetic stimulation improved mood in medication-resistant major depressive disorder patients [33]. Kosel et al. showed that magnetic seizure therapy caused remission of depression symptoms without cognitive side effects often associated with the treatment [34]. Finally, a study by Martiny et al. found that transcranially-applied pulsed electromagnetic fields produced positive effects for treating depression, with responses that were higher than other antidepressants [35]. All of these studies use electromagnetic radiation that is applied directly to the skull or brain, rather than external EMFs.

In contrast, other studies have found that EMF exposure negatively impacts mood. In both cases, external EMFs were used at frequencies similar to those of a cell phone or other commonly used device that emits electromagnetic radiation. These studies found that exposure to cell phone frequency and microwave frequency EMFs was associated with decreased mood and well-being, and even increased incidence of depression [36, 23].

Another study investigating external EMFs, specifically the field radiated from power lines, found no association between exposure and depression symptoms [37].

From these studies, it seems clear that direct electromagnetic stimulation and exposure produces significant mood-improving results and appears to be a promising potential method of treatment for medication-resistant depression. However, the effects of being in an external EMF and having that indirect electromagnetic exposure are still unclear and deserve further investigation, particularly in carefully controlled experiments rather than studies.

Conclusions

Based on the studies and experiments reviewed in this paper, there is sufficient evidence to show that electromagnetic fields affect both melatonin and serotonin levels, resulting in decreased nighttime melatonin levels and increased serotonin levels.

Since melatonin and serotonin play significant roles in various functions throughout the body, I investigated whether EMFs cause or are correlated changes in these processes, since then any effects observed would have a biochemical mechanism through which to occur. Put differently, with evidence strongly supporting that EMFs affect melatonin and serotonin, I wanted to see if EMFs could affect processes like sleep or mood through the mechanism of melatonin or serotonin.

Review of current research showed no consistent conclusion for EMF exposure having an effect on sleep, cognitive function, and mood. Studies pretty consistently agreed that EMF exposure had no significant association with cancer, and studies also suggested that direct electromagnetic exposure produced positive effects on mood, serving as a possible treatment for depressive disorders.

Going forward, I would suggest more research in the areas of sleep, cognition, and mood with exposure to electromagnetic radiation. More experiments using humans with greater sample sizes need to be performed, and some sort of standardization for quantifying results needs to be established for use in all future studies to make comparable, repeatable results. I would also suggest more experiments investigating melatonin and serotonin levels to be performed using humans, since it is known that sensitivity to light and other forms of electromagnetic radiation is highly species specific. Thus, the findings from rodents cannot be extended to apply to humans, and only a few experiments investigating the levels of melatonin and serotonin in response to EMF exposure have been performed. So few experiments makes it difficult to confidently determine a causal relationship.

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