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Electromagnetic Field Exposure and Health Among RF Plastic Sealer Operators

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Operators of RF plastic sealers (RF operators) are an occupational category highly exposed to radiofrequency electromagnetic fields. The aim of the present study was to make an appropriate exposure assessment of RF welding and examine the health status of the operators. In total, 35 RF operators and 37 controls were included. The leakage fields (electric and magnetic field strength) were measured, as well as induced and contact current. Information about welding time and productivity was used to calculate time integrated exposure. A neurophysiological examination and 24 h ECG were also carried out. The participants also had to answer a questionnaire about subjective symptoms. The measurements showed that RF operators were exposed to rather intense electric and magnetic fields. The mean values of the calculated 6 min, spatially averaged E and H field strengths, in line with ICNIRP reference levels, are 107 V/m and 0.24 A/m, respectively. The maximum measured field strengths were 2 kV/m and 1.5 A/m, respectively. The induced current in ankles and wrists varied, depending on the work situation, with a mean value of 101 mA and a maximum measured value of 1 A. In total, 11 out of 46 measured RF plastic sealers exceeded the ICNIRP reference levels. RF operators, especially the ready made clothing workers had a slightly disturbed two-point discrimination ability compared to a control group. A nonsignificant difference between RF operators and controls was found in the prevalence of subjective symptoms, but the time integrated exposure parameters seem to be of importance to the prevalence of some subjective symptoms: fatigue, headaches, and warmth sensations in the hands. Further, RF operators had a significantly lower heart rate (24 h registration) and more episodes of bradycardia compared to controls. Bioelectromagnetics 25:5–15, 2004.
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Key words: radiofrequency fields; induced current; EEG; two-point discrimination; subjective symptoms

INTRODUCTION

It is well established that exposure to radiofrequency electromagnetic fields (RF) can lead to thermal effects, and the present guidelines [ICNIRP, 1998; IEEE, 1999] are based on this. The knowledge of other possible effects is limited and discussions about potential nonthermal effects have been intense during the last decades.

Early studies from Eastern Europe and the former Soviet Union discuss effects such as neurasthenic symptoms (headaches, fatigue, etc.), but also cardiovascular effects from nonthermal exposure levels [Baranski and Czerski, 1976]. Zhao et al. [1994] found a higher prevalence of self reported neurasthenic symptoms such as headaches and fatigue among workers exposed to RF (<30 MHz). A similar tendency was found among male regulators of communication equipment (3–30 MHz) [Nikitina, 2000]. Bortkiewicz et al. [1996, 1997], Szmigielski et al. [1998], and Zhao et al. [1994] found disturbances in the ECG pattern in workers exposed to RF. Kolmodin-Hedman et al. [1988] found a significantly impaired two point discrimination (2 PD), as well as a higher consumption of headache pills among female RF operators compared to a control group.

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To better understand possible health effects from RF exposure in general, WHO recommends in their agenda more research on occupational groups highly exposed to RF [Repacholi, 1998]. Operators of RF plastic sealers (RF operators) are an occupational category highly exposed to RF with frequencies around 27 MHz. RF is used to produce heat to seal for instance plastics for tarpaulins, tents, rain clothes, and covers. Around an RF plastic sealer (RF sealer), both a magnetic and an electric field will be present, and close to the machine the coupling between the two is complex since far field conditions are not at hand. During RF exposure, a current is induced in the body, the magnitude of which is dependent on many factors, such as the electric and magnetic field strength, the polarization of the field, and the grounding conditions.

Within the group of RF operators, many different exposure situations exist which can roughly be divided into two main types; tarpaulin workers and ready made clothing workers. Tarpaulin workers often stand in front of the RF sealer and will experience ''whole body exposure,'' which often causes a high current to pass through the ankles. Ready made clothing workers often sit down in front of the RF sealer, often without perfect contact with the ground, but with their hands close to the electrode.

To get a good weld both the welding time and the total power can be adjusted. The combination of the two will produce enough energy to seal the plastic. Typical welding times range from 1 to 10 s, depending on the material being sealed. For more information about the welding process, see Eriksson and Hansson Mild [1985], Williams and Hansson Mild [1991], or ILO [1998]. The total exposure time will also vary between different RF sealing processes; in the same amount of time, more welds are made in the ready made clothing industry than in the tarpaulin industry.

The aim of this study was to make an appropriate exposure assessment for RF welding where measurements of electric and magnetic field as well as the induced current in ankles and wrists will be made. In a previous study [Wilén et al., 2001], we tested different techniques to measure the induced current in grounded as well as ungrounded conditions, the results of which will be taken into account in this study.

The measurements were complemented with information about welding time and productivity in order to calculate time integrated exposure and in the long run approach a dose concept. Cardiovascular effects were assessed by 24 h ECG, and a neurophysiological examination was also done.

Three hypotheses were tested: (1) RF operators have a disturbed 2 PD compared to a control group, (2) the prevalence of subjective symptoms such as headaches, fatigue (unusual drowsiness/tiredness) is higher among RF operators, and (3) RF operators experience episodes of bradycardia and arrhythmias. In the recommended guidelines [ICNIRP, 1998; IEEE, 1999] as well as in the present Swedish standard [Arbetarskyddsstyrelsen, 1987], the exposure limits are set to avoid thermal effects. Since this is not the main focus in this work, an effort to establish new exposure parameters is undertaken, and their relevance to the above mentioned effects is discussed. The previous performed study [Kolmodin-Hedman et al., 1988] has formed a basis for the present study, but with some improvements in exposure assessment and with added information about subjective symptoms and heart rate variability.

MATERIALS AND METHODS

Selection Procedure

We established contact with companies using RF sealers in their daily work by mailing to manufactures of tarpaulin and ready made clothing and to other industries manufacturing tents, protective clothing, or other products where RF sealers might be used in the production. The mailing contained questions about the use of RF sealers and the total numbers of RF sealers and people working with them. For a company to be included in the study the following selection criteria had to be met:

1. There had to be people working with RF sealers on a daily basis, full time, or part time. It had to be possible for the employees to leave their work for 1 h to participate in the examination.
2. Control persons also had to be available at the same company or at least in the same neighborhood, who had the same age and gender distribution and similar work tasks as the selected RF operators.
3. RF operators as well as controls could not have a diagnosed heart disease, diabetes, or be on heart medication.

In total, nine companies were selected. It is worth noting that all the companies that were invited to participate were interested in joining the study. In total, 35 RF operators and 37 controls were included.

Exposure Assessment

In front of each RF sealers used by any of the subjects included in the study, the electric and magnetic field strengths were measured in seven positions; head, trunk, waist, knees, feet, and both hands. In every position, four measurements were taken in each of the three

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orthogonal directions (Fig. 1). The Holaday HI-4413P (Cedar Park, TX) Optical Modem connected to a PC, with an electric field probe (HI-4433-STE) and a magnetic field probe (HI-4433-HCH) were used. Both the welding time and the duty cycle were documented in order to estimate time integrated and time averaged exposure.

The induced current in the ankles and in the wrists during ordinary work was measured with a Holaday current probe (HI 3702) connected to HI-4413P. The current was logged during a period of time when a number of welds were made. The contact current was measured with Narda 8850 (Happauge, LI, NY) contact current meter, and these measurements were taken in positions on the RF sealer where the RF operators regularly or accidentally could place their hands/fingers.

Some of the RF operators worked with more than one RF sealer; for those a mean value of the daily exposure has been used.

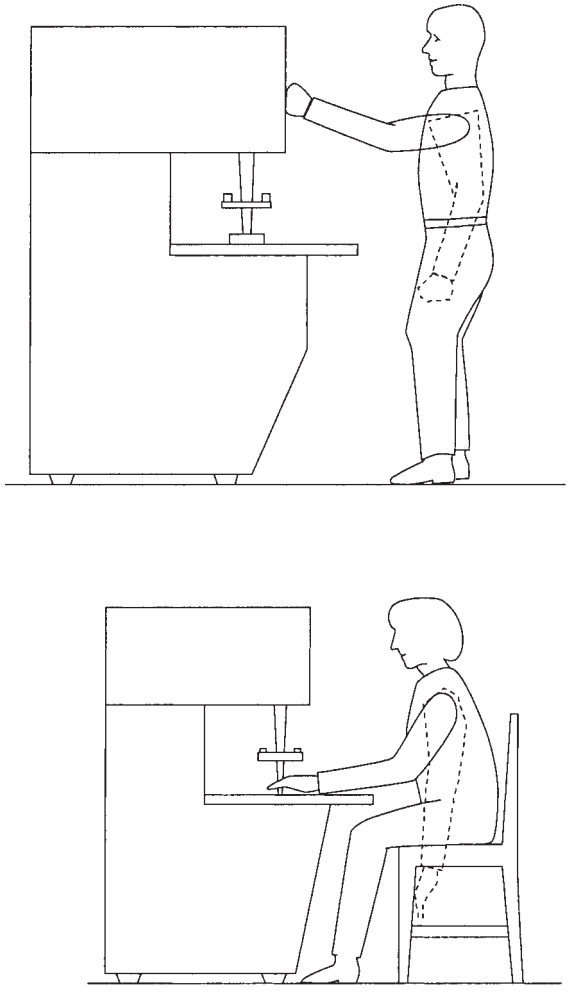

Fig. 1. Schematic drawing of tarpaulin (**top**) and ready made working (**bottom**) processes.

Exposure Parameters

The *E-field* (V/m) and *H-field* (A/m) were calculated as linear mean values of the exposure over the entire body, for example, the measured values close to the head, chest, wrist, hands, knees, and feet.

$$E\text{-}field = \frac{E_{head} + E_{chest} + E_{waist} + E_{knees} + E_{hands} + E_{feet}}{6}$$

$$H\text{-}field = \frac{H_{head} + H_{chest} + H_{waist} + H_{knees} + H_{hands} + H_{feet}}{6} \quad (1)$$

E-ICNIRP (V/m) and *H-ICNIRP* (A/m) were calculated as 6 min spatial average E^2 and H^2 values, according to ICNIRP's recommendations (Eqn. 2a,b), where $T = 6$ min and $t_n =$ time of nth weld in minutes.

$$E\text{-}spatial = \frac{\sqrt{E_{head}^2 + E_{chest}^2 + E_{waist}^2 + E_{knees}^2 + E_{hands}^2 + E_{feet}^2}}{6}$$

$$H\text{-}spatial = \frac{\sqrt{H_{head}^2 + H_{chest}^2 + H_{waist}^2 + H_{knees}^2 + H_{hands}^2 + H_{feet}^2}}{6} \quad (2a)$$

$$E\text{-}ICNIRP = \sqrt{\sum_n \frac{(E\text{-}spatial)_n^2 \cdot t_n}{T}}$$

$$H\text{-}ICNIRP = \sqrt{\sum_n \frac{(H\text{-}spatial)_n^2 \cdot t_n}{T}} \quad (2b)$$

E-weld (V/m · s) and *H-weld* (A/m · s) were calculated as integrated E and H fields over the time of one weld in seconds (t_{weld}) (Eq. 3):

$$E\text{-}weld = E\text{-}field \cdot t_{weld}$$
$$H\text{-}weld = H\text{-}field \cdot t_{weld}. \quad (3)$$

E-day (V/m · h) and *H-day* (A/m · h) are estimates of the daily exposure for each individual in the same way as (Eq. 3), but replacing t_{weld} with t_{day}, which is the approximated total welding time per day in hours.

Finally, *E-life* (V/m · h) and *H-life* (A/m · h) are estimates of the lifetime exposure for each individual, taking into account the total employment time where t_{weld} in (Eq. 3) has been replaced by t_{life}, which approximates the total welding time up to this point in

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operators' lives. In every analysis, the resultants (E_r and H_r) of the electric and magnetic field strength have been used (Eq. 4):

$$E_r = \sqrt{E_x^2 + E_y^2 + E_z^2} \quad \text{and} \quad H_r = \sqrt{H_x^2 + H_y^2 + H_z^2}. \tag{4}$$

For the induced current, *ankle* and *wrist* represent the total current (mA) passing through both ankles/wrists during a weld. The parameters *ankle-weld* and *wrist-weld* (mA · s), *ankle-day* and *wrist-day* (mA · h), *ankle-life* and *wrist-life* (mA · h) are calculated as above. A 6 min average value of the induced current *ankle* (6 *min*) and *wrist* (6 *min*) (mA) is calculated by (Eq. 5), where t_n is the time of the nth weld in minutes and T = 6 min.

$$\begin{aligned} \textit{Ankle-6 min} &= \sqrt{\sum_n \frac{ankle_n^2 \cdot t_n}{T}} \\ \textit{Wrist-6 min} &= \sqrt{\sum_n \frac{wrist_n^2 \cdot t_n}{T}} \end{aligned} \tag{5}$$

In some of the analyses, the RF operators have been divided into three different categories according to their different exposure situations; tarpaulin-workers, ready made clothing workers, and a mixed group of people working with both types. In Figure 1, a schematical sketch of the two working situations is given. Tarpaulin workers stand in front of the RF sealer, often with good contact with ground, which can cause a rather excessive induced current to pass through the body. Ready made clothing workers sit in front of the RF sealer, with poor or no contact with the ground, but sometimes with their hands close to the electrodes, which can cause significant exposure around their hands.

Questionnaire and Interview Form

Based on a previous study among RF operators [Kolmodin-Hedman et al., 1988] and experience from an epidemiological study among mobile phone users [Oftedal et al., 2000; Sandström et al., 2001], we prepared a questionnaire about subjective symptoms, health status, smoking habits, and work related factors. The subjective symptoms are *dizziness*, general discomfort (*discomfort*), difficulties concentrating (*concentration*), memory loss (*memory*) abnormal drowsiness/fatigue (*fatigue*), *headaches*, sensations of warmth in the hands (*warm hands*), sensations of warmth in the face (*warm face*), sensations of warmth in the feet (*warm feet*), sensations of warmth in the body in general (*warm body*), *chest pain*, *radiating pain* to the neck, arm and/or back, *eye symptoms*, and *sleeping disorders*. In addition, an open question about other symptoms was included (*others*). The answer options were: never, less than once a week, one to four times per week, and more than four times per week. An individual was defined as having a symptom if he/she had indicated that the symptom occurred at least once a week.

An interview form was also used, including questions about employment history, work schedule, time spent at RF sealers, and burns caused by RF welding. A psychosocial index was created based on four commonly used questions about workload, influence on work conditions, support from colleagues, and if the work was perceived as stimulating and interesting [Eriksson, 1996]. Each question was given a score, and the index was the sum of the scores (0–12) for all four questions. The index was divided into three categories, *low* (0–2), *medium* (3–5), and *high* (6–12), where *low* means that the person is experiencing a good psychosocial climate and the lowest psychosocial workload.

Neurophysiological Examination

Sensory-motor tests. Following a standardized procedure [Ekenvall et al., 1991], each individual underwent a two-point discrimination test (2 PD test) on the tip of the 2nd finger of both the left and the right hand. The results from the nondominating hand were used in the analyses.

The dexterity test is an examination where small pins are to be moved from a cup and placed in small holes arranged in a line. The test is performed in three steps, each with a total time of 30 s; using the right hand, using the left hand, and using both hands simultaneously. The total sum of the number of correctly placed pins for each separate test was used in the analysis.

The assembly test consists of pins, collars, and washers that are to be mounted with both hands operating the whole time, one picking up a pin, one a washer, one a collar, and so on. After 1 min the total number of completed assemblies are counted. The dexterity and assembly tests were carried out using the Purdue Pegboard #32020 (Lafayette Instrument, Lafayette, IN).

ECG monitoring. A continuous ECG was recorded during a 24 h period, using a two-channel 24 h ambulatory Holter recorder (Braemar DL700, Braemar, Inc., Burnsville, MN). For each individual, the Holter analysis started in the morning and ended the same time the day after. Because of missing values in the heart rate registration, only the recorded heart rates between 15:00 p.m. and 05:00 a.m. were used in the comparison of the hourly means of heart rate.

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After a visual examination for arrhythmia, extra systoles, and ST changes, the ECG data was digitized and transferred to a computer for analysis. The standard program (Danica Holter Replay Unit, Danica Biomedical, Sweden) detected and calculated pathological events as well as the dynamics of HR.

The ECG recording was also analyzed for the underlying rhythm and the frequency of supra- and ventricular extrasystoles. Analysis of ST changes was also made. For each minute an average QRST waveform was computed from those beats, which were regarded as ''normal.'' The measurement of ST levels was then made based on the QRST average, providing a stable measurement with a low sensitivity to noise. The ST segment was measured 60 ms after the J-point and depressions of at least 2 mm compared to the baseline with a duration of at least 1 min were considered to indicate myocardical ischemia (stated as significant). All data were reviewed and edited by the same technician.

Statistical Analysis

To compare differences in mean values, one way ANOVA (normal distributions) or the Mann–Whitney nonparametric test (other distributions) was used. Chi squared test was used to test for differences in prevalence of subjective symptoms. Multivariate regression analysis was used to evaluate the correlation between the tests (2 PD test, the dexterity test, and the assembly test) and the exposure parameters (*E-field, E-ICNIRP, E-weld, E-day, E-life, H-field, H-ICNIRP, H-weld, H-day, H-life, ankle, ankle-6 min, ankle-weld, ankle-day, ankle-life, wrist, wrist-6 min, wrist-weld, wrist-day*, and *wrist-life*). The differences in 24 h heart rates have been analyzed using repeated measure ANOVA.

RESULTS

In total, 46 RF sealers operated by 35 RF operators (some RF operators used more than one RF sealer) were measured. Sixteen of the 46 work places exceeded the Swedish standard [Arbetarskyddsstyrelsen, 1987] and out of those, eleven also exceeded the ICNIRP reference levels. The mean age and standard deviation (SD) for the RF operators were 40 (11) years. The corresponding values for the controls were 42 (12) years. The duration of employment ranged from 1 to 40 years, with mean values of 12 (10) years (RF operators) and 13 (13) years (controls), respectively. No one reported shift work and a typical 100% working day lasted from 7 a.m. to 4 p.m., including breaks. More information about the RF operators and controls is given in Table 1.

Exposure Parameters

The mean value (SD) of the electric and magnetic field strengths, linearly averaged over the entire body, for the RF operators were 88 (102) V/m and 0.19 (0.19) A/m, respectively. The induced current value was 101 (147) mA as a sum through both feet. The mean value of the induced current in the wrists was 102 (146) mA, calculated as an average value of the maximum measured value of the current passing through the left or right arm for each subject.

The maximum value of the electric field strength, 2 kV/m, was measured at the position of the hands during a weld. The corresponding magnetic field strength was 1.5 A/m, close to the area where the hands were kept during a weld. For the induced current, a maximum value of 1 A was measured in the wrists in front of a manually controlled RF sealer. More detailed information about the exposure is given in Tables 2 and 3.

TABLE 1. Characteristics of RF Welders and Controls

	RF-welders (N = 35)	Controls (N = 37)
Gender		
Male	18	14
Female	17	23
Age in year (SD)	40 (11)	42 (12)
Employment period in year (SD)	12 (10)	13 (13)
Psychosocial index		
Low	8 (23%)	8 (22%)
Medium	24 (69%)	28 (76%)
High	3 (9%)	1 (3%)
Mean body mass index BMI (SD)	25 (2.7)	25 (3.7)
Number of smokers	16 (46%)	12 (32%)
Mean no. of cig/day among smokers (SD)	12 (4)	10 (6)
Mean systolic blood pressure (SD)	130.5 (18.9)	130.7 (16.3)
Mean diastolic blood pressure (SD)	76.3 (10.7)	76.5 (12.3)

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TABLE 2. Mean Values and Standard Deviation (SD) of the Exposure Parameters

	N	E-field (V/m)	H-field (A/m)	E-spatial (V/m)	H-spatial (A/m)	E-ICNIRP (V/m)	H-ICNIRP (A/m)
Controls	37	—	—	—	—	—	—
RF welders	35	88 (102) [0–436]	0.19 (0.19) [0–0.69]	109 (128) [0–566]	0.24 (0.24) [0–0.87]	44 (59) [0–232]	0.10 (0.11) [0–0.46]
Tarpaulin	20	73 (105) [0–436]	0.14 (0.15) [0–0.69]	93 (134) [0–566]	0.17 (0.17) [0–0.80]	28 (43) [0–163]	0.05 (0.05) [0–0.19]
Mix	10	88 (11) [9–242]	0.17 (0.12) [0.05–0.36]	94 (123) [12–324]	0.19 (0.17) [0.08–0.50]	44 (62) [7–162]	0.09 (0.09) [0.04–0.25]
Ready made clothing	5	177 (82) [66–285]	0.49 (0.23) [0.18–0.67]	202 (92) [83–328]	0.59 (0.31) [0.19–0.87]	107 (74) [34–232]	0.29 (0.15) [0.08–0.46]

E-field and H-field are arithmetically averaged mean values, E-spatial and H-spatial are spatially averaged mean values, E-ICNIRP and H-ICNIRP are 6 min averaged spatially mean values. For detailed information, see Equations 1 and 2a,b. In brackets, the min and max values are given.

Note: A value of zero indicates a nonmeasurable value. The min and max values are based on the calculated averaged values, not single points.

Local Effects

The limit for pathological changes in 2 PD was set to 4 mm; and 4 out of 35 people among the RF operators exceeded this limit, with a maximum measured 2 PD value of 5 mm. No one in the control group showed any pathological changes. The mean value of the 2 PD test, the dexterity test, and the assembly test for RF operators and controls are shown in Table 4, where the mean values of the categorized groups of RF operators into tarpaulin workers, ready made clothing workers, and a mixed group are also included. A statistically significant difference was found for the 2 PD test among the groups of ready made clothing workers, the tarpaulin workers, and the mixed group. In general, there are no gender differences. Female controls had a mean value (SD) for 2 PD of 2.9 mm (0.6) and male controls had a value of 3.0 (0.6). Within the ready made clothing group, five (out of five) people had an excessive risk of high contact currents (>50 mA). This risk has been determined from actual measurement of contact currents, as well as an estimation of the risk of contact with the metallic structure of the RF sealer during their working procedure. The corresponding figures among the tarpaulin group and the mixed group are 2 out of 20 and 1 out of 10, respectively.

The dexterity and assembly test did not show any statistically significant differences between the groups.

No statistically significant correlation was seen between the exposure parameters and the results from the 2 PD test. The same is true for the dexterity test and the assembly test.

Among the ready made clothing workers, 4 out of 5 reported that they had experienced burns; the question was asked irrespectively of whether the cause of the burns was work-related or not. Three of those individuals reported that their work had caused them burns at least three times per year. The corresponding numbers among the tarpaulin workers and the mixed group were 11 out of 20 and 2 out of 10, respectively. None of those reported that their work had caused them burns more often than once a year. Nine out of 37 people in the control group reported burns, and none of those reported that they had caused by their work. No differences were found between ready made clothing workers, tarpaulin workers, the mixed group, or the control group concerning healing time for the burns, which ranged from 1 to 3 weeks.

No differences were found between RF operators and controls with respect to sensations of tingling/numbness in the fingers or feet. Approximately one third experienced tingling/numbness in their fingers,

TABLE 3. Mean Values (SD) of Induced Current Expressed as a Sum of Both Wrists/Ankles [Min–Max in Brackets]

	Wrists (mA)		Ankles (mA)	
	Mean (SD)	[min–max]	Mean (SD)	[min–max]
Controls	—	—	—	—
RF welders	103 (146)	[0–650]	101 (147)	[0–800]
Tarpaulin	124 (166)	[0–650]	128 (188)	[0–800]
Mixed	80 (140)	[0–345]	53 (44)	[0–128]
Ready made clothing	61 (44)	[0–115]	87 (36)	[50–125]

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TABLE 4. Mean Value (SD) of 2 PD Test, Dexterity Test, and Assembly Test

	No. of people	2-PD test (mm)	Dexterity test	Assembly test
Controls	37	2.9 (0.6)	41 (4.0)	33 (6.6)
Female	23	2.9 (0.7)	42 (4.0)	33 (6.8)
Male	14	3.0 (0.6)	40 (4.0)	34 (6.6)
RF welders	35	3.2 (0.9)	41 (4.7)	35 (6.7)
Tarpaulin	20	2.9 (0.9)	41 (4.4)	35 (7.0)
Mix	10	3.5 (0.3)	42 (5.6)	35 (7.3)
Ready made clothing	5	3.8 (0.8)	38 (2.2)	31 (3.3)

both among the RF operators and in the control group and one (RF operator) sensed tingling/numbness in the feet.

Subjective Symptoms

RF operators report more *fatigue*, *headaches*, *warmth sensations* (hands, body, arms, feet), and *sleeping disorders* than do controls. However, these differences are not significant (Table 5). For *fatigue*, *headaches*, and *warm hands* (Tables 6–8), the median values and 25th–75th percentile of the exposure parameters for the group of people with symptoms (*w-s*) and the group of people without symptoms (*wo-s*) are given. The other symptoms (dizziness, discomfort, concentration, memory, fatigue, headaches, warm hands, warm face, warm feet, warm body, chest pain, radiating pain, eye symptoms, and sleeping disorders) did not show any statistically significant differences with respect to the exposure and are therefore not mentioned in Tables 6–8.

ECG Monitoring

The heart rates recorded during 24 h for RF operators and controls are shown in Figure 2. The RF operators had a significant lower heart rate ($P = 0.02$) compared to the controls. All RF operators as well as controls were in sinus rhythm.

The mean number of episodes of bradycardia for RF operators is 30.5 (SD = 45.9) and the corresponding number for controls was 18.5 (SD = 43.2). The difference was significant ($P = 0.02$) (Table 9).

Fourteen RF operators and 10 controls had short series of supraventricular extrasystoles (couplets and series). Significantly more RF operators had series of supraventricular extrasystoles (SVES) compared to the controls (n=12 and 4, respectively). In total, only one (RF operator) had more than five consecutive SVES. No differences were found for ventricular extra systoles between RF operators and controls, and neither RF operators nor controls had any ST-changes of more than 2 mm.

DISCUSSION

RF operators are an occupational group highly exposed to RF; 16 of the 46 work places exceeded the ICNIRP reference levels. RF operators experience an almost whole body exposure situation where, depending on the machine and the work task, different parts of the body (hands, head, and chest) will obtain the highest exposure.

For some of the RF sealers, mainly those used in tarpaulin work, high exposure can be avoided by changes in the operating position of the RF operator.

TABLE 5. Prevalence of Symptoms, Consulting Physician, and for RF Welders, Association of Symptom With RF Welding

	RF-welders (n=35)			Controls (n=37)	
	Prevalence (%)	Consulted physician (%)	RF-welding (%)	Prevalence (%)	Consulted physician (%)
Dizziness	6	3	—	6	3
Discomfort	3	—	—	8	6
Concentration	6	—	—	14	3
Memory	0	—	—	6	—
Fatigue	20	6	6	11	—
Headaches	17	6	11	8	6
Warm hands	10	—	6	6	—
Warm face	18	—	3	6	—
Warm feet	12	—	3	3	—
Warm body	15		3	6	—
Chest pain	0	—	—	3	—
Radiating pain	14	3	3	19	8
Eye symptoms	6	3	—	0	—
Sleeping disorders	26	3	—	11	3

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TABLE 6. Median Values (25th and 75th Percentiles) of Exposure Parameters (E field) for People Experiencing Symptoms and People Not Experiencing Symptoms

	E-field (V/m)	E-spatial (V/m)	E-ICNIRP (V/m)	E-weld (V/m) · s	E-day (V/m) · h	E-life (V/m) · h
Fatigue						
w-s	187 (33–242)	220 (43–324)	87 (12–162)	402 (229–1208)	151* (15–245)	2.9E+9** (2 E+4–4E+5)
wo-s	36 (11–88)	45 (16–106)	13 (7–33)	251 (52–402)	15 (0–40)	1.6E+8 (0–4E+4)
Headaches						
w-s	105* (58–290)	135* (66–384)	55 (25–162)	702**(265–1560)	117* (29–237)	4.2E+7* (3E+4–3E+5)
wo-s	36 (9–113)	42 (15–132)	13 (7–29)	218 (55–391)	15 (0–39)	1.4E+8 (0–5E+4)
Warm hands						
w-s	139 (42–242)	188 (47–324)	77 (25–162)	833 (251–1208)	162* (36–242)	2.9E+8 (0–3E+5)
wo-s	36 (10–132)	43 (17–150)	13 (7–34)	298 (58–444)	15 (3–42)	1.7E+8 (0–5E+4)

Note: A value of zero indicates a nonmeasurable value.
w-s, with symptoms; wo-s, without symptoms.
*$P < .05$.
**$P < .01$.

This is much more difficult for ready made clothing workers, since a large number of repetitive welds are performed during a short period of time and the RF operator has to sit close to the machine to maintain a good manufacturing capacity.

To obtain as low exposure as possible around an RF sealer, the machine needs to be in good contact with the ground—but in general, many of the measured RF operators have poor contact with the ground, which might lead to high leakage E fields around the machine. The induced current in the body is dependent on the separation distance between the RF operator and the ground [Wilén et al., 2001]. The best situation—lowest induced current—is when ungrounded conditions occur, but this is seldom the case in reality. However, even a small separation distance of a couple of centimeters would significantly reduce the induced current in the body. The separation can be achieved by the use of rubber mats, which are also used for ergonomic purposes on cement floors.

The mixed group is not a homogenous group from an exposure point of view; this can be seen in the rather large SD. This fact has to be taken into account when comparing the results for the different groups (ready made clothing, mixed, and tarpaulin).

The results from the 2 PD test did not give a significant difference between RF operators and controls, as in Kolmodin-Hedman et al. [1988]; the reason for this is unclear. However, as an interesting side finding, a significant difference was found between the three exposure conditions (tarpaulin, mixed, and ready made clothing group). No clear connection between the results from the 2 PD test (in mm) and the exposure was found. However, burn injuries are more common among the ready made clothing group, and one can speculate whether the differences between the exposure groups are due to burn injuries rather than direct exposure to RF. The lack of correlation between wrist current and 2 PD might also be an implication that the current in the wrist is strongly

TABLE 7. Median Values (25th and 75th Percentiles) of Exposure Parameters (H-Field) for People Experiencing Symptoms and People Not Experiencing Symptoms

	H-field (A/m)	H-spatial (A/m)	H-ICNIRP (A/m)	H-weld (A/m) · s	H-day (A/m) · h	H-life (A/m) · h
Fatigue						
w-s	0.24* (0.14–0.36)	0.27 (0.17–0.50)	0.14 (0.06–0.25)	1.15 (0.86–1.79)	0.31* (0.07–0.49)	6.5 (2–60)
wo-s	0.11 (0.07–0.16)	0.12 (0.09–0.19)	0.04 (0.02–0.07)	0.71 (0.4–1.13)	0.06 (0.01–0.14)	3.8 (0–17)
Headaches						
w-s	0.15 (0.11–0.22)	0.18 (0.14-0.27)	0.06 (0.04–0.1)	0.85 (0.67–1.31)	0.12 (0.04–0.23)	2.7 (0–43)
wo-s	0.11 (0.07–0.28)	0.12 (0.09–0.30)	0.05 (0.02–0.16)	0.83 (0.4–1.24)	0.07 (0.01–0.19)	3.4 (0–17)
Warm hands						
w-s	0.14 (0.13–0.36)	0.16 (0.15–0.50)	0.08 (0.06–0.25)	0.85 (0.76–1.79)	0.15 (0.12–0.36)	2.5 (0–10)
wo-s	0.11 (0.07–0.24)	0.12 (0.10-0.27)	0.04 (0.03–0.14)	0.87 (0.44–1.18)	0.06 (0.01–0.16)	5.0 (0–22)

Note: A value of zero indicates a nonmeasurable field.
w-s, with symptoms; wo-s, without symptoms.
*$P < .05$.

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TABLE 8. Median Values (25th and 75th Percentiles) of Induced Current Parameters for People Experiencing Symptoms and People Not Experiencing Symptoms

	Ankle (mA)	Ankle-6 min (mA)	Ankle-weld (mA · s)	Ankle-day (mA · h)	Ankle-life (mA · h)	Wrist (mA)	Wrist-6 min (mA)	Wrist-weld (mA · s)	Wrist-day (mA · h)	Wrist-life (mA · h)
Fatigue										
w-s	125 (0–128)	19 (0–172)	315 (0–641)	94 (0–176)	1.5E+5 (0–19E+4)	50 (0–345)	19 (0–172)	144 (0–1723)	38 (0–474)	7.7E+4 (0–51E+4)
wo-s	51 (26–116)	8 (7–28)	272 (101–514)	29 (0–50)	6.9E+3 (0–6E+4)	40 (14–100)	8 (7–28)	202 (100–420)	13 (1–36)	9.3E+3 (0–3E+4)
Headaches										
w-s	98 (38–261)	44* (0–140)	591 (150–1568)	91 (24–192)	5.6E+4 (2E+4–19E+4)	107 (0–371)	44 (0–140)	654 (0–1967)	120 (0–269)	2.4E+4 (0–13E+4)
wo-s	51 (20–125)	12 (7–26)	250 (66–514)	29 (0–74)	6.1E+3 (0–6E+4)	50 (15–100)	12 (7–26)	202 (100–415)	14 (2–38)	1.0E+4 (0–3E+4)
Warm hands										
w-s	128 (13–325)	82 (2–172)	641 (75–1950)	128 (11–379)	6.8E+4 (0–15E+4)	200 (3–345)	82 (2–172)	1200 (18–1723)	233 (3–345)	4.2E+4 (0–41E+4)
wo-s	56 (30–125)	12 (7–54)	316 (180–514)	30 (0–84)	1.2E+4 (0–6E+4)	50 (16–115)	12 (7–54)	202 (105–545)	14 (1–53)	9.0E+3 (0–4E+4)

Note: A value of zero indicates a nonmeasurable induced current.
w-s, with symptoms; wo-s, without symptoms.
*$P < .05$.

Fig. 2. Twenty-four hours heart rate registration (mean values for each hour) from RF operators and controls, measured with a Holter recorder. Bars show the 95% CI.

dependent on the position of the arms during the weld. This effect is difficult to correlate for when measuring the induced current.

No gender differences were found for the results in the 2 PD test, a finding also supported by Shimokata and Kuzuya [1995], who did not find any significant difference in 2 PD between males (n = 1161) and females (n = 875).

The prevalence of self-reported subjective symptoms among the RF operators is somewhat higher (not significant) compared to the control group, especially fatigue, headaches, sleeping disorders, and the warmth sensations (hand, face, feet, and body). The lack of significant differences in the prevalence of subjective symptoms might be due to the diverse exposure situations for RF operators. This is supported by the finding of higher integrated E field values in the symptom group, especially for fatigue and headaches. This is an indication that exposure must be combined with exposure time to explain these effects.

Those reporting headaches had a statistically significantly higher time integrated exposure during a weld (*E-weld*), indicating an acute effect. Warmth sensations in the hands and fatigue seemed, however, to be correlated with exposure during a longer period of time, and a statistically significantly higher exposure during the day (*E-day*) and during the whole working life (*E-life*), respectively, were found.

An interesting observation was that the time integrated E field parameters were in general better correlated with the subjective symptoms than the time integrated H field as well as the induced current. The reason for this is, however, unclear.

Nikitina [2000] found an increased prevalence of headaches among male regulators of communication equipment (3–30 MHz). The exposure levels were reported to be of tens of V/m, sporadically increasing to

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TABLE 9. Number of Individuals With Conduction and Rhythm Disturbances

	RF operators (N = 35)	Controls (N = 37)
Mean heart rate (15:00 to 05:00)	68.9 (1.4)	76.2 (1.4)*
Mean no. of episodes of bradycardia (SD)	30.5 (45.9)	18.5 (43.2)*
Conduction disturbances		
Nonconductive extra systoles	1	2
AV-block I	0	0
Bundle branch block	0	0
AV-block II	2	2
Sino-atrial block and sinusarest	1	2
Rhythm disturbances		
Supraventricular ES (SVES)	30	33
Single ES	15	23
Bigemeni	0	0
Couplets	3	6
Series	12	4
Ventricular ES (VES)	21	25
Single ES	18	22
Bigemeni	0	1
Couplets	3	1
Series	0	1

*$P = 0.02$ (χ^2 test).

250 V/m. They also found a statistically significant difference between the exposed group and the controls as regards sleep disturbances, which has not been confirmed by the present study, other than RF operators reporting more sleeping disturbances than the controls (nonsignificant).

Previous Russian studies (see Presman [1970] for an overview) have found episodes of bradycardia among RF exposed individuals. In the present study, we have found a significantly lower mean heart rate during a 24 h period. Also, RF operators had statistically significantly more episodes of sinus-bradycardia compared to controls. This might indicate an effect of RF exposure on the autonomic function, but further analyses of heart rate variability (HRV) are needed to characterize possible disturbances in the autonomic function.

Szmigielski et al. [2000] found rhythm disturbances, both SVES and VES, among radio transmitting workers exposed to 10–30 MHz. In our study, the only significant difference between RF operators and controls was in the series of episodes of SVES (Table 9). However, the values of SVES for all RF operators (except one) and controls do not exceed acceptable levels. Szmigielski et al. [2000] state that the studied group is slightly above normal values of SVES and VES.

Due to the relatively few individuals in the study, it was not possible to adjust for confounding factors such as gender, age, and the psychosocial workload. There were, however, no obvious differences between the RF welders and the controls with respect to the above mentioned factors. The impact of the healthy worker effect cannot be neglected in this study, especially for the RF operators at larger companies where they might have the possibility to change working tasks within the company.

In general, only a few RF operators and controls have severe health problems concerning subjective symptoms, sensory-motoric tests, or ECG. There are, however, differences in the health outcome with respect to exposure. In further studies, it would be of interest to include more exposed individuals to increase the power in the comparison with respect to the exposure parameters.

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