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Is Fertility Reduced Among Men Exposed to Radiofrequency Fields in the Norwegian Navy?

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The effects of radiofrequency fields on human health are not well understood, and public concern about negative health effects has been rising. The aim of this study was to examine the relationship between workers exposed to electromagnetic fields and their reproductive health. We obtained data using a questionnaire in a cross-sectional study of naval military men, response rate 63% ($n = 1487$). We asked the respondents about exposure, lifestyle, reproductive health, previous diseases, work and education. An expert group categorized the work categories related to electromagnetic field exposure. We categorized the work categories ''tele/communication,'' ''electronics'' and ''radar/sonar'' as being exposed to electromagnetic fields. Logistic regression adjusted for age, ever smoked, military education, and physical exercise at work showed increased risk of infertility among tele/communication odds ratio (OR = 1.72, 95% confidence interval 1.04–2.85), and radar/sonar odds ratio (OR = 2.28, 95% confidence interval 1.27–4.09). The electronics group had no increased risk. This study shows a possible relationship between exposure to radiofrequency fields during work with radiofrequency equipment and radar and reduced fertility. However, the results must be interpreted with caution. Bioelectromagnetics 29:345–352, 2008. © 2008 Wiley-Liss, Inc.

Key words: electromagnetic field/radiation; radiofrequency fields; Royal Norwegian Navy; fertility

INTRODUCTION

The effects of electromagnetic fields on human health are not well understood. The escalating use of electromagnetic equipment in the past decade has increased concern about the possible negative health effects this might produce. Several reviews have concluded that a clear relationship between these fields and health outcomes is difficult to find [Knave, 1994; ICNIRP, 2001; Feychting et al., 2005]. This applies to both occupational and non-occupational exposure.

Personnel in the Royal Norwegian Navy, especially on board vessels, are exposed to electromagnetic radiation in the form of radiofrequency fields from navigation, communication and weapon systems [King, 1999]. In 2001, the Royal Norwegian Navy decided to conduct surveillance of the working environment and health among its personnel due to several observed problems, including concern about the health effects of radiofrequency fields. The University of Bergen conducted the surveillance to ensure an independent investigation. A questionnaire about several health aspects, work history in the navy, occupational exposure and lifestyle factors was sent to all employees.

An analysis of results from this survey showed that personnel who had served onboard a missile-torpedo patrol boat had a higher risk of congenital anomalies among their offspring than other personnel in the Navy [Magerøy et al., 2006]. Further investigation of the possible effects of radiofrequency fields on the reproductive ability of employees in the Navy was therefore of interest.

Earlier studies on reproduction and radiofrequency fields have not shown any clear relationships between these factors, but neither have they been able to remove the suspicion. Hjollund et al. [1999] reported a slightly increased time to pregnancy among welders exposed to magnetic fields compared with non-welders, but the results were not statistically significant. Juutilainen [2005] reviewed numerous experimental teratological studies and found no consistent effects of electromagnetic fields.

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Other studies have shown reduced sperm quality both among military men [Weyandt et al., 1996] and among radiofrequency heater operators [Grajewski et al., 2000]. Recent studies on the use of mobile phones also indicate a negative effect on sperm quality [Fejes et al., 2005; Kilgallon and Simmons, 2005; Erogul et al., 2006]. In contrast, some studies of this type show no effect on sperm quality [Schrader et al., 1998].

This study defined some work categories as being more exposed to electromagnetic fields than others and investigated their reproductive health. Reproductive health is defined here as problems with becoming pregnant with a partner for at least 1 year, congenital anomalies, preterm births, stillbirths, and infant deaths.

The aim of the study was to examine the relationship between male workers with exposure to electromagnetic radiation and male reproductive health, with special focus on workers exposed to radiofrequency fields.

MATERIALS AND METHODS

Data Collection

The data were obtained from a cross-sectional study. A questionnaire was sent by mail at the end of 2002 to all the employees who were currently serving in the Navy, both military and civilians. The questionnaires were returned directly to the research group at the University of Bergen. The name, address and National Insurance number were pre-printed on the form. The overall response rate was 58% ($n = 2265$). Only military men who had completed their compulsory military service were selected for this study as many of these men were known to be working with equipment causing exposure to electromagnetic fields. This group was also likely to have a more similar life style and background than the civilian workers, reducing the effect of confounders in the study. This group had a higher response rate, 63% ($n = 1487$).

Questionnaire

The baseline variables about which the respondents were asked included age, weight, height, education, duration of service in the Navy, duration of work outside the Navy, physical exercise, chronic diseases, allergy, asthma, cardiac infarction, cerebral hemorrhage, diabetes mellitus, multiple sclerosis, cancer, smoking, and alcohol consumption. The respondents were also asked about the work categories they had experienced while working in the Navy on a list of 18 pre-printed categories. The Navy provided the list. The civilian educational scale was divided into 4, where 1 = basic school (9 years), 2 = high school (3-4 years), 3 = college/university (4 years) and 4 = higher university (>4 years), while the military educational scale was divided into 3, where 1 = no naval academy, 2 = naval academy (2 years), 3 = naval academy (4 years). Physical exercise was obtained both at work and at leisure, divided into a four-point scale with hours per week and analyzed separately. Smoking was divided into present smokers, previous smokers and non-smokers. Alcohol was divided into consumption of more or less than 15 standard drinks per week [Aasland et al., 1990].

The participants also described their exposure in the Navy and at other workplaces or at leisure by filling out lists of whether they had been in contact with, worked with or been exposed to: ''organic solvents/paint,'' ''skin contact with oil/gasoline/diesel,'' ''vapor from oil/gasoline/diesel,'' ''smoke from burning oil,'' ''exhaust gas,'' ''pesticides,'' ''welding or torch cutting or working with the hull,'' ''lead,'' ''noise'' and ''vibration.'' They were also asked whether they had worked ''closer to high-frequency aerials than 10 m,'' ''closer to radar than 5 m'' and ''closer to communication equipment than 3 m.'' The answers were given on a five-point scale for all questions on exposure: none; very little; some; much; and very much.

The respondents were asked whether they had biological children. For each of these children they were asked to provide the year of birth, the sex, whether the child had a congenital or chromosome anomaly and whether the child was born premature, stillborn or died within the first week or during the first year of life. These questions were selected and modified from the European Studies of Infertility and Subfecundity Questionnaire [Karmaus and Juul, 1999]. Infertility was obtained by a single question: ''Have you and your partner ever tried for more than 1 year to get pregnant without success?'' The response categories were ''yes,'' ''no'' and ''do not know.'' No one answered ''do not know,'' and the analysis on this study therefore included only ''yes'' and ''no'' answers.

Exposure Assessment

An expert group was established for determining work categories related to electromagnetic field exposure. This group comprised eight people who all had jobs related to protection from and research on electromagnetic fields. This group discussed exposure to electromagnetic fields among the 18 work categories used in the questionnaire. The group agreed that because of their work tasks the categories ''tele/communication,'' ''electronics'' and ''radar/sonar'' means that they worked regularly with equipment causing possible exposure to electromagnetic fields, at least once per

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week. They were therefore probably more exposed to electromagnetic fields than the rest of the categories. Tele/communication workers are workers who repair communication equipment, radio operators or work with communication within the operation room. They can work both on board vessels and ashore. Radar/sonar workers are navigators on vessels or at land-based installations who use radar and other navigation equipment. Electronics workers repair and produce electronics for weapons and communication systems and work mainly in workshops. The workers who had not worked in any of these three work categories were classified as an unexposed group.

Statistical Methods

The three groups in question were all analyzed separately compared to the unexposed workers. We used Student's *t*-test to test differences in continuous variables and chi-square to compare categorical variables and Fisher's exact test for numbers below 5. We used logistic regression to test the differences between the groups adjusted for age, ever smoked, military education and physical exercise at work. Age and years of service in the Navy were correlated ($P < 0.05$), and only age was used in the regression analysis. In this analysis, we reduced the scales of self-reported exposure from five to two: ''high or very high exposure'' and ''some, low and no exposure.'' We used SPSS 13.0 for the statistical analysis. We set the statistical significance level at $P < 0.05$.

RESULTS

Background Information

The workers had a mean age of 36 years of age, range 20–62. Workers in the radar/sonar- and the tele/communication group were significantly older and had served significantly longer in the Navy than the unexposed workers. Radar/sonar workers had shorter military education, while tele/communication workers had shorter civilian education than the unexposed. There were also some differences related to physical exercise: at work electronics performed less physical exercise than the unexposed. There were more ever-smokers in the tele/communication group, but the groups did not differ in current daily smoking (Table 1). The groups did not differ in weight, height, alcohol consumption, or years of work outside the Navy.

Exposure

The three work categories of possible electromagnetic exposure all reported lower exposure to oil, gasoline or diesel vapor than the unexposed. These three groups in general had lower exposure to other factors than the unexposed, but the results were not significant for all types of exposure (Table 1). The three groups did not differ from the unexposed in exposure at leisure, except for radar/sonar which had a small difference in demolition work at leisure (Table 1). The three work categories in question all reported higher exposure to the three questions on radiofrequency fields than the unexposed (Table 1), but only two of the three work categories reported this exposure to be of a higher degree (very much and much exposed) (Table 2). These work categories were tele/communication and radar/sonar.

Diseases

Among the three work categories, there were few significant differences in the occurrence of diseases, but there were exceptions. The two groups more exposed to radiofrequency fields had increased food and drug allergy ($P < 0.01$ for radar/sonar and $P = 0.04$ for tele/communication), testicular cancer ($P < 0.01$ for radar/sonar and $P < 0.01$ for tele/communication), cardiac infarction ($P < 0.01$ for radar/sonar) and skin cancer ($P = 0.03$ for radar/sonar).

Fertility

The tele/communication and radar/sonar groups reported infertility more than the unexposed (Table 3). This was also found by logistic regression, adjusting for age, ever smoked, military education, and physical exercise at work: odds ratio (OR) = 1.72, 95% confidence interval (CI) 1.04–2.85 for tele/communication and OR = 2.28, 95% CI 1.27–4.09 for radar/sonar. The electronics group did not differ from the unexposed.

The groups did not differ in number of biological children, paternal age at birth of first child, occurrence of congenital anomalies or chromosomal errors among their children, preterm births or stillbirths or infant deaths within 1 year (Table 3).

Statistical Power

With the actual figures found in this study (Table 3), the power of detecting a significant difference between the unexposed group ($N = 1138$) and our smallest exposed group ($N = 99$) concerning fertility was 100, and for anomalies or chromosomal errors 99.2, with the significance level <0.05.

DISCUSSION

This study shows significantly reduced fertility among military men exposed to radiofrequency fields in their working environment. Further, the results show

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TABLE 1. Age, Education, Physical Exercise, Smoking and Work Exposure Among Military Personnel in the Norwegian Navy Participating in a Study of Work Exposure and Reproductive Health

Description	Work category	*N*	Mean	Std. dev	*P*-value (tested for each work category vs. exposed)
Age (years)	**Tele/communication**	**166**	**38.0**	**9.6**	**<0.01**[a]
	Electronics	169	36.0	8.4	0.83[a]
	Radar/sonar	**99**	**40.0**	**9.3**	**<0.01**[a]
	Unexposed	1138	36.0	9.6	
Age at first biological child (years)	Tele/communication	106	27.8	4.3	0.98[a]
	Electronics	99	27.7	4.6	0.79[a]
	Radar/sonar	69	27.4	4.9	0.22[a]
	Unexposed	698	27.4	4.2	
Years of service in the Navy (years)	**Tele/communication**	**167**	**17.8**	**9.9**	**0.00**[a]
	Electronics	169	15.8	8.9	0.09[a]
	Radar/sonar	**99**	**19.5**	**9.7**	**0.00**[a]
	Unexposed	1139	14.4	9.7	
Ever been daily smokers (yes/no)	Tele/communication		60.2%		<0.01[b]
	Electronics		49.1%		0.87[b]
	Radar/sonar		56.1%		0.15[b]
	Unexposed		48.3%		
Present daily smokers (yes/no)	Tele/communication		47.5%		0.59[b]
	Electronics		51.2%		0.90[b]
	Radar/sonar		41.1%		0.18[b]
	Unexposed		50.5%		

Description	**Scale**	Basic (%)	High school (%)	University/college (4 years) (%)	University/college (>4 years) (%)	*P*-value
Civilian education (scales 1–5)	**Tele/communication**	**5**	**59**	**23**	**5**	**<0.01**[b]
	Electronics	2	53	32	5	0.76[b]
	Radar/sonar	4	49	30	6	0.47[b]
	Unexposed	2	51	30	8	

Description	**Scale**	No naval academy (%)	Naval academy (2 years) (%)	Naval academy (4 years) (%)	**P-value**
Military education (scales 1–3)	Tele/communication	53	28	19	0.17[b]
	Electronics	51	30	20	0.16[b]
	Radar/sonar	**67**	**19**	**14**	**<0.01**[b]
	Unexposed	49	25	26	

Description	**Scale (h)**	0 (%)	<1 (%)	1–2 (%)	≥3 (%)	P
Hard physical exercise at work in hours per week (scales 1–4)	**Tele/communication**	40	33	19	9	0.07[b]
	Electronics	**39**	**37**	**17**	**8**	**0.01**[b]
	Radar/sonar	36	30	30	15	0.05[b]
	Unexposed	33	30	23	15	

Description	Scale (years)	None (%)	Very little (%)	Some (%)	Much (%)	Very much (%)	P-value
Working closer than 10 m to a HF antenna	Tele/communication	**4**	**14**	**41**	**17**	**23**	**<0.01**[b]
	Electronics	**7**	**29**	**41**	**15**	**8**	**<0.01**[b]
	Radar/sonar	**4**	**30**	**42**	**14**	**9**	**<0.01**[b]
	Unexposed	17	29	25	14	13	
Working closer than 3 m to comm.installations or transmitter antennas	**Tele/communication**	**6**	**21**	**35**	**20**	**19**	**<0.01**[b]
	Electronics	**13**	**36**		**8**	**6**	
	Radar/sonar	**7**	**42**	**34**	**10**	**6**	**<0.01**[b]
	Unexposed	24	35	20	10	8	**<0.01**[b]
Working closer than 5 m to radars	**Tele/communication**	**9**	**29**	**32**	**18**	**11**	**<0.01**
	Electronics	**8**	**30**	**36**	**17**	**10**	**<0.01**[b]
	Radar/sonar	**2**	**25**	**35**	**20**	**18**	**<0.01**[b]
	Unexposed	23	34	21	11	10	[b]
Organic solvents/paint	**Tele/communication**	**14**	**68**	**16**	**1**	**0**	**<0.01**[b]
	Electronics	6	55	35	4	1	0.10[b]
	Radar/sonar	**5**	**66**	**28**	**0**	**0**	**<0.01**[b]
	Unexposed	13	53	29	4	2	

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Skin contact with oil/gasoline/diesel vapor	**Tele/communication**	**21**	**56**	**21**	**1**	**1**	**<0.01**[b]
	Electronics	**8**	**50**	**31**	**7**	**3**	**0.03**[b]
	Radar/sonar	**8**	**58**	**26**	**5**	**2**	**0.02**[b]
	Unexposed	15	45	24	11	6	
Oil/gasoline/diesel vapor	**Tele/communication**	**15**	**58**	**22**	**4**	**1**	**0.02**[b]
	Electronics	13	55	24	6	2	0.19[b]
	Radar/sonar	13	59	19	7	1	0.15[b]
	Unexposed	15	46	26	9	4	
Pesticides	Tele/communication	88	9	0	0	0	0.72[b]
	Electronics	93	9	0	0	0	0.39[b]
	Radar/sonar	**92**	**5**	**1**	**0**	**0**	**<0.01**[b]
	Unexposed	89	9	0	0	0	
Welding	**Tele/communication**	**60**	**37**	**2**	**0**	**0**	**<0.01**[b]
	Electronics	51	41	7	1	0	0.29[b]
	Radar/sonar	62	32	5	1	0	0.67[b]
	Unexposed	56	33	10	1	0	
Explosives	Tele/communication	32	46	16	0	0	0.12[b]
	Electronics	**11**	**43**	**28**	**13**	**5**	**<0.01**[b]
	Radar/sonar	22	46	21	9	1	0.62[b]
	Unexposed	27	43	19	7	4	
Vibration	**Tele/communication**	**9**	**35**	**32**	**15**	**9**	**0.04**[b]
	Electronics	**9**	**37**	**33**	**9**	**13**	**0.03**[b]
	Radar/sonar	11	38	33	8	10	0.07[b]
	Unexposed	13	27	28	16	16	
Demolition work at leisure	Tele/communication	46	47	6	0	1	0.15[b]
	Electronics	48	48	4	1	1	0.07[b]
	Radar/sonar	**33**	**62**	**5**	**0**	**0**	**0.04**[b]
	Unexposed	46	46	7	1	0	

Results from comparing each exposed group separately to the unexposed workers are shown. Statistical significant values are marked with bold.
[a]Student's *t*-test.
[b]Chi-square test.

that the exposed personnel do not have an increased risk for fewer biological children.

There are few epidemiological studies of infertility among men exposed to radiofrequency fields. One study of infertile couples supports our findings by reporting reduced semen quality among couples in which the men had been exposed to such fields [Irgens et al., 1999]. Weyandt et al. [1996] also found significantly reduced sperm quality among military men using radar equipment. Lancranjan et al. [1975] and Grajewski et al. [2000] had similar findings. In contrast, both Hjollund and Bonde [1997] and Schrader et al. [1998] found no such results. Differences in exposure type and exposure level might explain these differences. The studies also differed from each other in their procedures for selecting the workers.

High exposure to electromagnetic fields may cause heating. This type of heating may adversely affect sperm quality. There is uncertainty about the possible non-thermal effects of these fields, and complex interactions may not have been taken into consideration [Erwin, 1988]. Fejes et al. [2005] have formulated two hypotheses of how such effects may occur. One suggests that the testis is affected by a change in the levels of hormone produced, such as melatonin. The other hypothesis is that the radiation may cause DNA damage in the genital tract.

Only two of the three groups the expert group categorized as exposed to electromagnetic fields in this study reported reduced fertility. The third group did not report high exposure to radiofrequency fields. The expert group categorized based on electromagnetic fields in general and did not focus on radiofrequency fields. This might indicate that the exposure differed among these groups and perhaps that the radiofrequency fields more adversely affect fertility than do other types of electromagnetic fields. However, these findings must be interpreted with caution, as we did not measure exposure objectively, and the descriptions of exposure are rough. Evaluating the exposure objectively would have been difficult, since the workers had been on many vessels and workplaces during their years in the Navy and no exposure data were available. We therefore assessed the exposure based on job categories decided by an expert group and self-reported exposure. Using both these types of exposure categorization might reduce the possibility of common method bias.

Tele/communication and radar/sonar workers were both significantly older and had served longer in the Navy than electronics. The longer service time can suggest a longer period of, and more exposure to, radiofrequency fields as the protection and guidelines were less restrictive earlier. The age difference could be

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TABLE 2. Self-Reported Exposure to Radiofrequency Electromagnetic Fields Among Three Groups of Military Personnel in the Norwegian Navy Participating in a Study of Work Exposure and Reproductive Health

	Exposure to non-ionizing radiation		
Work categories	Low exposure (1–3 on a scale from 1 to 5[a]) (%)	High exposure (4–5 on a scale from 1 to 5[a]) (%)	*P*-value
Tele/communication	**48.5**	**51.5**	**<0.01**
Unexposed	**68.5**	**31.5**	
Electronics	62.7	37.3	0.30
Unexposed	66.7	33.3	
Radar/sonar	**53.5**	**46.5**	**<0.01**
Unexposed	**67.1**	**32.9**	

We used chi-square to test the difference between each group and the unexposed. Statistical significant values are marked with bold.
[a]Scale: 1, none; 2, very little; 3, some; 4, much; 5, very much.

of importance regarding the infertility [Paul, 1993]. However, the groups did not differ in age at the time of their first biological child. Age and years of service in the Navy were correlated in our study and the results were adjusted for age only. Also, the age difference was not more than 2–4 years between the groups.

The groups did not differ in number of biological children. This suggests that the effect responsible for the reduced infertility might be time limited. However, we do not know when the respondents had their infertility problems. It is therefore possible that their children were born before the infertility problems developed.

The questionnaire in this study gave information about work tasks, occupational and non-occupational exposure and health aspects and offered a unique opportunity to investigate the possible health effects of working in an environment with known exposure to radiofrequency fields, as the population was rather large. Compared with previous studies, our study also has strength by including data both on occupation and residential exposure [ICNIRP, 2001, 2004]. The information gathered enabled us to adjust for confounding factors and to rule out other types of exposure as causative agents. The response rate was only 63%. However, the self-reported infertility totaled

TABLE 3. Infertility, Biological Children, Anomalies, Chromosomal Errors, Preterm and Stillbirths or Infant Deaths Among Military Personnel in the Norwegian Navy Participating in a Study of Work Exposure and Reproductive Health

Variable	Work categories	*n*	%	*P*-value
Infertility among Naval men	Tele/communication	**24**	**14.8**	**0.01**[a]
	Electronics	20	12.1	0.15[a]
	Radar/sonar	**17**	**17.5**	**<0.01**[a]
	Unexposed	106	8.7	
Naval men having biological children	Tele/communication	106	63.5	0.70[a]
	Electronics	99	58.6	0.40[a]
	Radar/sonar	69	70.4	0.10[a]
	Unexposed	704	620	
Children with anomalies or chromosomal errors	Tele/communication	10	6.0	0.18[a]
	Electronics	3	1.8	0.19[a]
	Radar/sonar	7	7.1	0.11[a]
	Unexposed	44	3.5	
Children with preterm births	Tele/communication	18	10.8	0.18[a]
	Electronics	16	9.5	0.44[a]
	Radar/sonar	9	9.1	0.37[b]
	Unexposed	98	7.9	
Stillbirths and infant deaths within 1 year	Tele/communication	6	3.6	0.22[b]
	Electronics	3	1.8	0.47[b]
	Radar/sonar	2	2.0	0.61[b]
	Unexposed	28	2.3	

Statistical significant values are marked with bold.
[a]Chi-square test.
[b]Fisher's exact test.

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8.7%, which is in accordance with other studies [Paul, 1993].

Unknown factors might have caused the reported infertility problems in this study. A report in Germany described the occurrence of ionizing radiation related to three radar devices in the army [German Radar Commission, 2003]. However, none of these types of radar is known to have been used in the Norwegian Navy [Frogner, 2006] and we have no knowledge about other sources of ionizing radiation. We also lack information about known abortions and partners; this can also influence the infertility problems in this study.

Our study found no increased risk of congenital anomalies, chromosomal errors, preterm births or stillbirths or infant deaths. A recent article on paternal occupational exposure to radiofrequency electromagnetic fields and the risk of adverse pregnancy outcome [Mjøen et al., 2006] supports our result. There are few studies of this subject among military men. Some studies have been performed on congenital anomalies among physiotherapists exposed to electrotherapy equipment, showing inconclusive results [Logue et al., 1985; Taskinen et al., 1990; Larsen, 1991].

The personnel exposed to radiofrequency fields had an increased risk of testicular and skin cancer, myocardial infarction and allergy. These findings must be interpreted with caution, as they were not the main objective of this study, and we had few cases. Melanoma has previously been investigated in relation to electromagnetic fields without finding any relationship [Guénel et al., 1993]. The relationship between electromagnetic exposure, breast cancer and testicular cancer has also been discussed, and studies have diverging conclusions. Cluster studies [Davis and Mostofi, 1993; Stenlund and Floderus, 1997; Richter et al., 2000] have shown adverse effects, whereas larger studies [Johansen, 2004; Hardell et al., 2006] show no effect.

In conclusion, this study shows a possible relationship between exposure to radiofrequency fields during work with radiofrequency equipment and radar and reduced fertility, but other studies are needed to confirm these findings.

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