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Testicular cancer and electromagnetic fields (EMF) in the workplace: results of a population-based case–control study in Germany

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Abstract

Objectives: In a population-based case–control study, we examined the association of testicular cancer and electromagnetic fields (EMF) in the workplace.
Methods: Incident cases (n = 269) were recruited between 1995 and 1997. A total of 797 controls matched on age and region were randomly selected from mandatory registries of residents. EMF exposure was assessed for five categories in standardized face-to-face interviews using closed questions. For each exposure category, odds ratios (OR) were calculated, stratified by age and region, and in a more complex model weighted by duration and distance using conditional logistic regression. Subgroup analyses were conducted for seminoma and non-seminoma and for blue- and white-collar workers. Additionally, potential radar exposure was individually assessed by experts based on all available information including free text.
Results: There was no excess risk for cases who reported to have ever worked near the following: radar units (OR = 1.0; 95% CI = 0.60–1.75); radiofrequency emitters (OR = 0.9; 95% CI = 0.60–1.24); electrical machines (OR = 1.0; 95% CI = 0.72–1.33); high-voltage lines or high-voltage electrical transmission installations (OR = 0.7; 95% CI = 0.38–1.18); or visual display units or complex electrical environments (OR = 0.9; 95% CI = 0.67–1.21). The results for the weighted exposure and subgroup analyses did not differ substantially. For radar exposure as assessed by the experts, the OR was 0.4 (95% CI = 0.13–1.16).
Conclusions: EMF exposure in the workplace does not seem to be a relevant risk factor for testicular cancer in our study.

Introduction

The incidence of testicular cancer in Europe has increased constantly over the past decades, and cancer registry data indicate a continuing increase in most countries since the Second World War [1–3]. Besides cryptorchism [4], there are no clearly identified risk factors nor are there determinants that offer promise for primary prevention. The early onset of testicular cancer, which most frequently occurs between the ages of 25 and 40 years, points to familial and prenatal factors as causes. Nevertheless, numerous occupational and environmental exposures have been reported as possible risk factors [5–7]. The association of testicular cancer to radar or electromagnetic fields (EMF) of lower frequency in the workplace has repeatedly been reported in case observations and epidemiological studies in the past 15 years [8–21] but has rarely been investigated in detail [10–12, 16, 17].

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Materials and methods

Subjects

The study area comprised five German geographic regions (cities of Hamburg, Bremen, Essen, Saarbrücken, and the Federal State of Saarland) covering a population of about 1.5 million male residents, 15–69 years old. Eligibility criteria for cases included all men with testicular cancer or an extragonadal germ cell tumor, newly diagnosed between 1 July 1995 and 31 December 1997, between 15 and 69 years of age. Cases were ascertained through an active reporting system of clinical and pathology departments in the study regions. In addition, cases in Hamburg were identified through the Hamburg Cancer Registry. Histology reports and histological slides or tissue blocks of the tumor were classified according to the guidelines of the International Agency for Research on Cancer (IARC) [22] and were reviewed by a reference pathologist. Controls were selected at random from the mandatory registries of residents in each study region. The selection of cases and controls was restricted to males who spoke German well enough to complete a face-to-face interview lasting about 1 hour and 15 minutes. Controls were matched to cases by region (five strata) and age (5-year age groups).

In all, 269 patients (two surrogates) could be interviewed, and the participation proportion in cases was 76%. Reasons for non-participation of cases were refusal (23 cases), refusal of the treating physician to contact the patient (37 cases), or other reasons (24 cases). A total of 170 cases were diagnosed as seminoma; 99 were classified as non-seminoma.

Out of 1982 controls, 918 subjects were interviewed (eight surrogates); the participation proportion was 57% excluding subjects who had moved (354 controls) or died (nine controls) before first contact. Reasons for non-participation were refusal (515 controls), inability to reach the subject at his residence (149 controls), or other reasons (37 controls).

The exclusion of 121 controls for whom no matching cases were available left 797 controls and 269 cases for the analysis.

Exposure assessment

The questionnaire included a specific section to assess exposure to different categories of electromagnetic fields in the workplace. Five categories of EMF exposure were distinguished: job tasks near visual display units or complex electrical environments, high-voltage lines, electrical machines, radiofrequency emitters, and radar units. In the interview, a list of specific exposure sources was offered to each respondent as categorical choices (see Table 1). Furthermore, the questionnaire included questions on the duration of exposure in years and distance from each source.

The exposures were grouped according to the electromagnetic spectrum and assumptions on the strength of the electric and magnetic fields measured in specific workplaces [23–30]. The exposure categories ranged from extremely low frequencies (ELF) to extremely high frequencies (EHF), including a mixed category (category C), where the exposure possibilities are rather diverse and low, medium, and high frequencies are found at certain workplaces depending upon the industrial process, as, for example, for electrical ovens.

A subject was classified as exposed within a category if he confirmed exposure to one or more of the specific sources within each category. In addition, a weighted score (W) was created taking into account duration of self-reported exposure in years (DY) and distance to the source (D). D was based on three categories: [1] $\geq$ 30 m; [2] = 10–29 m; [3] = 0–9 m. Multiple exposures within each EMF category were aggregated

$$\left(W = \sum_{i=1}^{n}(DY * D)\right).$$

Radar, the exposure category with the highest frequencies, was classified in a second approach via expert assessment for each subject who was possibly exposed. The purpose was to increase the specificity of exposure assessment, since retrospective self-reporting of exposures easily leads to non-differential misclassification, resulting in a bias of the effect estimate toward the null value [31].

We selected all job descriptions for subjects who had either reported radar exposure or who had worked in occupations and industries known for potential radar exposure. In addition to the specific section of the questionnaire on EMF exposure, all free text from standardized open questions in the occupational history describing industries, job tasks, and handled equipment was evaluated. Occupations were recorded for each job held during lifetime after leaving school, if a particular job was held for at least six months. Job titles were coded according to the *International Standard Classification of Occupations* (ISCO) [32], and industries were coded according to the *Classification of Industrial Branches of the European Union* (NACE) [33]. We used double coding and consensus agreement between both coders in case of discrepancies.

Table 1. Categories of electromagnetic exposures

Categories	Frequencies	Workplaces
A	ELF, VLF	Working in front of a visual display unit or in complex electrical environments such as:
		control or computer rooms
		telephone switchboard, etc.
B	ELF	Working near high-voltage lines or high-voltage electrical transmission installations:
		overhead high-voltage lines
		underground high-voltage lines
		high-voltage electrical transmission installations
C		Working near electrical machines such as:
	ELF	machine tools
	ELF	lifting trucks
	ELF, d.c.	train, subway
	VLF, MF, HF	electrical ovens or furnaces
	ISM	medical equipment
D		Working near radiofrequency emitters such as:
	VHF, UHF	radio sets
	UHF	mobile phones or similar devices (900 and 1800 MHz band)
E		Working near radar units:
	SHF, EHF	radar pistols (10–33 GHz)
	SHF, EHF	stationary traffic radar (10–33 GHz)
	SHF	in airplanes (various)
	SHF	at airports (5.0–5.5 GHz)
	EHF	radar on ships (31.8–33.4 GHz)
	UHF, SHF, EHF	military radar (various)

ELF, extremely low frequency; VLF, very low frequency; d.c., direct current; MF, medium frequency; HF, high frequency; ISM, industrial, scientific, medical: frequencies particularly used in the domain of medical and scientific applications; VHF, very high frequency; UHF, ultra high frequency; SHF, super high frequency; EHF, extremely high frequency.

The quantification concept for the expert assessment of radar exposure was developed with the aid of the scientific staff of the Federal Institute for Occupational Safety and Health, who estimated the likelihood of exposure for selected industries and job tasks with potential radar exposures. The estimates were based on measurements of magnetic field strength for these occupations and industries in Germany that are described in various (unpublished) expert reports (see Table 2).

The expert assessment was performed independently by two of the authors (C.B.-E. and W.A.) who assessed 114 job tasks blinded for the case–control status. In all controversial cases, further information was obtained by experts and used for a joint decision.

Statistical analysis

For each EMF category, OR (ever *versus* never exposure) and corresponding 95% confidence intervals (95% CI) were calculated by conditional logistic regression (SAS, procedure PHREG) [34] accounting for the matching factors age (ten 5-year age groups since there were no cases in the highest age group) and region of residence (five strata) through stratification. In each analysis, the respective unexposed served as the reference category. In order to identify a potential masking of effects through opposing risks to EMF and social economic status (SES), we performed a subgroup analysis for blue- and white-collar workers, which served as a surrogate for SES. The analysis distinguished between subjects who had worked only in white-collar jobs and those who mainly or at some point in time had worked in blue-collar jobs.

Generally, for subgroup analyses, which were carried out for seminoma and non-seminoma as well as for blue- and white-collar workers, the calculations were repeated including all controls using unconditional logistic regression, adjusted for age and region of residence, in order to check whether the loss of subjects due to matching in the conditional logistic regression would affect the results.

Furthermore, the scores which had been weighted for each EMF category by duration of self-reported exposure in years and distance to the source were categorized into tertiles according to the empirical distribution of scores in controls with reported exposure. An explorative analysis was carried out aggregating the weighted

Table 2. Occupations and industries with potential radar exposures

Occupations/Industries	NACE[a]	ISCO[b]	Likelihood of exposure[c]
Airplane crew			
Pilots		041.20–.60	0
Radio operators on airplanes		380.60	0
Ship crew			
Officers		042.15–.90 without 042.50	+
Ship engineers		043.15–.20, not 043.30	–
Radio operators on ships[d]		380.50	– (+)
Deck crew		981	+
Other occupations/industries			
Riggers		9–72.30	+
Stevedores		9–71.20	–
Boat loaders (liquids and gases)		9–71.40	–
Crane drivers in harbor	(63.22.1 or 63.22.2) and	9–73.xx	++
Traffic controllers (air traffic)		359.60	0
Harbor police	75.24.0 or	582.20	++
Servicemen/controllers for radar units		8–52.20 or 034.90 or 023.90	+ + +

[a] NACE: European Community Industrial Classification, revision I, revised 1992.
[b] ISCO: *International Standard Classification of Occupations.*
[c] Likelihood of exposure according to the Federal Institute for Occupational Safety and Health (Berlin, Germany): 0 = not exposed, – = exposure unlikely, + = exposure likely, ++ = frequent exposure, + + + = predominant exposure under typical working conditions.
[d] During the recent decade, the work of radio operators on ships has been performed by officers or via satellite.

scores across all exposure categories for each subject. In this analysis the reference group contained only subjects who never reported exposure to any of the exposure categories. Subgroup analyses were carried out for seminoma and non-seminoma as well as for blue- and white-collar workers.

For radar exposure, which was reassessed via expert assessment, we performed an additional analysis calculating OR and corresponding 95% CI by conditional logistic regression. Finally, we examined if there was any clue in the data pointing to the operation of a latency period for radar exposure and defined a latency period of 5 years.

Results

Table 3 shows the prevalences for the five EMF exposure categories based on self-reports. As expected, category A (working in front of visual display units or in a complex electrical environment) has the highest prevalence, 44.6% in cases and 45.4% in controls (OR = 0.9; 95% CI = 0.67–1.21). In second place, we find work near electrical machines, followed by work near radiofrequency emitters, high-voltage lines, or high-voltage electrical transmission installations and radar units. The prevalence of working near radar units amounts to 8.2% in cases and 7.3% in controls

Table 3. Prevalences, OR, and 95% CI for the five categories of EMF: ever exposed *vs.* never exposed

EMF categories	Controls (n = 797)		Cases (n = 269)		Odds ratios stratified[a]	
	No.	Percentage	No.	Percentage	OR	95% CI
Working in front of a visual display unit or in complex electrical environments	362	45.4	120	44.6	0.9	0.67–1.21
Working near high-voltage lines or high-voltage electrical transmission installations	77	9.7	17	6.3	0.7	0.38–1.18
Working near electrical machines	283	35.5	88	32.7	1.0	0.72–1.33
Working near radiofrequency emitters	166	20.8	50	18.6	0.9	0.60–1.24
Working near radar units	58	7.3	22	8.2	1.0	0.60–1.75

[a] Odds ratios and 95% confidence intervals (95% CI) are based on the matched analysis (5-year age-groups (15–19, 20–25, . . . , 65–69) and region of residence (five strata)).

(OR = 1.0; 95% CI = 0.60–1.75). In contrast to our *a-priori* hypothesis, we do not find an increased risk for radar exposure. All ORs are around or below 1.0.

For blue-collar workers, we generally find a higher exposure prevalence than for white-collar workers except for job tasks near visual display units or complex electrical environments. The ORs (ever *vs* never exposed) for the five EMF categories basically vary around 1. For blue-collar workers, they vary between 0.7 and 1.1, and for white-collar workers between 0.7 and 1.2 except for job tasks near electrical machines where we observe an OR of 1.6 (95% CI = 0.66–3.84) for white-collar workers. The number of exposed white-collar workers, however, is rather small (nine cases and 22 controls).

Weighting the scores for each exposure category by duration and distance changes the results only marginally. There is no indication of a dose–effect relationship (see Table 4).

The explorative analysis for the combined score, which includes all EMF exposures across the different categories weighted by duration and distance, shows an OR of 1.0 (95% CI = 0.70–1.56) for the first tertile, 1.0 (95% CI = 0.64–1.42) for the second tertile, and 0.8 (95% CI = 0.49–1.17) for the third tertile. For non-seminoma, we observe an OR of 1.2 in the first two tertiles, and for seminoma, all risk estimates are below 1.0. In the subgroup of blue-collar workers, the ORs are near and below 1.0; for white-collar workers, we find slightly higher risk estimates up to 1.4 (95% CI = 0.67–2.76) in the second tertile. There are no consistent trends. The results are comparable for both conditional and unconditional regression analyses.

Following self-reports, 77 of 114 job tasks are related to radar units (38 in connection with military radar, 39 in other occupational settings). Fifty percent of the self-reported exposures to military radar are confirmed by the expert rating; for other occupational settings, the confirmation rate is 46%. The analysis of free text reveals 37 further job tasks which were analyzed for radar exposure (stevedores/boat loaders: 14, harbor police: 11, servicemen/controllers for radar units: eight,

Table 4. OR and 95% CI for exposure to EMF weighted by duration and distance from source

Exposure categories	Controls (n = 797)		Cases (n = 269)		Odds ratios stratified[a]	
	No.	Percentage	No.	Percentage	OR	95% CI
Working in front of a visual display unit or in complex electrical environments						
Not exposed	435	54.6	149	55.4	1.0	
1. Tertile (>0 to ≤4)	115	14.4	38	14.1	0.9	0.59–1.41
2. Tertile (>4 to ≤11.5)	123	15.4	47	17.5	1.0	0.66–1.49
3. Tertile (>11.5 to ≤118)	124	15.6	35	13.0	0.8	0.51–1.23
Working near high-voltage lines or high-voltage electrical transmission installations						
Not exposed	735	92.2	256	95.2	1.0	
1. Tertile (>0 to ≤18)	22	2.8	3	1.1	0.4	0.11–1.31
2. Tertile (>18 to ≤102)	19	2.4	7	2.6	1.1	0.42–2.61
3. Tertile (>102 to ≤552)	21	2.6	3	1.1	0.5	0.14–1.75
Working near electrical machines						
Not exposed	525	65.9	187	69.5	1.0	
1. Tertile (>0 to ≤68)	89	11.2	37	13.8	1.2	0.75–1.79
2. Tertile (>68 to ≤224)	94	11.8	27	10.0	0.8	0.52–1.35
3. Tertile (>224 to ≤1984)	89	11.2	18	6.7	0.6	0.44–1.34
Working near radiofrequency emitters						
Not exposed	635	79.7	220	81.8	1.0	
1. Tertile (>0 to ≤6)	52	6.5	19	7.1	1.0	0.56–1.74
2. Tertile (>6 to ≤15)	54	6.8	14	5.2	0.7	0.38–1.35
3. Tertile (>15 to ≤102)	56	7.0	16	5.9	0.9	0.46–1.56
Working near radar units						
Not exposed	741	93.0	251	93.3	1.0	
1. Tertile (>0 to ≤45)	15	1.9	7	2.6	1.4	0.55–3.77
2. Tertile (>45 to ≤135)	21	2.6	4	1.5	0.5	0.17–1.55
3. Tertile (>135 to ≤2225)	20	2.5	7	2.6	0.9	0.36–2.19

[a] Odds ratios and 95% confidence intervals (95% CI) are based on the matched analysis (5-year age-groups (15–19, 20–25, . . . , 65–69) and region of residence (five strata)).

ship crew: four) from which six job tasks involve radar exposure. The agreement between raters is 87.7%.

According to the expert assessment, four cases and 27 controls are exposed to radar. The prevalence is 1.5% in cases and 3.4% in controls (OR = 0.4; 95% CI = 0.13–1.16). Analyses taking into account a latency period of 5 years alter the results only marginally (OR = 0.4; 95% CI = 0.14–1.26).

Discussion

Potential hazards from occupational or residential exposures to EMF have led to controversial discussions in recent decades [35, 36]. Particularly childhood leukemia and brain cancer, but also breast cancer, melanoma of the skin, and testicular cancer have been investigated in this context. Previous results on the association of testicular cancer and occupational exposures to EMF have been inconclusive.

In our study, in which we distinguished five exposure categories ranging from ELF to EHF, including also a category with mixed frequencies, we could not observe an increased risk for testicular cancer in any of the categories.The risks did not increase with duration of exposure and decreasing distance from the source. We could also not find a substantial difference in results for seminoma and non-seminoma as in the case–control studies by Stenlund and Floderus [17] or Hayes *et al.* [12], who found higher risks for non-seminoma (OR = 3.2; 95% CI = 1.4–7.4) compared to seminoma (OR = 2.8; 95% CI = 0.9–8.6) after self-reported occupational exposures to micro-/radiowaves.

Preceding studies had shown elevated risks for testicular cancer and employment in the electronic industry, electrical industry, or related occupations [11, 13, 21, 36] with ORs ranging from 1.2 to 2.8, while other studies did not find an excess relative risk for occupation in the electrical industry and testicular cancer [14, 15, 18, 20]. Törnquist *et al.* [19], who analyzed cancer in the electric power industry in Sweden, reported an increased SMR for power station operators but did not find an elevated risk for power linesmen. In our study, we found an OR of 1.4 (95% CI = 0.96–2.07) for subjects who ever worked as electricians.

Elevated risks for the use of handheld radar were observed in a cohort of policemen by Davis and Mostofi [8]; later a Canadian cohort study [9] showed only a slightly increased risk (SIR = 1.3; 90% CI = 0.89–1.84). Richter *et al.* [38] reported on cases of cancer in young radar technicians, among them a man with testicular cancer who was exposed to high levels of radiofrequency or microwave radiation (RF/MW) for a long period in a setting where preventive measures were negligent. Elevated risks for exposure to radar were also reported in a Swedish case–control study [11]; however, the number of exposed subjects to radar was very small. Ryder *et al.* [16] found no association between testicular cancer and work as a radiation worker or holders of a radiation record in their study, which included cases and controls of the Royal Navy. In cases classified as radiation workers, the prevalence for radar exposure was 3.6%, in controls 4.8%. Altogether 12.7% of the cases and 13.0% of the controls held a radiation record. In our study, exposure to radar units also did not show an increased risk (OR = 1.0; 95% CI = 0.60–1.75). The effect estimate declined after increasing the specificity of the exposure assessment for radar by an expert rating (OR = 0.4; 95% CI = 0.13–1.16). Moreover, according to the expert rating, the prevalence for radar exposure decreased considerably in cases (1.5%) and in controls (3.4%) compared to self-reported radar exposures (8.2% in cases and 7.3% in controls). On one hand, this was due to the fact that, according to the expert assessment, only a small percentage of men who worked near radar units during military service presumably experienced higher EMF exposures than the general population. On the other hand, for particular workplaces for which radar exposures were reported, exposure is rather unlikely according to measurements at these workplaces. For example, men who worked at airports frequently reported exposure to radar. Exposure to radar, however, is rather unlikely unless a person works as a serviceman or controller for radar units.

Exposure to extremely low frequency (ELF) electromagnetic fields was elaborately analyzed in a Swedish case–control study [17] which linked job titles to a job exposure matrix (JEM) based on measurements of ELF [39]. After adjusting for age, education, and solvent exposure, the OR for testicular cancer in men under 40 years, whose mean daily exposure was $\geq$0.41 microtesla (highest exposure group), amounted to 3.9 (95% CI = 1.4–11.2). This finding was mainly attributable to non-seminoma. A recent large cohort study by the same authors, that linked census information on occupations to a job-exposure matrix, showed an increased incidence of testicular cancer in young workers under 40 years as the most prominent finding [10]. In our study, we did not observe an increased risk for occupational exposure to ELF or VLF.

In conclusion, a major reason for the incongruity of reported study results on occupational exposures to electromagnetic fields and testicular cancer stems from the difficulty of accurately assessing the exposure.

This difficulty is magnified by the fact that our understanding of the biological effects of EMF is still scant. While many studies are solely based on job titles or industry, few studies carefully describe the type of EMF exposure and quantify it. Our study, which analyzes different categories of EMF exposures, also taking into account duration and distance to the source, does not provide any evidence for an association of testicular cancer and EMF at the workplace.

However, a number of limitations of this study should be discussed. While the participation proportion of cases (76%) reached a satisfactory level, the participation proportion among controls amounted only to 57%. Next to age, which was controlled for by matching, social economic status (SES) must be considered a potential confounder or factor causing selection bias. A number of studies show that SES is positively associated with testicular cancer [18, 37, 40], while others show only a moderate or no association [41–43]. In our study, we did not find any apparent differences in the level of schooling between cases and controls; only a slightly higher proportion of cases than controls had completed an apprenticeship or a university degree (including universities for applied sciences).

Since we cannot judge whether responders and nonresponders in the control group differ in SES, we controlled for SES by conducting subgroup analyses for blue- or white-collar workers, which may serve as a surrogate for SES. In both groups, the ORs (ever *vs* never exposed) for the five EMF categories basically vary around 1.0 except for job tasks near electrical machines, where we observe an OR of 1.6 (95% CI = 0.66–3.84) for white-collar workers. The number of exposed white-collar workers, however, is quite small. Since there is no unique pattern which points to a masking effect of SES, we conclude that it is unlikely that confounding by SES seriously biases our study results.

A further limitation may lie in the fact that our study does not take into account the detailed strength of the electromagnetic field; nor does it consider the effect of pulsed *vs* non-pulsed frequencies. Thus, biologically essential aspects of exposure to EMF may not be correctly represented in this quantification concept. The effect of solvents, which are considered a potential confounder [5], was also not investigated. Since the power of our subgroup analysis on radar is rather low, due to the small number of exposed subjects, the effect estimate is also imprecise and therefore not informative.

However, if there were an association of EMF and testicular cancer, potential hazards would presumably be limited to a few subjects with particular kinds and patterns of exposures.

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