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Blood Laboratory Findings in Patients Suffering From Self-Perceived Electromagnetic Hypersensitivity (EHS)

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Risks from electromagnetic devices are of considerable concern. Electrohypersensitive (EHS) persons attribute a variety of rather unspecific symptoms to exposure to electromagnetic fields. The pathophysiology of EHS is unknown and therapy remains a challenge. We hypothesized that some electrosensitive individuals are suffering from common somatic health problems. Toward this end we analysed clinical laboratory parameters including thyroid-stimulating hormone (TSH), alanine transaminase (ALT), aspartate transaminase (AST), creatinine, hemoglobine, hematocrit and c-reactive protein (CRP) in subjects suffering from EHS and in controls that are routinely used in clinical medicine to identify or screen for common somatic disorders. One hundred thirty-two patients ($n = 42$ males and $n = 90$ females) and 101 controls ($n = 34$ males and $n = 67$ females) were recruited. Our results identified laboratory signs of thyroid dysfunction, liver dysfunction and chronic inflammatory processes in small but remarkable fractions of EHS sufferers as potential sources of symptoms that merit further investigation in future studies. In the cases of TSH and ALT/AST there were significant differences between cases and controls. The hypotheses of anaemia or kidney dysfunction playing a major role in EHS could be unambiguously refuted. Clinically it is recommended to check for signs of treatable somatic conditions when caring for individuals suffering from self-proclaimed EHS. Bioelectromagnetics 30:299–306, 2009.

Key words: electromagnetic hypersensitivity (EHS); blood laboratory; TSH; CRP; anaemia; creatinine

INTRODUCTION

Electromagnetic fields are considered by some a source of potential health risks [WHO, 2004; Carpenter and Sage, 2008]. The discussion ranges from impaired well-being to carcinogenic effects and also touches regulatory issues. Individuals with electromagnetic hypersensitivity (EHS) or, synonymously, hypersensitivity to electric and magnetic fields (HSEMF) describe adverse health effects while using or being in the vicinity of devices emanating electric and/or magnetic fields of low intensity [Hillert et al., 1999]. Complaints are usually present without indication of organic lesion. Nevertheless, the health complaints related to EHS result in considerable psychological stress in these patients [Seitz et al., 2005]. Complainants relate their symptoms most frequently to exposure to mobile phone base stations, mobile phones, cordless phones and power lines [Hillert et al., 2002; Röösli et al., 2004] although there is apparently no strong link between field exposure and complaints [Lonne-Rahm et al., 2000; Röösli, 2008]. The group of symptoms usually appears or worsens during perceived exposure to a specific source of electromagnetic fields (EMFs), and they are reported to diminish when patients are distant from the EMF-sources.

An additional phenomenon in this context is the proclaimed ability to perceive electromagnetic fields at a much lower threshold than the general population without necessarily developing health symptoms: electromagnetic sensibility [Leitgeb and Schröttner, 2003]. The decreased perception and the attribution of health symptoms to EMF exposure can be considered as two independent phenomena. Nevertheless, in a survey among self-declared EHS individuals, 56% declared

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their ability to perceive electromagnetic fields [Röösli et al., 2004].

Early reports stress the occurrence of dermatological symptoms (facial dermatosis such as seborrheic eczema, acne vulgaris, mild rosacea, and atopic dermatitis) which are mainly related to exposure to video display units (VDUs) and mostly have a good prognosis [Lindén, 1981; Nilsen, 1982; Berg, 1988; Berg et al., 1990; Bergqvist and Wahlberg, 1994; Bergqvist and Vogel, 1997]. In more recent reports, patients show multiple non-specific health complaints such as sleep disturbances, headache, nervousness or distress, general anxiety, depression, fatigue or problems in concentrating, memory problems, respiratory problems (difficulty breathing), gastrointestinal symptoms, dry eyes, photosensitivity, palpitations, loss of weight, increased sweating and heat intolerance [Bergdahl, 1995; Knave, 2001; Hietanen et al., 2002; Röösli et al., 2004; Silny et al., 2004].

So far a commonly accepted pathophysiological basis for the symptoms presented by EHS sufferers has not been reported. Due to the lack of knowledge of the EHS pathophysiology, adequate medical treatment for these patients remains a challenge. Several authors have concluded that EHS in most cases can be considered a somatoform disorder. It is well conceivable that EHS is not a homogeneous entity but rather a heterogeneous mixture of a whole variety of disorders ranging from delusional disorders to severe somatic disorders. Many of the symptoms can be found in disorders quite common in the general population such as thyroid dysfunction, chronic liver disease, anaemia, chronic kidney disease and chronic inflammatory processes (see Table 1).

Therefore, we hypothesized that there might be a large fraction of electrosensitive individuals who are in essence suffering from common somatic health problems secondarily ill-attributed to EMF. Toward this end we analysed clinical laboratory findings in subjects suffering from EHS and in controls that are routinely used in clinical medicine to identify or screen for common somatic disorders.

SUBJECTS AND METHODS

Patients

This study is part of a broader effort to clinically characterize EHS patients within the framework of the German Mobile Telecommunication Research Program (DMF) [www.emf-forschungsprogramm.de]. For the present analysis, 132 patients ($n = 42$ males and $n = 90$ females) and 101 controls ($n = 34$ males and $n = 67$ females) were recruited. Patients were from German EMF self-help groups, the 'Mainzer EMF-Wachhund', an Internet watchdog project [Schüz et al., 2006] or by local advertisement in Mainz and Regensburg. Inclusion criteria for electromagnetic hypersensitive patients were: (1) an EMF-related symptom load of at least 14 points on a modified 'Regensburger EMF-complaint list' [Frick et al., 2002]; (2) attribution of the health symptoms experienced to named electromagnetic emission sources (e.g., mobile phone base stations, wireless routers for internet access, etc.); (3) aged 18–65 years. Exclusion criteria were acute psychiatric disorders such as acute depressive or paranoid psychosis. All subjects were seen by an experienced psychiatrist (ND). In addition, the standardized interview for the detection of psychiatric disorders 'Mini-DIPS' was used [Markgraf, 1994].

Patients and controls were matched for age, sex and BMI (Table 2). All participants gave written, informed consent to the study. The study protocol was approved by the ethic committee of the medical association of Rhineland-Palatinate that is responsible for all clinical studies of the University of Mainz.

Measurements

The blood chemistry parameters were measured with a Roche Hitachi 917 Analyzer (Roche Diagnostic,

TABLE 1. Comparison of EHS Symptoms With Symptom of Disorders Common in the General Population

Symptoms	EHS	Thyroid dysfunction	Liver disease	Anaemia	Kidney disease	Chronic Inflammation
Sleep disorder	+++	++	+	++	+	+
Fatigue	+++	+++	+++	+++	++	+++
Skin problems	+++	++	++	+	+	++
Headache	+++	++	++	++	++	+++
Nervousness/distress	++	++	++	+	+	+
Difficulty in concentrating	+	++	+	+	+	++
Nausea or dizziness	+	+	+	++	+	+
Unspecific symptoms like coughing, eye irritation, hoarse or dry throat, runny or stuffy nose	++	+	−	−	+	++

Modified according to Harrison's Principles of Internal Medicine 16th edition [Hillert et al., 2002; Röösli et al., 2004].

TABLE 2. Characterization of Cases and Controls

Characteristics	EHS cases	Controls	*P*-values
n	132	101	
Males	42 (31.8%)	34 (33.7%)	
Females	90 (68.2%)	67 (66.3%)	
Age (years)	51.5 ± 13.3	49.7 ± 12.6	0.263
Males	53.7 ± 12.8	52.4 ± 11.0	
Females	50.5 ± 13.5	48.3 ± 13.2	
BMI (kg/m^2)	24.6 ± 4.5	24.7 ± 3.5	0.669
Males	25.9 ± 3.9	25.0 ± 2.8	
Females	24.0 ± 4.7	24.6 ± 3.9	
Symptoms most frequently attributed to EMF			
Sleep disturbances	101 (77%)	2 (2%)	<0.001
Fatigue	101 (77%)	2 (2%)	<0.001
Difficulty in concentrating	93 (70%)	1 (1%)	<0.001
Duration of disease (years)	9.10 ± 8.05		
Males	9.08 ± 4.63		
Females	9.11 ± 9.23		
Age of onset (years)	42.8 ± 12.5		
Males	43.5 ± 12.8		
Females	42.4 ± 12.4		

Only symptoms attributed to EMF are given.

Mannheim, Germany) and the parameters of the red blood count were detected with the Coulter LH-750 Hematology Analyzer (Fa. Beckmann/Coulter, Krefeld, Germany) at the Institute of Clinical Chemistry and Laboratory Medicine of the University of Mainz Hospital.

Statistical Analysis

All statistical analyses were performed using SPSS v12 (SPSS, Chicago, IL). Descriptive results of continuous variables are expressed as means $\pm$ SD. Group differences were tested with the Student's *t*- or Mann–Whitney *U*-test. For the assessment of correlations, Spearman correlation coefficients were calculated. *P*-values of <0.05 were considered to be statistically significant.

RESULTS

Thyroid (TSH)

More patients than controls had TSH levels below the reference value of 0.3 mU/L (6.1% vs. 0.9%; $P = 0.042$).

Liver (ALT, AST)

Mean ALT and AST levels were significantly higher in the group of EHS affected individuals. In the analysis of the male and female subgroup, this difference was only significant in the females (see Table 2). Elevated ALT (ALT $\geq$ 35 U/L) was found in 27 (20.9%) EHS affected persons and in 11 (11%) of the controls ($P = 0.045$). Elevated AST (AST $\geq$ 35 U/L) was found in 16 (12.4%) affected persons and 6 (5.9%) of the controls ($P = 0.098$). Three persons in the EHS group had ALT $>$ 70 U/L and only one person in the EHS group had AST $>$ 70 U/L. None of the ALT or AST levels exceeded 120 U/L. As expected, ALT and AST were significantly higher in males (ALT: 30.03 ± 14.2 U/L; AST: 30.03 ± 14.2 U/L) than in females (ALT: 24.52 ± 8.86 U/L, $P = 0.001$; AST: 25.78 ± 9.4 U/L, $P < 0.001$).

Anaemia (Hb, MCV, MCHC, Hct, Iron, Ferritin, ZPP)

No pathological Hb concentration or Hct levels were found in the EHS group.

Kidney (Creatinine and Electrolytes)

Twenty-eight percent of the EHS group and 32% of the controls had creatinin levels above 0.9 mg/dl ($P = 0.706$). Only one individual in the EHS group had a serum creatinin level above the more stringent reference value of 1.4 mg/dl and none above 1.7 mg/dl. The mean sodium level in the EHS group was slightly higher than in the control group (140.34 ± 3.28 vs. 139.87 ± 2.48; $P = 0.042$), especially within the female subgroups (140.53 ± 3.27 vs. 139.40 ± 2.36; $P = 0.001$). The male groups showed no significant difference ($P = 0.312$). Within the EHS group were six cases of hypernatraemia; the maximum sodium concentration was 148 mmol/L, well below the threshold for severe hypernatraemia of 160 mmol/L. Hyponatraemia was detected in four EHS individuals.

The minimal sodium concentration was 119 mmol/L. Hyperchloremia was found in five EHS individuals. Hypochloremia was noted in 4 EHS patients. The maximum chloride concentration was 111 mmol/L, the minimum was 86 mmol/L.

Inflammation (CRP, Leucocytes, Thrombocytes, MPV)

Increased CRP levels (>5 mg/L) were found in both groups, with 10 samples in each. Three values in the EHS group were above 10 mg/L with two being between 10 and 15 mg/L and the maximum value of 25 mg/L. In the control group, platelet count above the reference range was found in six controls whereas only one pathological value was found in the EHS group ($P = 0.024$). There were no significant differences in MPV between patients and controls ($P = 0.332$), only the female subgroup showed a significant difference (9.53 ± 0.96 vs. 9.09 ± 1.04; $P = 0.012$).

The complete data set is given in Table 3 (mean values) and Table 4 (number of individuals outside of reference values). There were no correlations between laboratory data and number or intensity of symptoms (data not shown).

DISCUSSION

Symptoms presented by individuals suffering from EHS resemble symptoms from individuals suffering from common conditions such as hypo- or hyperthyroidism, liver disorders, anaemia, kidney disorders or chronic inflammations (Table 1). By analysing a range of blood chemistry parameters we were able to test the hypothesis that EHS symptoms are caused by detectable common disorders.

Thyroid Dysfunction (TSH)

The prevalence of hyperthyroidism in Germany is 2–5% in women and 0.2–0.7% in men. Main symptoms are nervousness or distress, loss of weight, heat intolerance, sweating, fatigue, headache and eye and vision symptoms. Additional symptoms include the sense of not feeling well, emotional irritability, a tendency towards depressiveness and an increased lack of vitality and activity [Suwalska et al., 2005]. Although overt hyper- and hypothyroidism individuals show the most symptoms, subclinical hyperthyroidism may also cause symptoms [Gulseren et al., 2006]. TSH is an effective screening instrument for the detection of thyroid dysfunctions [Spencer et al., 1987].

The finding of an enlarged fraction of persons showing TSH levels below the reference value raises two questions: (1) Does a fraction of EHS patients truly suffer from thyroid gland dysfunction? (2) Is there a link between thyroid function and EMF exposure? To answer the first question a well-designed replication study would be necessary. The replication should also comprise the measurement of the thyroid hormones T3 and T4. Currently we consider our result a 'signal' awaiting replication. In any case, the fraction of persons

TABLE 3. Mean Values ± Standard Deviation of Measured Blood Parameters

	All			Males			Females		
	Patients ($n = 132$)	Controls ($n = 101$)	P	Patients ($n = 42$)	Controls ($n = 34$)	P	Patients ($n = 90$)	Controls ($n = 67$)	P
TSH[a] (mU/L)	1.35 ± 0.98	1.34 ± 1.13	0.334	1.38 ± 0.90	1.20 ± 0.68	0.461	1.34 ± 1.02	1.40 ± 1.30	0.531
ALT[a] (U/L)	26.54 ± 15.66	22.50 ± 13.65	**0.007**	33.40 ± 19.25	31.76 ± 18.37	0.54	23.23 ± 12.43	17.73 ± 6.66	**0.001**
AST[a] (U/L)	26.88 ± 9.09	25.64 ± 13.42	**0.003**	29.17 ± 8.05	31.09 ± 19.38	0.405	25.78 ± 9.40	22.88 ± 7.87	**0.002**
Iron (µg/dl)	94.63 ± 34.71	95.10 ± 34.36	0.919	98.67 ± 32.70	100.52 ± 26.31	0.792	92.66 ± 35.67	92.43 ± 37.60	0.969
Ferritin[a] (ng/ml)	97.59 ± 93.74	93.16 ± 106.96	0.192	155.84 ± 110.71	167.10 ± 141.41	0.965	70.86 ± 70.88	55.63 ± 55.57	0.101
ZPP[a] (mmol/molHb)	58.99 ± 24.05	61.58 ± 22.41	0.393	50.13 ± 22.69	57.21 ± 22.98	0.246	63.15 ± 23.67	63.87 ± 21.95	0.602
Erythrocyte (per pl)	4.63 ± 0.40	4.59 ± 0.40	0.464	4.87 ± 0.36	4.88 ± 0.36	0.926	4.52 ± 0.33	4.45 ± 0.34	0.235
Haemoglobin (g/dl)	14.28 ± 1.20	14.16 ± 1.22	0.489	15.24 ± 1.03	15.14 ± 1.05	0.649	13.80 ± 0.97	13.67 ± 0.99	0.413
Hematokrit (%)	41.57 ± 3.32	41.17 ± 3.66	0.395	44.15 ± 2.69	43.94 ± 3.38	0.771	40.31 ± 2.85	39.77 ± 2.95	0.253
MCH (pg)	30.83 ± 1.76	30.84 ± 1.44	0.973	31.31 ± 1.73	31.07 ± 1.36	0.505	30.60 ± 1.74	30.72 ± 1.48	0.638
MCV (fl)	89.68 ± 4.47	89.64 ± 4.09	0.935	90.65 ± 5.02	90.16 ± 4.43	0.657	89.21 ± 4.13	89.37 ± 3.92	0.809
MCHC[a] (g/dl)	34.39 ± 1.15	34.42 ± 1.01	0.546	34.57 ± 0.85	34.49 ± 1.12	0.727	34.30 ± 1.26	34.38 ± 0.95	0.293
Creatinin[a] (mg/dl)	0.84 ± 0.17	0.85 ± 0.19	0.84	0.94 ± 0.16	0.98 ± 0.19	0.565	0.79 ± 0.15	0.78 ± 0.15	0.684
Sodium[a] (mmol/L)	140.34 ± 3.28	139.87 ± 2.48	**0.042**	139.95 ± 3.29	140.79 ± 2.50	0.312	140.53 ± 3.27	139.40 ± 2.36	**0.001**
Chloride[a] (mmol/L)	103.12 ± 3.45	102.49 ± 2.68	**0.041**	102.98 ± 3.52	103.35 ± 2.97	0.773	103.18 ± 3.44	102.05 ± 2.41	**0.006**
Potassium[a] (mmol/L)	4.24 ± 0.53	4.18 ± 0.47	0.452	4.27 ± 0.50	4.23 ± 0.35	0.821	4.22 ± 0.55	4.15 ± 0.52	0.275
CRP[a] (mg/L)	1.83 ± 2.90	2.20 ± 3.51	0.601	1.23 ± 1.41	1.47 ± 1.83	0.393	2.11 ± 3.38	2.56 ± 4.07	0.899
Leukocyte (per nl)	6.48 ± 1.65	6.62 ± 2.05	0.541	6.44 ± 1.67	6.14 ± 2.06	0.477	6.49 ± 1.64	6.87 ± 2.01	0.198
Thrombocyte (per nl)	264.04 ± 64.29	267.36 ± 68.25	0.706	254.19 ± 59.65	233.59 ± 57.60	0.133	268.85 ± 66.25	284.49 ± 67.19	0.152
MPV (fl)	9.41 ± 0.97	9.27 ± 1.10	0.332	9.14 ± 0.97	9.61 ± 1.16	0.086	9.53 ± 0.96	9.09 ± 1.04	**0.012**

[a]Non-Gaussian variables.
Significant differences in bold.

TABLE 4. Number of Individuals Outside the Reference Values

		<Ref. range			>Ref. range		
	Reference range	Patients ($n = 132$)	Controls ($n = 101$)	P	Patients ($n = 132$)	Controls ($n = 101$)	P
TSH (mU/L)	0.3–4.2	8 (6.1%)	1 (0.9%)	**0.042**	2 (1.5%)	3 (2.9%)	0.514
ALT (U/L)	<35 U/L				27 (20.5%)	11 (10.8%)	0.045
AST (U/L)	<35 U/L				16 (12.1%)	6 (5.9%)	0.098
Iron (μg/dl)	37–145	2 (1.5%)	2 (1.9%)	0.860	13 (9.8%)	7 (6.9%)	0.403
Ferritin (ng/ml)	30–320	24 (18.2%)	32 (31.7%)	**0.028**	0 (0%)	1 (0.9%)	0.263
ZPP (mmol/molHb)	<40				105 (79.5%)	90 (89.1%)	0.126
Erythrocyte (per pl)	4.1–5.1	10 (7.6%)	9 (8.9%)	0.765	12 (9.1%)	14 (13.8%)	0.288
Haemoglobin (g/dl)	12.1–16.1	0 (0%)	3 (2.9%)	**0.049**	11 (8.3%)	7 (6.9%)	0.642
Hematokrit (%)	35–47	0 (0%)	4 (3.9%)	**0.023**	8 (6.1%)	3 (2.9%)	0.249
MCH (pg)	27–34	0 (0%)	1 (0.9%)	0.259	5 (3.8%)	0 (0%)	**0.045**
MCV (fl)	80–100	2 (1.5%)	0 (0%)	0.207	0 (0%)	1 (0.9%)	0.259
MCHC (g/dl)	31.5–36	0 (0%)	1 (0.9%)	0.259	4 (3.1%)	5 (4.9%)	0.450
Creatinin (mg/dl)	0.5–0.9	0 (0%)	1 (1%)	0.259	37 (28%)	32 (31.7%)	0.706
Sodium (mmol/L)	135–144	4 (3.1%)	2 (1.9%)	0.597	6 (4.5%)	3 (2.9%)	0.514
Chloride (mmol/L)	97–108	4 (3.1%)	1 (0.9%)	0,282	5 (3.8%)	1 (0.9%)	0.177
Potassium (mmol/L)	3.6–4.8	5 (3.8%)	2 (1.9%)	0.460	8 (6.1%)	5 (4.9%)	0.683
CRP (mg/L)	<5				10 (7.6%)	10 (9.9%)	0.530
Leukocyte (per nl)	3.9–10.0	6 (4.5%)	8 (7.9%)	0.311	4 (3.1%)	6 (5.9%)	0.301
Thrombocyte (per nl)	150–400	5 (3.8%)	2 (1.9%)	0.401	1 (0.8%)	6 (5.9%)	**0.024**
MPV (fl)	7.6–11.2	2 (1.5%)	3 (2.9%)	0.544	3 (2.3%)	7 (6.9%)	0.134

showing noteworthy TSH values was below 10%. Therefore, our result points towards the hypothesis of EHS being a heterogeneous mixture of conditions rather than reflecting a single pathophysiology. The link between EMF and thyroid function has been poorly explored so far and the few publications fall into either of the two categories positive reports without replication or negative reports. In the largest study involving humans Bergamaschi et al. [2004] studied TSH values in 2,598 employees grouped according to the extent of mobile phone use. No statistically significant difference regarding TSH values below 0.4 UI/L was observed but there was a greater prevalence of subjects with low TSH values among 192 employees with more than 33 h/month conversation time. Djeridane et al. [2008] studied TSH levels in 20 healthy young men in an experimental design with the pre-exposure levels as controls and found no effect of 900 MHz EMF exposure on TSH profiles.

Liver Disease (ALT, AST)

In liver diseases fatigue is a major symptom and at times the presenting symptom [Kumar and Tandon, 2002]. In addition malaise, lethargy, anorexia, listlessness, loss of social interest and inability to concentrate are commonly associated with liver affectations. Cauch-Dudek et al. [1998] and Swain [2006] showed that the genesis of the symptom of fatigue in chronic disease is complex and poorly understood, although the cause of fatigue could be multifactorial. Depression is also common in fatigued patients whereas it is unclear whether fatigue leads to depression or vice versa. Serum alanine aminotransferase (ALT) and serum aspartate aminotransferase (AST) levels are the most common screening tests as part of a routine evaluation of liver damage [Leclercq et al., 1999] with ALT being the most specific marker of liver cell damage.

The vast majority of the ALT and AST values were within the narrowly defined normal range < 35 U/L and only three ALT-values were above 70 U/L in the EHS group. None was above 120 U/L. This result shows that liver affectations might play a role in a small minority of patients but are of no concern in most cases of EHS.

Anaemia (Hb, MCV, MCHC, Hct, Iron, Ferritin, ZPP)

Anaemia is a condition in which the haemoglobin concentration in the blood is below the reference level, resulting in a reduced oxygen-carrying capacity of red blood cells. About half of all cases of anaemia can be attributed to iron deficiency; other common causes include infections and genetic factors. In its severe form, anaemia is associated with fatigue, weakness, dizziness and drowsiness. Pregnant women and children are particularly vulnerable. It is well known that normal haemoglobin distributions vary with age and gender, at different stages of pregnancy, and with altitude and smoking. The main indicators of anaemia

are haemoglobin level (Hb) and haematocrit (Hct). Severe anaemia is defined as haemoglobin < 7 g/dl and requires medical treatment. Among all the red cell indices measured by electronic blood counters, mean corpuscular volume (MCV) and mean corpuscular haemoglobin (MCH) are the two most sensitive indices of iron deficiency. Reduction in mean corpuscular volume (MCV) occurring in parallel with anaemia is a late phenomenon in the development of iron deficiency [WHO, 2006]. Low serum iron by itself is no proof of iron deficiency as it also occurs in inflammatory disorder [Cartwright, 1966] and malignancies [Banerjee and Narang, 1967]. Ferritin is an established additional parameter with which to evaluate endogenous iron availability [Wish, 2006].

No pathological Hb concentration or Hct levels were found in the EHS group. Fatigue and related symptoms caused by anaemia do not appear to be of particular relevance in EHS. This result is in line with human data on the EMF effects on blood parameters although highly speculative reports on the potential link between EMF and iron metabolism also exist [Hachulla et al., 2000]. For example, the results of Dasdag et al. [2002] suggest that electromagnetic fields did not affect the haematological and immunologic parameters of welders. Likewise, the results of Selmaoui et al. [1996] and Akdag et al. [2006] indicated that both continuous and intermittent 50 Hz MFs had no effects on the iron levels, electrolytes, liver enzymes or lipids.

Kidney Disease (Creatinine, Na, K, Cl)

Symptoms of renal diseases such as fatigue/tiredness, pruritus, constipation, anorexia, sleep disturbance, anxiety, dyspnoea, nausea and depression are often underrecognized [Murtagh et al., 2007]. Serum creatinine level is the most commonly used measure of kidney function in clinical practice. Serum creatinine is derived from the metabolism of creatine in muscle and the generation of creatinine tends to be proportional to muscle mass. In addition, associations of higher creatinine with male sex, older age, black race, history of diabetes and cimetidine use have been reported [Salive et al., 1995]. Increased serum creatinine concentrations were also noticed after meals rich in meat.

In our study, there were slightly elevated creatinine levels ($>$0.9 mg/dl) in almost one third of the probands of both groups. However, in both groups clinically relevant creatinine levels were not observed. Only one individual in the EHS group had a serum creatinine level above the more stringent reference value of 1.4 mg/dl and none were above 1.7 mg/dl. None of the values was of immediate clinical relevance. Thus, it can be safely concluded that kidney dysfunction is not of major concern in EHS.

Inflammation (CRP, Leucocytes, Thrombocytes, MPV)

Chronic inflammation could be a reason for the non-specific symptoms of EHS patients. CRP and leucocytes are reliable and easily accessible biomarkers for clinical use. CRP is the most sensitive of the acute phase reactants. Its concentration increases rapidly during inflammatory processes. In most cases, mild to moderately elevated platelet counts are seen when chronic inflammation is present. Mean platelet volume (MPV) has been proposed as a potential marker of clinical disease activity, being inversely proportional to the levels of classical inflammatory markers such as CRP [Danese et al., 2004].

7.6% of the EHS group displayed elevated ($>$5 mg/L) CRP levels; three individuals had CRP $>$ 10 mg/dl. Thus, at least three and up to 10 individuals in the EHS group (2.3%) were harbouring an inflammatory process. The potential link between immune function, EMF exposure and EMF effect is unclear and immune suppressive as well as immune stimulatory effects have been reported in addition to the absence of effects. Moreover, in some exposure studies it was impossible to discriminate potential EMF effects, the effects of stress and potential pre-existing abnormalities [review by Boscolo et al., 2007].

In summary, our results identified thyroid dysfunction, liver dysfunction and chronic inflammatory processes in small but remarkable fractions of EHS sufferers as potential sources of symptoms that merit further investigation in future studies. In the cases of TSH and ALT/AST there were significant differences between cases and controls. The hypotheses of anaemia or kidney dysfunction playing a major role in EHS could be unambiguously refuted. The results are compatible with those of Hillert et al. [2002] who measured routine laboratory parameters in 14 EHS patients without detecting a specific pattern of abnormalities. EHS might not be a single disorder with defined pathophysiology but rather a complex mixture of different etiologies held together by the subject's EHS disorder model. Clinically it is recommended to check for signs of treatable somatic conditions when caring for individuals suffering from self-proclaimed EHS.

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REFERENCES

Akdag MZ, Dasdag S, Aksen F, Isik B, Yilmaz F. 2006. Effect of ELF magnetic fields on lipid peroxidation, sperm count, p53, and trace elements. Med Sci Monit 12(11):BR366–BR371.

Banerjee RN, Narang RM. Haematological changes in malignancy. 1967. Br J Haematol 13(6):829–843.

Berg M. 1988. Skin problems in workers using visual display terminals. Contact Dermat 19:335–341.

Berg M, Lidén S, Axelson O. 1990. Facial complaints and work at visual display units. J Am Acad Dermatol 22:621–625.

Bergamaschi A, Magrini A, Ales G, Coppeta L, Somma G. 2004. Are thyroid dysfunctions related to stress or microwave exposure (900 MHz)? Int J Immunopathol Pharmacol 17 (2 Suppl):31–36.

Bergdahl J. 1995. Psychological aspects of patients with symptoms presumed to be caused by electricity or visual display units. Acta Ondotol Scand 53:304–310.

Bergqvist U, Vogel E, editors. 1997. Possible health implications of subjective symptoms and electromagnetic fields: A report by a European group of experts for the European Commission. Solna/Sweden: Directorate-General V. National Institute for. Working Life.

Bergqvist U, Wahlberg JE. 1994. Skin symptoms and disease during work with visual display terminals. Contact Dermat 30:197–204.

Boscolo P, Di Gioacchino M, Di Giampaolo L, Antonucci A, Di Luzio S. 2007. Combined effects of electromagnetic fields on immune and nervous responses. Int J Immunopathol Pharmacol 20 (2 Suppl 2):59–63.

Carpenter DO, Sage C. 2008. Setting prudent public health policy for electromagnetic field exposures. Rev Environ Health 23(2):91–117.

Cartwright GE. 1966. The anemia of chronic disorders. Semin Hematol 3(4):351–375.

Cauch-Dudek K, Abbey S, Stewart DE, Heathcote EJ. 1998. Fatigue in primary biliary cirrhosis. Gut 43(5):705–710.

Danese S, Motte Cd Cde L, Fiocchi C. 2004. Platelets in inflammatory bowel disease: Clinical, pathogenic, and therapeutic implications. Am J Gastroenterol 99(5):938–945.

Dasdag S, Sert C, Akdag Z, Batun S. 2002. Effects of extremely low frequency electromagnetic fields on hematologic and immunologic parameters in welders. Arch Med Res 33(1):29–32.

Djeridane Y, Touitou Y, de Seze R. 2008. Influence of electromagnetic fields emitted by GSM-900 cellular telephones on the circadian patterns of gonadal, adrenal and pituitary hormones in men. Radiat Res 169(3):337–343.

Frick U, Rehm J, Eichhammer P. 2002. Risk perception, somatization, and self report of complaints related to electromagnetic fields–a randomized survey study. Int J Hyg Environ Health 205(5):353–360.

Gulseren S, Gulseren L, Hekimsoy Z, Cetinay P, Ozen C, Tokatlioglu B. 2006. Depression, anxiety, health-related quality of life, and disability in patients with overt and subclinical thyroid dysfunction. Arch Med Res 37(1):133–139.

Hachulla E, Caulier-Leleu MT, Fontaine O, Mehianoui L, Pelerin P. 2000. Pseudo-iron deficiency in a French population living near high-voltage transmission lines: A dilemma for clinicians. Eur J Intern Med 11(6):351–352.

Hietanen M, Hämäläinen AM, Husman T. 2002. Hypersensitivity symptoms associated with exposure to cellular telephones: No causal link. Bioelectromagnetics 23(4):264–270.

Hillert L, Hedman BK, Söderman E, Arnetz BB. 1999. Hypersensitivity to electricity: Working definition and additional characterization of the syndrome. Psychosom Res 47(5): 429–438.

Hillert L, Berglind N, Arnetz BB, Bellander T. 2002. Prevalence of self-reported hypersensitivity to electric or magnetic fields in a population-based questionnaire survey. Scand J Work Environ Health 28:33–41.

Knave B. 2001. Electromagnetic fields and health outcomes. Ann Acad Med Singapore 30(5):489–493.

Kumar D, Tandon RK. 2002. Fatigue in cholestatic liver disease—A perplexing symptom. Postgrad Med J 78(921):404–407.

Leclercq I, Horsmans Y, De Bruyere M, Geubel AP. 1999. Influence of body mass index, sex and age on serum alanine aminotransferase (ALT) level in healthy blood donors. Acta Gastroenterol Belg 62(1):16–20.

Leitgeb N, Schröttner J. 2003. Electrosensibility and electromagnetic hypersensitivity. Bioelectromagnetics 24(6):387–394.

Lindén V. 1981. Video computer terminals and occupational dermatitis. Scand J Work Environ Health 7:62–67.

Lonne-Rahm S, Andersson B, Melin L, Schultzberg M, Arnetz B, Berg M. 2000. Provocation with stress and electricity of patients with ''sensitivity to electricity''. J Occup Environ Med 42:512–516.

Markgraf J. 1994. Mini-DIPS—Handbuch [revised by Jacobs S, Krampe H and Wagner T.]. Berlin: Springer.

Murtagh FE, Addington-Hall J, Higginson IJ. 2007. The prevalence of symptoms in end-stage renal disease: A systematic review. Adv Chronic Kidney Dis 14(1):82–99.

Nilsen A. 1982. Facial rash in visual display unit operators. Contact Dermat 8:25–28.

Röösli M. 2008. Radiofrequency electromagnetic field exposure and non-specific symptoms of ill health: A systematic review. Environ Res 107(2):277–287.

Röösli M, Moser M, Baldinini Y, Meier M, Braun-Fahrländer C. 2004. Symptoms of ill health ascribed to electromagnetic field exposure—A questionnaire survey. Int J Hyg Environ Health 207(2):141–150.

Salive ME, Jones CA, Guralnik JM, Agodoa LY, Pahor M, Wallace RB. 1995. Serum creatinine levels in older adults: Relationship with health status and medications. Age Ageing 24(2):142–150.

Schüz J, Petters C, Egle UT, Jansen B, Kimbel R, Letzel S, Nix W, Schmidt LG, Vollrath L. 2006. The ''Mainzer EMF-Wachhund'': Results from a watchdog project on self-reported health complaints attributed to exposure to electromagnetic fields. Bioelectromagnetics 27(4):280–287.

Seitz H, Stinner D, Eikmann T, Herr C, Röösli M. 2005. Electromagnetic hypersensitivity (EHS) and subjective health complaints associated with electromagnetic fields of mobile phone communication—A literature review published between 2000 and 2004. Sci Total Environ 349(1–3): 45–55.

Selmaoui B, Lambrozo J, Touitou Y. 1996. 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.

Silny J, Meyer M, Wiesmüller GA, Dott W. 2004. Health effects from radiofrequency electromagnetic fields of mobile phones

and other new communication systems. Umwelt Med Forsch Prax 9(3):127–136.

Spencer C, Eigen A, Shen D, Duda M, Qualls S, Weiss S, Nicoloff J. 1987. Specificity of sensitive assays of thyrotropin (TSH) used to screen for thyroid disease in hospitalized patients. Clin Chem 33(8):1391–1396.

Suwalska A, Lacka K, Lojko D, Rybakowski JK. 2005. Quality of life, depressive symptoms and anxiety in hyperthyroid patients. Annales Academiae Medicae Bialostocensis 50 (Suppl 1):61–63.

Swain MG. 2006. Fatigue in liver disease: Pathophysiology and clinical management. Can J Gastroenterol 20(3):181–188.

WHO. 2004. Workshop on electromagnetic hypersensitivity. October 25–27, Prague, Czech Republic: World Health Organization. Available from: http://www.who.int/peh-emf/publications/reports/EHS_Proceedings_June2006.pdf [Last updated June 2006].

WHO. 2006. Iron Deficiency Anaemia [Internet]. Geneva (CH): World Health Organization. Available from: http://www.who.int/reproductive-health/docs/anaemia.pdf [Last updated 10 July 2006].

Wish JB. 2006. Assessing iron status: Beyond serum ferritin and transferrin saturation. Clin J Am Soc Nephrol 1 (Suppl 1): S4–S8.