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Assessment of cortisol secretory pattern in workers chronically exposed to ELF-EMF generated by high voltage transmission lines and substations

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ABSTRACT

We investigated the effects of extremely-low frequency electromagnetic fields (ELF-EMFs; 50 Hz) on the secretion of cortisol in 14 men (mean age = 38.0 ± 0.9 years) working in extra-high voltage (EHV) substations. The workers dwelt in houses that were close to substations and high-voltage lines. Thus, they had long histories (1–20 years) of long-yerm exposure to ELF-EMFs. Magnetic field strength was recorded using Emdex dosimeters worn by the volunteers day and night for seven days; the one-week geometric mean ranged from 0.1 to 2.6 μT. Blood samples were taken hourly from 20:00 to 08:00 the next morning. Cortisol concentrations and patterns were compared to age-matched, unexposed control subjects whose exposure level was ten times lower. The comparison of the control group (n = 15) and the groups exposed to fields of 0.1–0.3 μT (n = 5) and > 0.3 μT (n = 9), respectively, revealed a significant effect of field intensity on the cortisol secretory pattern. This study strongly suggests that chronic exposure to ELF-EMFs alters the peak-time serum cortisol levels. Studies are required on the effect of this disruption in high-risk populations such as children, elderly people, and patients with cancer.

1. Introduction

Any living matter is exposed to extremely low frequency electromagnetic fields (ELF-EMFs) that are produced around electrical conductors, electrical networks, high-voltage lines, or household appliances. The human environment has thus been transformed in recent decades by the increasing use of electrical energy. The amplitude of the electrical component is a function of voltage; consequently, the strongest electric fields are found around high-voltage lines. The magnetic field, the amplitude of which depends on the intensity of the current, is strongest in the immediate vicinity of electrical devices.

In humans, epidemiological surveys have highlighted possible health risks associated with exposure to ELF-EMFs of 50 Hz (Europe) and 60 Hz (USA). The first study linking childhood cancer to ELF-EMF exposure reported that the risk for developing childhood leukemia is higher for residences with higher levels of exposure to ELF-EMFs (Wertheimer and Leeper, 1979, 1982). Subsequently, many epidemiological studies have confirmed this association and also highlighted the association of ELF-EMF exposure with brain cancer (Kheifets et al., 2017; Huss et al., 2018; Carles et al., 2020; Khan et al., 2021) and neurodegenerative diseases (Vergara et al., 2013; Gunnarsson and Bodin, 2019). However, no firm conclusions can be drawn, given the contradictory data in the available literature. Notwithstanding, in 2002 the International Agency for Research on Cancer (IARC) placed ELF-EMFs in group 2B of agents that are possibly carcinogenic to humans, indicating that a positive association was established between the occurrence of cancer and exposure to ELF-EMFs, but the contributing role of chance, bias, or confounding factors cannot be excluded with sufficient certainty. The group 2B contains several agents (n = 322 as of January 2022) that may be carcinogenic to humans (IARC, 2019).

Thus far, a number of in vitro and in vivo animal studies have highlighted some biological effects of ELF-EMF exposure, although the underlying mechanisms remain unclear. Some authors reported reduced pineal synthesis of melatonin in laboratory animals as the most consistent biological effect (Brendel et al., 2000; Selmaoui and Touitou, 1995, 1997, 1999; Touitou et al., 2010), which resulted in a "melatonin hypothesis" (Stevens and Davis, 1996). Contrarily, we found that long-term exposure to magnetic fields did not affect melatonin secretion in humans (Touitou et al., 2003) which rebutted the melatonin hypothesis. Another potential mechanism that was observed in studies on rodents is

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the stress response induced by ELF-EMF, resulting in an increase in corticosterone secretion and depression and/or anxiety-like behavior (Szemerszky et al., 2010; Kitaoka et al., 2013, 2016; de Kleijn et al., 2016; Klimek and Rogalska, 2021; Rauš Balind et al., 2016). Taking into account the latter data on on the adrenal gland together with the relationship between the hypothalamic–pituitaryadrenal axis and ELF-EMF exposure, recently highlighted in a Cochrane review (Rensen et al., 2017), we found worth to document, in healthy human subjects, the effects of magnetic fields on the secretion of cortisol, the major glucocorticoid hormone. This paper is, to our knowledge, the first dealing with the effects of long-term exposure to ELF-EMFs that ranged from 1 to 20 years and took place both during daytime at work and during nighttime at home, since the subjects lived near EHV substations.

2. Experimental protocol

The previously described protocol (Touitou et al., 2013) was approved by the hospital ethics committee and conducted in accordance with the Declaration of Helsinki (Portaluppi et al., 2010; Touitou et al., 2006). The main elements of the protocol are described below.

2.1. Subjects

Twenty-nine men participated in the study and had the following characteristics: aged between 30 and 48 years, non-smokers (<5 cigarettes per day), non-alcoholics (GGT < 50), coffee consumption < 4 cups per day, no medications, no sleep disturbances, no transmeridian flight in the three weeks preceding the study, and no on-call duty in the 48 h prior to the assessment. The exposed group comprised 15 of these subjects who were chronically exposed to magnetic fields. Their residences in the Paris metropolitan region were near the substations and had overhead high-voltage lines. A group of 15 matched subjects with similar characteristics served as a control group. All the subjects were volunteers, had the same circadian synchronization (work and rest schedules), and were similar in age, size, and level of physical activity. All underwent a clinical examination of their medical and surgical history, and a biological examination to verify compliance with endocrine reference standards and current blood parameters. The study, carried out at the clinical investigation center (CIC) of the Pitié-Salpêtrière Hospital Group (Paris, France), involved 12-h monitoring periods, from 20:00 to 08:00 the next morning; blood samples were taken hourly, i.e., 13 samples per subject for each 12-h monitoring period. The volunteers left the CIC at 08:00 after the thirteenth sample was drawn. The subjects wore a dosimeter approximately the size of a cellphone (Emdex; Enertech Consultants, Campbell, CA, USA) day and night for one week, allowing the continuous recording of the magnetic field exposure for seven weeks, both at work and at home, according to a previously described protocol (Touitou et al., 2013).

2.2. Hormone assays

Blood samples were collected in tubes without anticoagulants and then centrifuged to obtain the serum which was stored at −20 °C until assayed. To prevent assay variation, the samples were tested in a single series using a fully automated analyzer running a commercial enzyme-linked immunosorbent assay (ELISA; Boehringer Mannheim, Meylan France). The intra-assay coefficient of variation was 6.1% for a serum cortisol level of 290 nmol/L.

2.3. Statistical analysis

Statistical analysis of the experimental data was carried out using EMCALC software (Enertech Consultants) provided with the dosimeters. The arithmetic and geometric means with standard deviations and medians were calculated for the seven days of exposure, as well as the lowest and highest values. Repeated measures analysis of variance (ANOVA) was performed to evaluate the statistical differences ($p < 0.05$) between the exposed subjects and controls, using the raw, untransformed values. Three factors were investigated: time, field effect, and time × field interaction. The F and p values are shown in Table 1. Post-test Bonferroni correction was applied. The significance level was set at $p < 0.05$. The repeated measures factor corresponds to the time pattern of the studied hormone. As our working hypothesis was to find an effect of magnetic fields on concentrations and the temporal profile of cortisol, we looked at both the "field" effect and "time" factor (secretory pattern).

3. Results

The weekly geometric mean intensity of individual exposures in the exposed group ranged from 0.1 to 2.6 μT; the arithmetic mean of the exposure values (n = 14) was 0.72 μT. The arithmetic means of the residential and daytime exposures of the exposed subjects were 0.82 μT and 0.64 μT, respectively.

The weekly geometric mean of individual exposures in the control group ranged from 0.004 to 0.092 μT; the arithmetic mean of the exposure values (n = 15) was 0.04 μT. Using a statistical *t*-test to compare the means, a significant statistical difference ($p < 0.05$) was observed between the arithmetic and geometric means.

The cortisol secretory pattern of the control group showed the typical progressive decline in serum concentration until 00:00, followed by a progressive reascent to the peak at 06:00–08:00. The comparison between groups showed a statistically significant difference in the cortisol concentrations between the exposed and the control groups (time factor; Table 1). In the exposed group (n = 14), the cortisol secretory pattern was roughly the same until 06:00, followed by an abrupt decline in the serum cortisol levels at the last two time points. The effect of field intensity is shown in the comparison between the control group (n = 15), the group exposed to magnetic fields in the intensity range of 0.1–0.3 μT (n = 5), and the group exposed to the highest intensity level > 0.3 μT (n = 9) (Table 1 and Fig. 1 and 2). Regardless of the condition and group, a statistical validation was carried out for the field × hour interaction. Consequently, it is suggested that there was circadian desynchronization of this candidate marker, cortisol, as a result of long-term exposure to ELF-EMFs (Table 1) (see Fig. 2).

4. Discussion

For the general population, the levels of exposure to electric and magnetic fields vary from 5 to 50 V/m and 0.01–0.2 μT, respectively. The potential health risk posed by exposure to EMFs has become a public

Table 1
Repeated Measures Analysis Of Variance. Comparison between chronically exposed men and age-matched controls. Statistical analysis examined the following three factors: the hour factor, the field effect factor, and the hour-field interaction.

CONTROLS /EXPOSED (15/14)		
Variables/factors	*F*	*p*
Cortisol		
Field	0.52	0.48
Hour	55.78	< 0.0001
Field × hour interaction	3.09	0.0004
	CONTROLS/0.1 – 0.3 μT (15/5)	
Cortisol		
Field	0.78	0.39
Hour	21.61	< 0.0001
Field × hour interaction	2.01	0.027
	CONTROLS/> 0.3 μT (15/9)	
Cortisol		
Field	0.29	0.60
Hour	47.68	< 0.0001
Field × hour interaction	2.34	0.0076

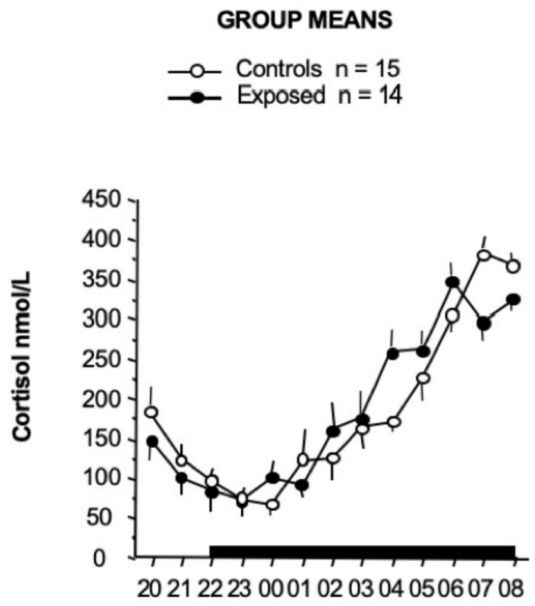


Fig. 1. Cortisol secretory patterns in 14 healthy male electricity workers working in extra high voltage station with a history of long-term exposure (1–20 years) to extremely low frequency electromagnetic fields (ELF-EMFs). They were compared to 15 age-matched controls. Blood samples were taken hourly (from 20 :00 h to 08 :00 h) the next morning, resulting in 13 samples per subject for each 12-h monitoring span of time. The weekly geometric mean of individual exposures ranged from 0.1 to 2.6 μT. Each point is the mean value of cortisol levels.

concern, prompting numerous scientific studies on the subject. Considering the great increase in environmental exposure to magnetic fields, their potentially deleterious effects on human health is a cause for serious concern, and has resulted in several epidemiological studies suggesting an association between exposure to low-frequency electromagnetic fields (50 Hz and 60 Hz) and increased risk of cancer and Alzheimer's disease, although there are contradictory epidemiological studies that did not report these effects (Carles et al., 2020; Kheifets et al., 2017; Huss et al., 2018; Khan et al., 2021). In search of potential mechanisms, research has been carried out in animal models and humans, mostly involving short-term exposure, with a particular focus on its effects in the endocrine and immune systems.

Most short-term exposure studies on the biological effects of ELF-EMFs and the underlying mechanisms have made use of laboratory animals (mainly rats and mice). Unfortunately, the data are contradictory, as some authors reported biological effects while others did not (Selmaoui et al., 1996a,b, 2011; Touitou et al., 2010, 2012; Lundberg et al., 2019). One of the commonly reported biological effects of magnetic field exposure in laboratory animals relates to the metabolism of indolamines and the reduced synthesis of melatonin in the pineal gland, depending on the duration and intensity of exposure (Selmaoui and Touitou, 1995, 1999), but other biological effects have also been reported (Selmaoui et al., 2011; Touitou et al., 2010, 2020; Touitou and Point, 2020). Epidemiological studies have suggested that altered melatonin secretion is a major mechanism involved in the biological effects of magnetic field exposure (Stevens and Davis 1996), although proving this is difficult. However, this proposed mechanism was rebutted in a long-term human study (Touitou et al., 2003). In another study using rats exposed nightly to different magnetic field strengths (1, 10, and 100 μT) for 12 h, we showed that the lowest intensities (1 μT and 10 μT) had no effects on melatonin concentration and immunological variables; however, chronic exposure for one month to the same intensities showed that even the lower intensities affected melatonin secretion and the activity of pineal N-acetyltransferase (NAT), the key enzyme in the synthesis of melatonin (Selmaoui and Touitou, 1995). This clearly shows that the effects of exposure to EMFs cannot be assumed from short-term studies, as additional effects due to long-term exposure cannot be ruled out.

Increased corticosterone secretion in rodents, associated with anxious behavior of the animals, supported the hypothesis of a stress-response mechanism induced by magnetic fields (Szemerszky et al., 2010; Kitaoka et al., 2013, 2016; de Kleijn et al., 2016; Rauš Balind

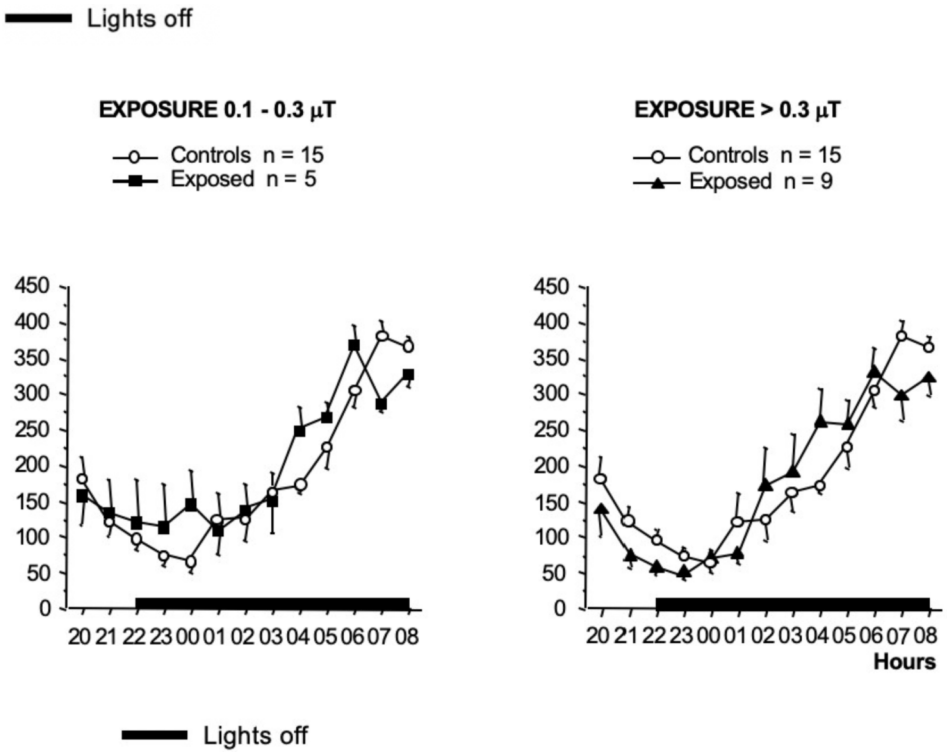


Fig. 2. Cortisol secretory patterns in 14 healthy male electricity workers, working in extra high - voltage station with a history of long-term exposure (1–20 years) to extremely low frequency electromagnetic fields (ELF-EMFs). They were compared to 15 age-matched controls. Blood samples were taken hourly (from 20 :00 h to 08 :00 h) the next morningv resulting in 13 samples per subject for each 12-h monitoring span of time. The weekly geometric mean of individual exposures ranged from 0.1 to 2.6 μT. Each point is the mean value of cortisol levels. Left part of the Figure: Intensity of exposure of between 0.1 and 0.3 μT; Right part: exposure > 0.3 μT.

et al., 2016; Rensen et al., 2017; Klimek and Rogalska, 2021). In contrast to animal studies, human studies on the effects of ELF-EMF on cortisol secretion are scarce and focused mainly on the effects of short-term exposure; moreover, most reported no biological effects (Touitou and Selmaoui, 2012). The stress-response hypothesis motivated our study on the pattern of cortisol secretion in humans exposed to 50-Hz magnetic fields over a long time span (1–20 years). We previously reported that short-term nighttime exposure (10 μT for 9 h) in healthy young adult volunteers had no effect on serum cortisol levels and secretory patterns, among other biochemical variables (Selmaoui et al., 1996b; Touitou et al., 2010; Touitou and Selmaoui, 2012).

Cortisol is a good candidate marker of the circadian system because it exhibits a strong circadian rhythm that is highly reproducible and resistant to slight and momentary environmental changes (Selmaoui and Touitou, 2003). We documented serum cortisol levels at different times of the day in workers chronically exposed to EMFs, in the context of their work but also in their homes. We found that this chronic exposure to ELF-EMFs resulted in a significant alteration to the cortisol secretory pattern with a statistically significant decline in the peak-time (06:00–08:00) serum cortisol levels even at the lowest intensity of exposure. Our data cannot be compared to other results since this paper, to our knowledge, is the first dealing with the effects of long-term exposure to ELF-EMFs that ranged from 1 to 20 years and took place both during daytime at work and during nighttime at home, since the subjects lived near EHV substations. We found no previous studies that involved such an extended period of chronic exposure. We showed that cortisol secretion was slightly decreased by long-term exposure to 50 Hz EMFs; therefore, the levels of this hormonal marker should be monitored in the follow-up of subjects exposed to EMF, at least in the case of long-term, continuous exposure. Because our monitoring period ran for 12 h and not 24 h, we cannot draw definitive conclusions regarding circadian desynchronization; however, our sampling program allowed us to study nighttime hormone secretory profiles with the minimum value at 00:00 and daytime schedules with the maximum values observed between 06:00 and 08:00 (peak-time), which strongly suggests that the workers in this study had the typical cortisol secretory profile. These data complement the results we recently obtained on the suppressive effects of magnetic fields on another marker of stress and endocrine cancer, chromogranin A (Touitou et al., 2020), which indicates an inhibitory effect on the activity of the sympathetic nervous system.

In conclusion, the characteristics of the magnetic field (e.g., linear or circular polarization) and the species of the test subject are important elements to consider when studying the biological effects of ELF-EMF exposure, but differences in the results could also be linked to the duration, timing, and intensity of exposure as well as the age of the subject, all of which may affect the biological response. This study revealed that ELF-EMF exposure decreased the peak-time serum cortisol levels, although the general secretory pattern of cortisol was unaffected. The data presented here on cortisol levels complement and match previous data on chromogranin A, a marker of stress and neuroendocrine tumors (Touitou et al., 2020).

It may be necessary to monitor the levels of residential exposure in high-risk populations such as children, elderly people, and patients with cancer, particularly because the latter group is known to have altered circadian patterns of cortisol secretion (Touitou et al., 1996). Further research on the intensity, duration of exposure, age of exposed subjects, among other parameters, will enable a better understanding of the magnitude, site and nature of the effects of ELF-EMF on human organism.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Brendel, H., Niehaus, M., Lerchl, A., 2000. Direct suppressive effects of weak magnetic fields (50 Hz and 16 2/3 Hz) on melatonin synthesis in the pineal gland of Djungarian hamsters (Phodopus sungorus). J. Pineal Res. 29 (4), 228–233.

Carles, C., Esquirol, Y., Turuban, M., Piel, C., Migault, L., Pouchieu, C., Bouvier, G., Fabbro-Peray, P., Lebailly, P., Baldi, I., 2020. Residential proximity to power lines and risk of brain tumor in the general population. Environ. Res. 185, 109473. https://doi.org/10.1016/j.envres.2020.109473.

Gunnarsson, L.G., Bodin, L., 2019. Occupational Exposures and Neurodegenerative Diseases-A Systematic Literature Review and Meta-Analyses. Int. J. Environ. Res. Public Health 16, 337. https://doi.org/10.3390/ijerph16030337.

Huss, A., Spoerri, A., Egger, M., Kromhout, H., Vermeulen, R., 2018. Occupational extremely low frequency magnetic fields (ELF-MF) exposure and hematolymphopoietic cancers – Swiss National Cohort analysis and updated meta-analysis. Environ. Res. 164, 467–474. https://doi.org/10.1016/j.

IARC, 2019. In: International Agency for Research on Cancer. Night Shift Work, vol. 124. IARC Working Group, Lyon, France (IARC Monogr Eval Carcinog Risk Chem Hum).

Khan, M.W., Juutilainen, J., Auvinen, A., Naarala, J., Pukkala, E., Roivainen, P., 2021. A cohort study on adult hematological malignancies and brain tumors in relation to magnetic fields from indoor transformer stations. Int. J. Hyg. Environ. Health 233, 113712. https://doi.org/10.1016/j.ijheh.2021.113712.

Kheifets, L., Crespi, C.M., Hooper, C., Cockburn, M., Amoon, A.T., Vergara, X.P., 2017. Residential magnetic fields exposure and childhood leukemia: a population-based case–control study in California. Cancer Causes Control 28 (10), 1117–1123.

Kitaoka, K., Kitamura, M., Aoi, S., Shimizu, N., Yoshizaki, K., 2013. Chronic exposure to an extremely low-frequency magnetic field induces depression-like behavior and corticosterone secretion without enhancement of the hypothalamic-pituitary-adrenal axis in mice. Bioelectromagnetics. 34 (1), 43–51.

Kitaoka, K., Kawata, S., Yoshida, T., Kadoriku, F., Kitamura, M., Tsuji, Y., 2016. Exposure to an Extremely-Low-Frequency Magnetic Field Stimulates Adrenal Steroidogenesis via Inhibition of Phosphodiesterase Activity in a Mouse Adrenal Cell Line. PLoS ONE 11 (4), e0154167.

de Kleijn, S., Ferwerda, G., Wiese, M., Trentelman, J., Cuppen, J., Kozicz, T., de Jager, L., Hermans, P.W.M., Verburg-van Kemenade, B.M.L., 2016. A short-term extremely low frequency electromagnetic field exposure increases circulating leukocyte numbers and affects HPA-axis signaling in mice. Bioelectromagnetics. 37 (7), 433–443.

Klimek, A., Rogalska, J., 2021. Extremely Low-Frequency Magnetic Field as a Stress Factor-Really Detrimental? Insight into Literature from the Last Decade. Brain Sci. 11, 174. https://doi.org/10.3390/brainsci11020174.

Lundberg, L., Sienkiewicz, Z., Anthony, D.C., Broom, K.A., 2019. Effects of 50 Hz magnetic fields on circadian rhythm control in mice. Bioelectromagnetics. 40 (4), 250–259.

Portaluppi, F., Smolensky, M.H., Touitou, Y., 2010. Ethics and methods for biological rhythm research on animals and human beings. Chronobiol. Int. 27 (9-10), 1911–1929.

Rauš Balind, S., Manojlović-Stojanoski, M., Milošević, V., Todorović, D., Nikolić, L., Petković, B., 2016. Short- and long-term exposure to alternating magnetic field (50 Hz, 0.5 mT) affects rat pituitary ACTH cells: Stereological study. Environ. Toxicol. 31, 461–468.

Rensen N, Gemke RJ, van Dalen EC, Rotteveel J, Kaspers GJ. 2017. Hypothalamic-pituitary-adrenal (HPA) axis suppression after treatment with glucocorticoid therapy for childhood acute lymphoblastic leukaemia. Cochrane Database Syst Rev. 11: CD008727. doi: 10.1002/14651858.CD008727.pub4. PMID: 29106702; PMCID: PMC6486149.

Selmaoui, B., Touitou, Y., 1995. Sinusoidal 50-Hz magnetic fields depress rat pineal NAT activity and serum melatonin. Role of duration and intensity of exposure. Life Sci. 57 (14), 1351–1358.

Selmaoui, B., Lambrozo, J., Touitou, Y., 1996a. Magnetic fields and pineal function in humans: evaluation of nocturnal acute exposure to extremely low frequency magnetic fields on serum melatonin and urinary 6-sulfatoxymelatonin circadian rhythms. Life Sci. 58 (18), 1539–1549.

Selmaoui, B., Bogdan, A., Auzeby, A., Lambrozo, J., Touitou, Y., 1996b. Acute exposure to 50 Hz magnetic field does not affect hematologic or immunologic functions in healthy young men: a circadian study. Bioelectromagnetics. 17 (5), 364–372.

Selmaoui, B., Lambrozo, J., Touitou, Y., 1997. Endocrine functions in young men exposed for one night to a 50-Hz magnetic field. A circadian study of pituitary, thyroid and adrenocortical hormones. Life Sci. 61 (5), 473–486.

Selmaoui, B., Touitou, Y., 1999. Age-related differences in serum melatonin and pineal NAT activity and in the response of rat pineal to a 50-Hz magnetic field. Life Sci. 64 (24), 2291–2297.

Selmaoui, B., Touitou, Y., 2003. Reproducibility of the circadian rhythms of serum cortisol and melatonin in healthy subjects. A study of three different 24-h cycles over six weeks. Life Sci. 73 (26), 3339–3349.

Selmaoui, B., Lambrozo, J., Sackett-Lundeen, L., Haus, E., Touitou, Y., 2011. Acute exposure to 50-Hz magnetic fields increases interleukin-6 in young healthy men. J. Clin. Immunol. 31 (6), 1105–1111.
Stevens, R.G., Davis, S., 1996. The melatonin hypothesis: electric power and breast cancer. Environ. Health Perspect. 104 (suppl 1), 135–140.
Szemerszky, R., Zelena, D., Barna, I., Bárdos, G., 2010. Stress-related endocrinological and psychopathological effects of short- and long-term 50Hz elecromagnetic field exposure in rats. Brain Res. Bull. 81, 92–99.
Touitou, Y., Bogdan, A., Lévi, F., Benavides, M., Auzéby, A., 1996. Disruption of the circadian patterns of serum cortisol in breast and ovarian cancer patients: relationships with tumour marker antigens. Br. J. Canc. 74 (8), 1248–1252.
Touitou, Y., Lambrozo, J., Camus, F., Charbuy, H., 2003. Magnetic field and the melatonin hypothesis. A study of workers chronically exposed to 50-Hz magnetic fields. Am. J. Physiol. 284, R1529–R1535.**.
Touitou, Y., Smolensky, M.H., Portaluppi, F., 2006. Ethics, standards, and procedures of animal and human chronobiology research. Chronobiol. Int. 23 (6), 1083–1096.
Touitou, Y., Coste, O., Dispersyn, G., Pain, L., 2010. Disruption of the circadian system by environmental factors: effects of hypoxia, magnetic fields and general anesthetic agents. Adv. Drug Deliv. Rev. 62, 928–945.
Touitou, Y., Selmaoui, B., 2012. The effects of extremely low-frequency magnetic fields on melatonin and cortisol, two marker rhythms of the circadian system. Dialogues Clin Neurosci. 14 (4), 381–399.
Touitou, Y., Djeridane, Y., Lambrozo, J., Camus, F., Selmaoui, B., 2013. Long-term (up to 20 years) effects of 50-Hz magnetic field exposure on immune system and hematological parameters in healthy men. Clin. Biochem. 46 (1-2), 59–63.
Touitou, Y., Point, S., 2020. Effects and mechanisms of action of light-emitting diodes on the human retina and internal clock. Environ. Res. 190, 109942 https://doi.org/10.1016/j.envres. 109942. Epub 2020 Jul 19 PMID: 32758719.
Touitou, Y., Lambrozo, J., Mauvieux, B., Riedel, M., 2020. Evaluation in humans of ELF-EMF exposure on chromogranin A, a marker of neuroendocrine tumors and stress. Chronobiol. Int. 37 (1), 60–67.
Vergara, X., Kheifets, L., Greenland, S., Oksuzyan, S., Cho, Y.S., Mezei, G., 2013. Occupational exposure to extremely low-frequency magnetic fields and neurodegenerative disease: a meta-analysis. J. Occup. Environ. Med. 55 (2), 135–146.
Wertheimer, N., Leeper, E.D., 1979. Electrical wiring configurations and childhood cancer. Am. J. Epidemiol. 109 (3), 273–284.
Wertheimer, N., Leeper, E.D., 1982. Adult cancer related to electrical wires near the home. Int. J. Epidemiol. 11 (4), 345–355.

Further reading

Touitou, Y., Le Hoang, P., Claustrat, B., Attye, T., Auzeby, A., Brun, J., Bogdan, A., Touitou, C., 1986. Decreased nocturnal plasma melatonin peak in patients with a functional alteration of the retina in relation with uveitis. Neurosci. Lett. 70 (1), 170–174.