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ORIGINAL ARTICLE

The influence of electromagnetic fields generated by wireless connectivity systems on the occurrence of emotional disorders in women: A preliminary report

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Abstract

OBJECTIVES: The aim of the study was to assess the influence of electromagnetic fields (EMFs) generated by wireless connectivity systems on the occurrence of emotional disorders in women working in the health service and in trade. We also analyzed the relationship between physical activity and emotional state.
METHODS AND RESULTS: The study was conducted on a sample of 200 women aged 25 to 35, in Lublin, Poland, in 2017. Shopping center staff spent more time using their mobile phones for conversations and online activities. Medical staff were exposed to stronger electromagnetic fields generated by stationary wireless phones than shopping center staff, they were less exposed to the effect of relay stations.
CONCLUSIONS: The study showed that exposure to electromagnetic fields from GSM 900 and 1800 generated by base stations contributed to the occurrence of depressive disorders among medical personnel, while exposure to WLAN EMF had the opposite effect. Spending time on phone conversations decreased the feeling of depression and increased trait anxiety in medical staff. Spending free time on physical activity intensified depressive states in women working in trade. Further studies on the influence of low-frequency EMFs on the human nervous system are needed.

Abbreviations & Units:

EMF	- non-ionizing electromagnetic field
IRAC	- international agency for research on cancer
RF	- radio-frequency
VGCC	- voltage-gated calcium channel
IPAQ	- international physical activity questionnaire
MET	- motor activity (minutes per week)
BAI	- beck anxiety inventory
STAI	- state-trait anxiety inventory
MAX	- maximum value
RMS	- effective value
GSM	- global system for mobile communications
UMTS	- universal mobile telecommunications system
DECT	- digital enhanced cordless telephony
WLAN	- wireless local area network

INTRODUCTION

Non-ionizing electromagnetic field (EMF) has always accompanied mankind, occurring naturally in the environment. Since the mid-20th century, with the development new technologies using EMF – we have been constantly influenced by various kinds of artificial sources emitting electromagnetic waves of different frequencies. Both at the workplace and in the home environment, an average person is surrounded by an increasing number of devices that emit EMF (radios, mobile phones, wireless LAN network, bluetooth, electric installations, etc.) (Mazurek *et al.* 2016).

The use of wireless digital technology has rapidly increased over the recent decades, and producers seek to abandon equipment wiring for wireless technology, which relies on electromagnetic waves as the transmission medium (Hardell *et al.* 2016, Mazurek *et al.* 2017). The energy emitted by these devices penetrates into the body and produces various effects (Wdowiak *et al.* 2017). The outcomes of the influence of electromagnetic waves are divided into thermal and non-thermal effects (Challis 2005). While thermal effects have been fairly well researched, information about non-thermal effects is still rather ambiguous (Pall, 2018).

Exposure to EMF may increase the risk of cancers (lymphomas, sarcomas, brain tumor, CNS tumors, leukemia – particularly in children). Epidemiological studies have shown that radio-frequency radiation increases the risk of glioma and acoustic neuroma in humans. The International Agency for Research on Cancer (IARC) classified radio-frequency (RF) radiation as Group 2B – a factor possibly carcinogenic to humans (Wiedemann *et al.* 2014). Researchers have also proved the possible positive potential of this field to be used in medicine for diagnostic and therapeutic purposes (Putowski *et al.* 2016).

Apart from the possible cancerogenic effects, it is believed that exposure to EMF may influence the functioning of the central nervous system and lead to an increase in the risk of emotional mental disorders, including depression. Especially during the use of mobile phones, the body organ that is the most strongly exposed to electromagnetic waves is the brain. The literature reports (Pall, 2016) on the emergence of a new group of patients, signaling non-specific symptoms whose occurrence they associate with exposure to EMF. The sudden increase in the prevalence of emotional disorders in society interestingly coincides with the immense popularization of mobile telephony and the related technologies. Since the earliest studies on the electrical activity of the brain, researchers have collected plenty of scientific evidence pointing to subtle changes in the functioning of the central nervous system during and after short-term exposure to various types of electromagnetic fields.

The influence of low-frequency EMF is explained as stemming from the effect of electromagnetic waves on the voltage-gated calcium channels (VGCC) that are located all over the nervous system. Calcium channels take part in releasing neurotransmitters, and their hyperactivity plays a role in the emergence of neuropsychiatric changes in people. It is probably also the influence on the VGCC that constitutes the basis of pain therapy and drug-resistant depression therapy using a device generating low-frequency magnetic field (Kotnik, 2010; Kotnik & Miklavcic, 2006).

Emotional disorders may have multi-factor etiology (Leykin *et al.* 2007; Beck *et al.* 1979; Vrbova *et al.* 2018). Among other factors, the emotional state is determined by physical activity (Pérez-López *et al.* 2017). Motor activity involved in prolonged and intense effort is responsible for the secretion of endorphins, which contribute to the improvement of well-being. The existing research reports link nutrition to the occurrence of depression, too (Minobe *et al.* 2017; Bishwajit *et al.* 2017; Wirth *et al.* 2017). Sexual activity also affects the quality of a person's emotional experience (Bangasser & Wicks, 2017; Kashdan *et al.* 2017). The multi-factor background of emotional disorders makes it difficult to identify the factors that cause their emergence (Ociskova *et al.* 2017).

Despite a considerable number of studies, the current state of knowledge does not provide sufficient data on non-thermal effects of EMF. The results reported by authors who have undertaken to investigate this topic are diverse, which makes it difficult to unambiguously assess the influence of EFMs on the functioning of the human organism. The aim of our study was to assess the exposure of women to EMF at selected types of workplaces. We also made an attempt to analyze the influence of low-frequency electromagnetic fields as well as physical activity on the occurrence of emotional disorders.

MATERIALS AND METHODS

Ethical approval

The study was approved no. KE-0254/16/2017 from 26/01/2017 by the Bioethics Commission of Medical University of Lublin, Poland.

Study group

The participants in the study were women aged 25 to 35, 100 of them working in the health service sector and

100 employed as shop assistants in shopping centers. We selected women in the first phase of the menstrual cycle (in order to exclude the influence of the premenstrual syndrome on the emotional state), without ovulation disturbances, not diagnosed with a mental disease and without a past record of one, and not taking any pharmacological substances affecting the psyche. They volunteered for the study and received no monetary reward. They were informed about the anonymity of the research.

Methods

The International Physical Activity Questionnaire (IPAQ) as adapted into Polish by Biernat, Gajewski, and Stupnicki (2007), measuring the level of physical activity. The questionnaire consists of five parts, devoted to different human activities, such as career-related physical effort or physical effort connected with moving. The participants' task is to specify how many hours per week or days per week they spend doing a given activity. Motor activity is converted into MET units (minutes per week). MET is a metabolic equivalent corresponding to oxygen consumption in the course of basal metabolism. According to what researchers have established, 1 MET is equal to 3.5 ml O_2/kg body mass per minute. It has been established that intense physical effort is an expenditure of 8 MET in each minute of its duration, moderate effort is 4 MET, and walking (marching, quickly strolling) is 3.3 MET. Computing total energy expenditure – i.e., specifying an individual's level of physical activity – consists in multiplying the frequency and duration of effort by the corresponding intensity level expressed in MET units.

Beck Depression Inventory (BDI) adapted into Polish by Zawadzki, Popiel, and Pragłowska (2009), consists of 21 items measuring the level of depression. The scale enables the distinction between healthy individuals and those with symptoms of depression, as well as the evaluation of depression severity. Responses are rated on a 4-point Likert scale and range from 0 (not at all) to 3 (severely). The total score for all symptoms, ranging between 0 and 63 points, is considered an indicator of depression severity. When interpreting the study results we used the following cut-off values for depression severity degrees: 0–11 – no depression, 12–26 – mild depression, 27–49 – moderate depression, 50–63 – severe depression. The resulting Beck Anxiety Inventory (BAI) is a 21-item scale that showed high internal consistency (α = .92) and test–retest reliability over an interval of one week, *r* (81) = .75 (Beck *et al.* 1961; Beck *et al.* 1988).

State-Trait Anxiety Inventory (STAI) by Spielberger, Gorsuch, and Lushene, adapted into Polish by Sosnowski and Wrześniewski (1983), measuring the levels of state and trait anxiety. The State-Trait Anxiety Inventory makes it possible to measure anxiety both as a relatively stable personality trait and as a situation-induced state. The questionnaire comprises two scales: STAI-1 measures state anxiety and STAI-2 measures trait anxiety. Each scale comprises 20 statements. The respondents rate their subjective feelings about each statement using a scale from 1 to 4. Sten scores of 1–4 indicate low anxiety, 5–6 – moderate anxiety, and 7–10 – high anxiety (Sosnowski *et al.* 2011). Internal consistency coefficients for the scale ranged from .86 to .95; test-retest reliability coefficients over a 2-month interval ranged from .65 to .75 (Spielberger *et al.* 1983).

Measurements of the influence of EMF on the organism were performed by means of an ESM 140 dosimeter, produced by Maschek company. This device registers the frequency and level of the electric component of electromagnetic field in a person's close environment. The meter measures the levels of electric field for particular frequencies. The dosimeter is a safe device because it does not generate any high-frequency radiation. In metrological terms, the identification of electric field strength levels was limited to the frequency bands used by telecommunication technologies (GSM, UMTS, DECT, and WLAN) (Table 1.).

Transmission in the GSM system takes place in duplex mode. Transmission in the GSM 900 system is pulse-based and uses one of the 124 dual frequency channels, while in the GSM 1800 system 374 (dual) frequency channels are available. During transmission initiation in the GSM system (as well as in UMTS), the pulse-shaped and digitally encoded electromagnetic wave signal is simultaneously received and transmitted. This information is selectively given by the ESM 140 dosimeter as up and down values – which makes it possible to determine if the source of electromagnetic field is a base station

Tab. 1.

Technologies examined	Range of frequencies	Application in daily life
GSM 900 GSM 1800 UMTS	880-960 MHz 1710-1880 MHz 1920-2170 MHz	mobile phone, smartphone, electronic devices with prepaid cards (laptop computers, tablets), industrial 2G modems, industrial routers, intelligent telemetry modules for cooperation with monitoring or alarm systems
DECT	1880-1900 MHz	wireless phones in analog or digital phone systems
WLAN	2.4-2.43 GHz	Wi-Fi communication devices (laptop computers, notebooks, smartphones, network printers, smart television sets), wireless mice, keyboards, headphones, computer microphones , video cameras, industrial devices with WLAN communication modules, Wi-Fi access point transmitting-receiving devices

or a phone device. "Up" transmission indicates that the women were talking on their mobile phone or standing near another person talking on a mobile phone. "Down" transmissions indicate that the women were in the vicinity of a base station transmitter. In the case of transmissions in DECT or Wi-Fi systems, propagation takes place via one (the same) channel, bidirectionally, which means that direction and source are not identified. The meter registers electromagnetic field strength with two detectors – maximum value (MAX) and effective value (RMS). The maximum value (MAX), also known as peak value, is defined as the highest instantaneous value in the amplitude of any time waveform. For periodic and periodically changing waveforms (which occur in telecommunication transmissions), the maximum value is the highest value for one period.

$$X_{PEAK} = max|x(t)| \qquad (1)$$

The effective value defines the energetic parameters of a signal (e.g., electromagnetic wave). It is determined in accordance with the integral relationship averaged in time:

$$X_{RMS} = \sqrt{\frac{1}{T_{RMS}} \int_0^{T_{RMS}} x^2(t)dt} \qquad (2)$$

where:

$x(t)$ – instantaneous value of a given parameter characterizing the electromagnetic field at a particular moment t;

T_{RMS} – time period for which effective value is computed; if $T_{RMS} = 1/f$, it is the period of change in time of instantaneous value of a given parameter; for harmonious fields, effective value (*RMS*) is equal to peak value (*P*) divided by $\sqrt{2}$; during the assessment of risks stemming from the thermal effects of the influence of electromagnetic field with a frequency of 100×10^3 Hz $< f < 6\times10^9$ Hz, the default value of T_{RMS} = 6 minutes.

The participants in the study were randomly selected from among shopping center and medical staff. The dosimeter was fastened on the participant's left arm, the measurement cycle lasted 10 hours, and the results were analyzed in the meter-dedicated software. The participants completed the survey on an anonymous basis, immediately after the measurement. Fifteen individuals refused to take part in the study.

STATISTICAL METHODS

The data were statistically analyzed using STATISTICA software. We estimated the mean values (*M*) and standard deviations (*SD*) for continuous variables as well as absolute numbers (*n*) and percentages (%) of the occurrence of items for categorical variables.

We used the *t*-test to compare continuous variables between the two groups of women and the $\chi2$ test to compare categorical variables between these two groups. We performed an *F*-test (analysis of variance) to compare the severity of depression and anxiety between the three levels of education. Pearson correlation coef-

Tab. 2. Sample characteristics

Variable	Category	Parameter	Medical staff	Shopping center staff	Comparison test
Age	years	*M*±*SD*	31.4±4.5	31.2±4.8	t=0.303, p=.762
Level of education	secondary	*n* (%)	18 (18.00)	28 (28.00)	χ^2=9.723, p=**.008**
	college		24 (24.00)	36 (36.00)	
	university		58 (58.00)	36 (36.00)	
Place of residence	urban	*n* (%)	76 (76.00)	74 (74.00)	χ^2=0.107, p=.744
	rural		24 (24.00)	26 (26.00)	
BMI	kg/m^2	*M*±*SD*	24.4±3.3	23.9±4.4	t=1.005, p=.316
	normal weight	*n* (%)	62 (62.00)	70 (70.00)	χ^2=4.285, p=.117
	overweight		30 (30.00)	18 (18.00)	
	obese		8 (8.00)	12 (12.00)	
Socioeconomic living conditions	very good	*n* (%)	46 (46.00)	34 (34.00)	χ^2=3.000, p=.083
	good		54 (54.00)	66 (66.00)	
	inadequate		0 (0.00)	0 (0.00)	
Physical activity	low	*n* (%)	4 (4.00)	2 (2.00)	χ^2=1.194, p=.551
	moderate		48 (48.00)	54 (54.00)	
	high		48 (48.00)	44 (44.00)	
	MET minutes per week	*M*±*SD*	2329±1512	2492±1797	t=0.696, p=.487

Tab. 3. Levels of Anxiety and Depression in the Study Groups

Variable	Category	Parameter	Medical staff	Shopping center staff	Comparison test
Depression (BDI)	score	*M*±*SD*	3.1±1.6	4.0±3.3	*t*=2.577, *p*=**.011**
	none	*n* (%)	100 (100.00)	94 (94.00)	χ^2=6.186, *p*=**.013**
	mild		0.00 (0.00)	6.00 (6.00)	
	moderate		0.00 (0.00)	0.00 (0.00)	
	severe		0.00 (0.00)	0.00 (0.00)	
State anxiety	score	*M*±*SD*	32.5±6.6	32.7±9.9	*t*=0.134, *p*=.893
	Low	*n* (%)	15 (15.00)	29 (29.00)	χ^2=5.855, *p*=.054
	moderate		77 (77.00)	63 (63.00)	
	severe		8 (8.00)	8 (8.00)	
Trait anxiety	score	*M*±*SD*	35.7±4.1	35.7±5.6	*t*=0.001, *p*=.999
	Low	*n* (%)	23 (23.00)	29 (29.00)	χ^2=3.131, *p*=.209
	moderate		77 (77.00)	69 (69.00)	
	severe		0 (0.00)	2 (2.00)	

ficient was used in the analyses of correlations between depression severity, anxiety severity and sample characteristics as well as exposure to electromagnetic waves. The significance level was assumed at 0.05.

RESULTS

The two examined groups of women did not differ significantly in terms of age, place of residence, BMI, socioeconomic living conditions, and physical activity (Table 2). The women were aged from 25 to 35, with a mean age 31 years; ¾ of them lived in towns and cities. Their mean BMI was approximately 24 kg/m^2; most of them had normal weight, half of them lived in good socioeconomic conditions, about a half of them had moderate physical activity, and about a half were characterized by high physical activity in which they used an average of about 2400 MET minutes per week. Women working in the health service were higher educated than women working in shopping centers. A higher percentage of medical staff had university education and a lower percentage had secondary education compared to shopping center staff.

The results of the analysis of depression and anxiety levels in the examined groups of women are presented in Table 3. Based on the BDI, we found that women working as shop assistants in shopping centers had a significantly higher level of depression than women working in the health service. None of the health service employees had depression, whereas in the case of shopping center staff 94% did not have depression and 6% had mild depression. There were no individuals with moderate or severe depression in the sample.

The two examined groups of women did not differ significantly in terms of state anxiety and trait anxiety levels. The mean score on state anxiety was 32.5 for medical staff and 32.7 for shopping center staff, which indicates moderate anxiety. Fifteen percent of the examined medical staff and 29% of shopping center staff had low state anxiety, three-fourths and two-thirds had a moderate level of state anxiety, respectively, and 8% of the participants in each group exhibited a high of this state. More than 20% of the participants in both groups had low trait anxiety and about 70% had moderate trait anxiety; only two participants working in shopping centers and none of those working in the health service had a severe level of trait anxiety.

Women working in shopping centers spent significantly more minutes per day using a mobile phone (for phone conversations, telecommunication transmissions, and online activities) compared to women working in the health service (Table 4). Women working in shopping centers were exposed to electromagnetic fields from GSM900down, UMTSdown, and WLAN-RMS telecommunication technologies to a significantly greater degree than women working in the health service, and they were exposed to EMFs from UMTSup and DECT technologies to a smaller degree. Exposure to GSM900up, GSM1800up, GSM1800down, and WLAN did not differ significantly between the two examined groups of women.

Correlations of depression and anxiety with sample characteristics are presented in Table 5. In women working in the health service we found no correlations between depression level and BMI, physical activity, level of education, or socioeconomic living conditions, whereas the levels of both state and trait anxiety correlated with the level of education. Women working in the health service with secondary education had significantly higher levels of both types of anxiety than women with college or university education. The levels of the two types of anxiety did not correlate with BMI,

Tab. 4. Exposure to Electromagnetic Waves in the Study Groups

Variable	Medical staff *(M±SD)*	Shopping center staff *(M±SD)*	*t*	*p*
Daily mobile phone use time (minutes)	29.8±19.3	44.0±45.1	-2.888	**.004**
Daily Internet use time via mobile phone (minutes)	1.7±1.1	2.4±2.2	-3.009	**.003**
GSM900upRMS	0.017±0.018	0.020±0.016	-1.236	.218
GSM900upPeak	0.079±0.178	0.062±0.109	0.818	.414
GSM900downRMS	0.029±0.028	0.041±0.031	-2.884	**.004**
GSM900downPeak	0.052±0.031	0.062±0.035	-2.215	**.028**
GSM1800upRMS	0.014±0.009	0.014±0.009	-0.008	.994
GSM1800upPeak	0.058±0.028	0.059±0.026	-0.327	.744
GSM1800downRMS	0.008±0.010	0.008±0.010	0.263	.793
GSM1800downPeak	0.016±0.007	0.015±0.008	0.526	.599
UMTSupRMS	0.012±0.017	0.008±0.010	2.249	**.026**
UMTSupPeak	0.031±0.022	0.021±0.015	3.598	**.000**
UMTSdownRMS	0.010±0.010	0.015±0.012	-3.367	**.001**
UMTSdownPeak	0.019±0.008	0.023±0.009	-3.417	**.001**
DECTRMS	0.017±0.019	0.012±0.015	1.982	**.049**
DECTPeak	0.115±0.143	0.079±0.112	2.023	**.044**
WLANRMS	0.015±0.011	0.020±0.015	-2.428	**.016**
WLANPeak	0.062±0.054	0.072±0.065	-1.197	.233

physical activity, and socioeconomic living conditions in medical staff.

In women working in shopping centers, the level of depression correlated positively with physical activity: the more MET minutes they used per week, the higher mean level of depression they had. In this group of women we found no correlation between depression level and BMI, education level, or socioeconomic living conditions.

The level of state correlated with the level of education and trait anxiety correlated with socioeconomic living conditions in women employed in shopping centers. Women with secondary education had a significantly higher level of state anxiety that those with college or university education. Women living in good conditions had a significantly higher level of trait anxiety than those living in very good conditions. We found no correlation between anxiety and the remaining analyzed characteristics of female shopping center staff.

Depression level correlated negatively with daily mobile phone use time and with exposure to WLANRMS and WLANPeak, and positively with exposure to GSM900downRMS and GSM1800downRMS in medical staff, while in shopping center staff the level of depression correlated positively with daily Internet use time via mobile phone.

The level of state anxiety correlated negatively with exposure to GSM900upRMS and positively with exposure to GSM1800upRMS in women working in shopping centers, whereas in women working in the health service we found no significant correlation between the level of state anxiety and exposure to electromagnetic fields generated by the remaining frequencies investigated.

The level of trait anxiety correlated positively with daily mobile phone use time and with exposure to UMTSdown, and negatively with exposure to WLANPeak in female medical staff, while in female shopping center staff the level of trait anxiety correlated positively with exposure to UMTSupRMS and UMTSupPeak and negatively with exposure to GSM1800upPeak.

DISCUSSION

The main aim of the presented research was to investigate he relationship between exposure to electromagnetic field at the workplace and mental health. We found that shopping center staff spent more time talking on their mobile phones than medical staff, which probably stems from the nature of their work. Medical staff were exposed to stronger electromagnetic fields generated by stationary wireless phones than shopping center staff. UMTS connectivity is undoubtedly more widespread in health care facilities. This may stem from the fact that the UTMS technology was introduced into hospitals and clinics earlier than GSM and has remained unchanged until the present day. In shopping centers shops are often replaced by other shops, which makes it more practical for entrepreneurs to use the GSM option. High diversity of EMF strength across various locations where

Tab. 5. Depression and Anxiety Versus Sample Characteristics

Variable	Category	Parameter	Medical staff			Shopping center staff		
			Depression	State anxiety	Trait anxiety	Depression	State anxiety	Trait anxiety
BMI	kg/m^2	*r*	.041	.063	-.148	-.084	-.102	.077
		p	.687	.533	.143	.406	.314	.446
MET	minutes per week	*r*	.133	.015	.164	.454	.129	-.032
		p	.187	.883	.102	**<.001**	.201	.750
Level of education	secondary	*M±SD*	3.0±1.8	39.7±7.3	38.6±5.6	4.7±3.7	36.1±12.4	37.6±7.1
	college	*M±SD*	3.7±1.6	31.7±8.4	35.5±3.6	3.4±2.0	29.7±5.7	34.9±3.9
	university	*M±SD*	2.9±1.6	30.9±3.6	34.9±3.4	4.1±3.9	33.0±10.3	35.0±5.6
		F	2.016	16.770	6.152	1.211	3.593	2.260
		p	.139	**<.001**	**.003**	.302	**.031**	.110
Socioeconomic living conditions	very good	*M±SD*	3.2±1.2	32.0±6.8	34.9±3.6	4.3±3.8	32.5±11.1	33.9±4.6
	good	*M±SD*	3.1±1.9	33.0±6.5	36.3±4.4	3.9±3.0	32.8±9.3	36.6±5.9
		t	0.713	0.705	1.739	0.580	0.137	2.266
		p	.478	.482	.085	.563	.891	**.026**

people are present has also been confirmed in the studies by Bolte and co-authors (2012) as well as Sagar and co-authors (2018). Own research revealed that shopping center staff were more exposed to EMFs connected with WLAN technology. WLAN is a local network in which connections between devices are made wirelessly in the 2.4 GHz or 5 GHz band (laptop computers, notebooks, smartphones, network printers, wireless mice, keyboards, video cameras, industrial devices with WLAN communication modules, Wi-Fi access point transmitting-receiving devices). In trade facilities this technology is most probably used more extensively than in health service facilities, which may explain the results we have obtained. Moreover, the study by Hedendahl and colleagues (2017) revealed that exposure to EMF from WLAN rapidly increases during prolonged data transmission via Internet-connected devices.

Individuals working in trade were more exposed to EMFs generated by base stations than medical staff. This is probably due to the fact that base stations are located close to densely populated areas, such as shopping centers. Medical facilities, by contrast, are more often located far from densely populated zones. The strong effect of electromagnetic fields from base stations in densely populated zones in Lublin, Poland, where we conducted our study, is confirmed the study of Mazurek and co-authors (2016).

The decrease in the level of depression and trait anxiety observed in medical staff exposed to WLAN may stem from the fact that the use of WLAN frequency, particularly in the case of computer use, serves entertainment purposes, which could explain the mood improvement in the individuals using it. This can be linked with the fact that longer time spent on phone conversations or in front of the computer attests to lower workload. This is also confirmed by the observed decrease in the level of depression in individuals who spent more time talking on mobile phones. This can be explained by the fact that phones are often used for keeping in touch with the family and friends, and social support can reduce depressive symptoms (e.g. Peirce *et al.* 2000).

Our study revealed that exposure to electromagnetic fields generated by base stations fostered depression in medical staff. A German study conducted by Buchner and Eger (2011) in which the participants were residents of a neighborhood where a GSM mobile telephony station had been built, revealed that over six months the level of stress hormones (adrenalin and noradrenalin) significantly increased and then, after 18 months, decreased but did not reach the original level. The level of dopamine first decreased and subsequently increased, but it did not reach the initial level, either. The results reported by Buchner & Eger may explain the relationship we have observed.

Moreover, in a Polish study on GSM network employees it was found that electromagnetic fields generated by mobile phones are predictors not only of stress but also of poor well-being as well as increase the occurrence of complaints such as headaches (Szyjkowska *et al.* 2017). The study revealed no relationship between exposure to EMFs and headache complaints. Similar results were obtained by Frei and co-authors (2012), who conducted a survey-based study with a sample of about 1,000 randomly selected participants from Basel (Switzerland). They used the von Zerssen checklist to assess the somatic symptoms and the HIT-6 test to assess headache. The results reported by Frei and co-authors (2012) do not suggest a relationship between exposure to strong or close electromagnetic field in daily life and the development of nonspecific symptoms or buzzing noise in the ears.

Tab. 6. Correlations Between Anxiety, Depression, and Exposure to Electromagnetic Waves

Variable	Medical staff						Shopping center staff					
	Depression		State anxiety		Trait anxiety		Depression		State anxiety		Trait anxiety	
	r	*p*	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*
Daily mobile phone use time (minutes)	-.267	**.007**	.136	.177	.211	**.035**	.141	.161	-.002	.984	.024	.811
Daily Internet use time via mobile phone (minutes)	.001	.995	.072	.477	.094	.355	.209	**.037**	.044	.664	.062	.540
GSM900upRMS	.003	.978	.089	.379	-.099	.329	-.101	.318	-.236	**.018**	.067	.505
GSM900upPeak	-.145	.151	.026	.798	-.068	.499	-.034	.739	-.192	.056	.046	.647
GSM900downRMS	.260	**.009**	-.045	.656	.113	.264	-.078	.444	-.077	.445	-.002	.981
GSM900downPeak	.183	.069	-.007	.948	.177	.078	-.113	.262	-.120	.233	.024	.812
GSM1800upRMS	-.043	.674	.034	.735	-.083	.414	.141	.162	.277	**.005**	.049	.631
GSM1800upPeak	-.129	.201	-.097	.339	.000	1.000	-.040	.692	-.045	.660	-.288	**.004**
GSM1800downRMS	.215	**.032**	-.025	.806	.105	.300	.018	.861	-.062	.543	-.119	.238
GSM1800downPeak	.096	.344	-.040	.690	.195	.052	.138	.173	.035	.730	.018	.862
UMTSupRMS	.019	.855	.110	.277	-.079	.434	-.006	.954	.061	.546	.307	**.002**
UMTSupPeak	-.035	.729	.103	.309	-.054	.595	.001	.989	.015	.882	.314	**.001**
UMTSdownRMS	.160	.111	-.053	.599	.036	.720	.070	.488	.066	.517	.011	.912
UMTSdownPeak	.147	.144	-.040	.694	.282	**.005**	.152	.130	.095	.346	-.136	.176
DECTRMS	-.061	.548	.049	.630	-.075	.886	-.221	.027	.089	.381	.621	.827
DECTPeak	-.037	.715	-.002	.986	-.877	.995	-.244	.015	.048	.636	.168	.095
WLANRMS	-.266	**.008**	-.112	.267	-.340	**.001**	-.134	.183	.018	.857	.045	.655
WLANPeak	-.253	**.011**	-.099	.330	-.305	**.002**	-.188	.061	-.129	.200	-.084	.406

Different results concerning headaches were presented by Redmayne and colleagues (2013), who investigated teenagers' self-reported well-being and daily use of wireless phone and Internet. The study showed that the number and duration of phone calls were associated with an increased risk of headaches and that sending text messages and prolonged phone use was associated with painful sensation in the thumb (when writing). The use of a wired headset was associated with a buzzing noise in the ears, while the use of a wireless headset was associated with headache, worse well-being/dejection, and waking up at night. Being woken up at night by the phone was strongly associated with subsequent fatigue during the day; interestingly, waking up at night was less likely to occur in individuals who had a Wi-Fi connection at home. Wi-Fi technology is based on WLAN connectivity, and waking up at night less frequently may be linked with our results, suggesting an anti-depressive effect of this frequency (waking up too early is one of the symptoms of depression).

The time devoted to phone calls results in exposure to EMF, but direct exposure also depends on the emission of electromagnetic waves by other people's phones and by base stations. Field strength depends also, individually, on the phone model. Older models generate stronger EMFs (Michałowska *et al.* 2018). This fact explains the apparent contradiction between the fact that the daily time devoted to phone calls decreases the symptoms of depression and the fact that individual exposure (measured with a dosimeter) is associated with an increase in depression as a result of exposure to EMF from GSM 900 and 1800.

Based on our study investigating the exposure of women to various types of EMF frequencies, we observed an influence of the UMTSup frequency on the emergence of state anxiety. The relationship between these variables was not strong, but its presence may attest to a possible negative influence of these frequencies on emotional experience, or it may stem from the more frequent need to receive phone calls, which had negatively influenced the subjects' well-being. This link may be due to the nature of their work, which requires receiving phone calls that are frustrating and induce anxiety in the female participants. It is possible at this point to refer to the concept of emotional work, characteristic of service-based occupations, where the employee is expected to comply with specific norms regarding the expression of emotions towards customers – which is often a burden and leads to negative consequences, increasing the level of stress and decreasing satisfaction (Szczygieł *et al.* 2009).

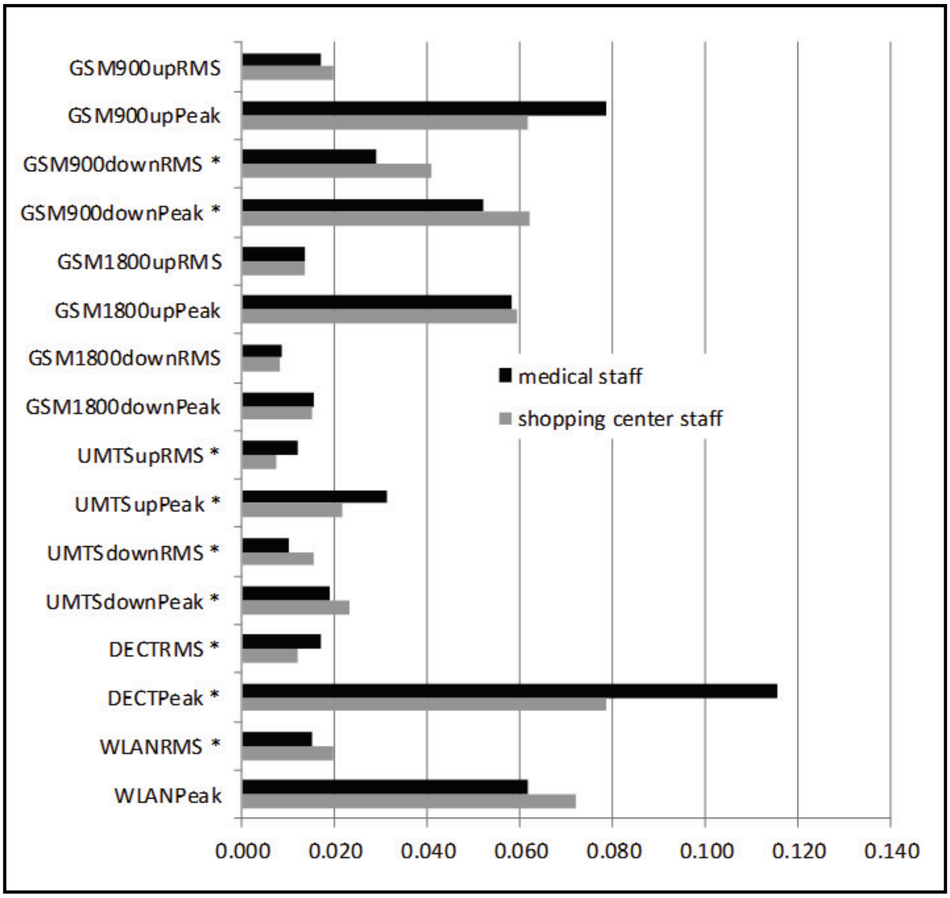

Fig. 1. Mean exposure to electromagnetic waves in the study groups.
* significant differences

With the increase in the number of phones and the frequency of their use, the concept of mobile phone addiction emerges in the literature. It is defined as a social disorder or phobia associated with dependence on communication in the virtual reality by means of a mobile phone (Han *et al.* 2017; Błachnio & Przepiórka, 2018). A study on Iranian university and college students suggests that a high level of mental health (knowing one's own abilities, coping with the stresses of life) is associated with a low level of phone addiction (Babadi-Akashe *et al.* 2014). A positive relationship was found between frequent use of mobile phones and stress, sleep problems, as well as depression symptoms (Thomée *et al.* 2011). Excessive use of mobile phones (particularly writing text messages) makes a person prone to depressive and anxiety states, which is confirmed by the results of our study concerning the negative influence of UMTSup frequencies, contributing to an increase in state anxiety (Lu *et al.* 2011). Research shows that excessive use of mobile phones increases ADHD symptoms as well as significantly decrease mood and psychological well-being (Hedendahl *et al.* 2017).

In the literature there is one study by Thomas and co-authors (2008) concerning well-being of adults exposed to electromagnetic waves of various frequencies. The study was conducted with ESM-140 among 329 respondents who were asked to report their acute symptoms in a day-long diary. During an interview with participants data on five groups of chronic symptoms and potential confunders were assessed. The results of the study show that there is no statistically significant correlation between the exposure and chronic/acute symptoms.

In the present study we observed a link between low physical activity and depression. Similar conclusions were reported by Uqlesić and colleagues (2014), who used the Beck Depression Inventory (BDI) and a sports activity questionnaire to examine 664 university or college students. The BDI scores were significantly lower in the case of those students who were active in sports (median score = 3) compared to the recreational group (median score = 4) and in correlation with the group who was not active in sports (median score = 5) (Kruskal-Wallis: $p < .001$). The authors of the study observed that women experienced symptoms of depression more often than men did. While sports activity did not significantly influence depression in the population of men, its influence was significant in decreasing the symptoms of depression in women. In their research, Wojdat and co-authors (2017) prove that there is a relationship between low predisposition to depression and the time of physical activity in individuals practicing judo. Their research confirm that, apart from bringing physiological benefits, physical effort has a positive influence on the psyche. Regular exercise and active lifestyle have a beneficial effect on the development of cognitive functions, self-esteem, mood, social relations, coping with stress, acceptance level, anxiety reduction, and sleep quality improvement.

Emotional disorders have many determinants. It is also possible that some frequencies influence the work of ion channels by stimulating voltage-gated calcium channels this requires confirmation in future research. Pall (2016, p. 43) writes: "Calcium channel blockers block EMF effects and several types of additional evidence confirm this mechanism. Low intensity microwave EMFs have been proposed to produce neuropsychiatric effects, sometimes called microwave syndrome". Among the more commonly reported changes are sleep disturbance/insomnia, headache, depression/depressive symptoms, fatigue/tiredness, dysesthesia, concentration/attention dysfunction, memory changes, dizziness, irritability, loss of appetite/body weight, restlessness/anxiety, nausea, skin burning/tingling/dermographism and EEG changes.

LIMITATIONS AND FUTURE STUDIES

In the presented study we have examined the level of exposure to EMF in women employed in different workplaces; we have also examined the influence of low-frequency electromagnetic fields and physical activity on the occurrence of emotional disorders. Although the presented study constitutes an original contribution to the existing knowledge, it is not without limitations. Our research was conducted only on a sample of women, and only two types of workplace were considered. Future studies should include also a group of men. Moreover, it would be an interesting direction for research to control dimensions of mental health other than depression and anxiety. Another interesting direction would be to recruit a control group of individuals cut off from the influence of electromagnetic fields.

CONCLUSIONS

1. Exposure to electromagnetic fields from GSM 900 and 1800 generated by base stations contributes to the occurrence of depressive disorders among medical staff, while exposure to WLAN EMFs has the opposite effect.
2. Spending time on phone conversations decreases the feeling of depression and increases trait anxiety in health service staff.
3. Spending free time on physical activity increases depressive states in women working in trade.

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