European Journal of Epidemiology (2005) 20: 677–681
DOI 10.1007/s10654-005-7922-z

All-cause mortality among Belgian military radar operators: A 40-year controlled longitudinal study

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Accepted in revised form 23 May 2005

Abstract. *Background*: It has been suggested that exposure to radiofrequency/microwaves radiations could be associated with greater health hazards and higher mortality. *Methods*: The all-cause mortality of 27,671 Belgian militaries who served from 1963 until 1994 in battalions equipped with radars for anti-aircraft defence was studied over the period 1968–2003. End of the seventies, technical modifications brought to the shielding of the micro-wave generators resulted in a reduction in irradiations. A control group was formed by 16,128 militaries who served during the same period in the same military area but who were never exposed to radars. Administrative procedures for identifying militaries and their vital status were equivalent in the radar and the control groups. *Results*: The age-standardized mortality ratio (SMR) in the radar battalions was 1.05 (95% CI: 0.95–1.16) in professional militaries, and 0.80 (95% CI: 0.75–0.85) in conscripts. In professional militaries no difference in mortality was found according to duration (less than, or five years or more) or to period of service (before 1978 or after 1977). *Conclusions*: During a 40-year period of observation, we found no increase in all-cause mortality in Belgian militaries who were in close contact with radar equipments of anti-aircraft defence battalions.

Key words: epidemiology, military, mortality, radar, radiofrequency

Introduction

Radars are used by many military forces since the 1950s, for steering aircrafts, boats and vehicles, and also for guiding anti-aircraft missiles. The health hazards that could be associated with exposure to electromagnetic fields remain a contentious subject in many countries where worries have emerged on health hazards incurred by militaries who served in units that implied regular exposure to radars [1]. Concerns have been raised on the safety of the electromagnetic (microwave) emission of radars, as well as on ionizing rays that are emitted on short distance (< 2 m) by devices producing microwaves.

In Belgium, militaries who serviced in units operating the anti-aircraft defence systems 'Nike' and 'Hawk' were fully dedicated to the functioning of these defence systems, and were thus in regular contact with radars. The Nike and Hawk systems have been widely used since 1950 in countries belonging to the North Atlantic Treaty Organization (NATO). The Hawk anti-aircraft defence unit was created in the Belgian army in 1963, and was suppressed in 1994. The Hawk system used middle range radars emitting electromagnetic waves between 1 and 10 GHz frequency. Two kinds of radars were used: acquisition radars (wide range radar for detection of aircraft) and illumination radars (narrow beam radar for guiding missiles). Both radars types used continuous waves or pulsed mode emission. The average radiated power was about 1.5 kW. The peak power emitted by the pulses was about 500 kW.

In this study, we compare the mortality figures of militaries who served between 1963 and 1994 in Hawk anti-aircraft units of the Belgian Army to the mortality observed in units of Belgian militaries who were never exposed to radars.

Methods

The study was designed as a retrospective double-cohort of all Belgian militaries who were ever exposed to Hawk radar systems from 1963 until 1994, and of Belgian militaries who never served in battalions equipped with radar.

Militaries exposed to radars

All professional militaries and military conscripts who served in the 'battalions Hawk 43A and 62A'

from 1963 until 1994 constituted the radar group. The two battalions were located in Germany during the entire period. A military who served for at least one day in the hawk battalions was considered as exposed to radars.

A distinction was made between professional and conscript. Military conscripts stayed maximum one year in a battalion, while professional militaries may have served up to 30 years in the same battalion. Professional militaries were more likely to operate these complex devices and they were thus in closer contact with radars than conscripts.

Control group

One armoured and two artillery battalions located in the same area in Germany during the same period from 1963 until 1994 but who never utilized radars were used as control group. Fifty militaries of the armoured and artillery battalions served for at least one day in Hawk battalions and were classified as exposed militaries.

Constitution of exposed and of control groups

For the period 1963–1977, no electronic record existed, and there was no centralized listing of militaries. We thus had recourse to the administrative archives of the battalions for reconstructing a complete list of all militaries who served in each battalion. These administrative archives consisted in 'daily orders' (DO) and in 'Reports from the Chief of Unit' (RCU). The DO and RCU were related to the daily life of battalions, and all new arrival of militaries, reassignment, nominations, training and leaves were recorded. Each military cited in DO or RCU was entered in the database, with his date of arrival, his unique identification number, and time spent in the battalion. Distinction between conscript and professional militaries was possible because their unique identification number had a different format.

For the period 1978–1994, we could utilize computerized records. We however double-checked the completeness of computerized records using DOs and RCUs.

DOs and RCUs only provided the first name, the family names, and the unique identification number. Lists derived from DOs and RCUs were then matched with lists of the Department of Human Resources of the Belgian Army in order to find birthdays (that department did not know the battalions where militaries served). Then after, using the first name, the family name and the birthday, the National Number used by the Belgian State could be retrieved.

Identification of individuals with their National Number was more successful for conscripts because of a higher quality of administrative records at the battalion level. For instance, in professional militaries, unique battalion numbers of militaries who left the battalion were often reattributed to newly arrived militaries, a procedure that did not exist with conscripts.

Mortality records

The Department of Human Resources of the Belgian Army receives on a regular basis administrative updates from the Belgian National Register on active and retired militaries. These updates include the National Number and the vital status: alive or dead, with the date of death. Deaths were recorded by the Human Resource Department from January 1968 onwards. We completed vital status data for the radar and the control group from January 1968 until December 2003 by matching files we assembled from the Department of Human Resources with files received from the Belgian National Register. Hence the observation period of mortality was 36 years.

Statistical analysis

We defined 10-year age categories. The number of person-year spent in the cohort by each individual in each age category was computed, and death numbers were distributed in age categories. Then annual age-specific death rates were calculated for each age category. For comparing death rates between the radar and the control subjects, we used the age-standardized mortality ratio (SMR) method by calculating first the expected number of deaths in each age category of the radar group using age-specific mortality rates observed in the control group. Then, the total number of expected deaths was summed across all age categories. The division of the observed number of deaths in the radar group by the expected number of deaths yielded the SMR. The 95% confidence interval (95% CI) was estimated using the normal approximation i.e., $SMR \pm (1.96 = SE)$, with $SE = SMR/\sqrt{(\text{observed deaths})}$ [2].

Data from professional militaries were fitted a Cox proportional hazard model with vital status end of 2003 (dead or alive) as dependent variable, and exact number of years served, exact age at service start, and belonging to radar or control battalions as independent variables.

Mortality rates of militaries were also compared with sex and age-specific mortality rates in the Belgian population in 1994. The year 1994 was chosen because 50% of deaths in both professional and military conscripts occurred before 1994.

The number of deaths in one group as compared to another group was said as significantly different if the 95% CI of the associated SMR did not include unity. The Mann-Whitney test was used for testing differences in medians. All p values are two-sided.

Results

In total, 50,247 militaries who served between 1963 and 1994 were encoded in the database created with ODs and RCUs (Table 1). Militaries in the Hawk ($n = 31,616$) and in the control group ($n = 18,631$) were

all males. Complete data for identification and vital status were retrieved for 27,671 militaries in the radar group and 16,128 militaries in the control group (Table 1). The proportion of complete data retrieval was lower for professional militaries than for military conscripts, but these proportions were quite similar in both groups. The average follow-up duration was 26 years for all militaries and was equivalent in all groups.

On 43,799 militaries for whom complete data were retrieved, 2366 deaths (5.4%) were recorded from 1968 until 2003 (Table 1). Higher proportions of deaths were observed among professional militaries, owing to their higher age (Table 2).

Table 2 shows that mean ages in the radar and in the control group remained equivalent during the entire observation period. Professional militaries were older than military conscripts. The narrowing of the age difference between professional and military conscripts from 1970 to 2000 was due to the fact that with time, newly engaged professional militaries were steadily younger (data not shown). Professional militaries of the radar group stayed on average 6.1 year in their battalion (range 1–32), for 4.1 years (range 1–29) for professional militaries of the control group. Military conscripts stayed no more than 12 months in the battalions.

Professional militaries

The mean number of years served in the radar battalions was 6.5 (SD = 5.6) in professional militaries who died between 1968 and 2003, and 6.1 (SD = 5.1) in professional militaries alive on 31/12/2003 ($p = 0.30$).

During the entire observation period, the annual mortality rate of professional militaries was 342/100,000/year in the radar group, and 321/100,000/year in the control group (Table 3), and the SMR of the radar vs. the control group was 1.05 (95% CI: 0.95–1.16). When restricting the analysis to professional militaries who served five years or more in the radar or in the control battalions, the SMR was 0.98 (95% CI: 0.86–1.13).

Table 4 shows the number of deaths observed between 1968 and 2003 according to numbers of year served in battalions from 1963 until 1994. For examining whether mortality in radar and control battalions was influenced by the duration of service in battalions, we fitted a Cox proportional hazard model with vital status (dead or alive) end of 2003 as dependent variable. After adjustment for exact number of years served and exact age at service start, compared to militaries in the control battalions, the hazard ratio for being dead end 2003 for militaries in the radar battalions was 1.07 (95% CI: 0.90–1.23).

End of the seventies, technical modifications were brought to the shielding of the micro-wave generators that were responsible for the emission of ionizing radiation on short distances. These modifications resulted in a reduction in irradiations. Compared to militaries who served in control battalions from 1963 until 1977, the SMR in professional militaries who served in radar battalions during the same period was 1.04 (CI 95% 0.93–1.16). Compared to militaries who served in control battalions from 1978 until 1994, the SMR in professional militaries who started their ser-

Table 1. Belgian militaries included in the two cohorts

	Professional		Conscripts		
	Radar	Control	Radar	Control	Total
Militaries in battalion from 1963 until 1994	5 817	4 116	25 799	14 515	50 247
Militaries with complete data	4 427	2 947	23 244	13 181	43 799
Percentage with complete identification (%)	76	72	90	91	
Mean (range) number of years of follow-up	26 (9–40)	26 (9–39)	26 (9–40)	27 (9–39)	
Number (%) of deaths from 1968 until 2003	398 (9.0%)	246 (8.3%)	950 (4.1%)	772 (5.9%)	2366 (5.4%)

Table 2. Mean age in the two groups of Belgian militaries according to year of age calculation

	Professional		Conscripts	
Year	Radar	Control	Radar	Control
1970	32.5*	32.2	24.1	24.2
1980	34.5	33.5	28.7	29.8
1990	37.2	38.2	34.9	36.8
2000	46.7	47.1	43.8	45.4

*Mean age at that year.

Table 3. Professional Belgian Militaries: Mortality rates in the radar and in the control group

Age	Radar			Control			1994 Belgian population death rate
	Person-years	No. of deaths (1968–2003)	Death rate*	Person-years	No. of deaths (1968–2003)	Death rate*	
10–19	1958	5	255	1279	4	313	48
20–29	29,699	45	152	19,138	30	157	122
30–39	38,275	49	128	24,826	35	141	156
40–49	24,679	74	300	17,218	43	250	338
50–59	13,362	86	644	9148	48	525	812
60–69	6958	84	1207	4041	51	1262	2089
70–79	1437	50	3479	926	33	3564	5209
80–89	60	5	8333	46	2	4348	13,710
Total	116,428	398	342	76,622	246	321	

* Annual death rate/100,000 persons.

Table 4. Professional Belgian Militaries: Vital status end of 2003 according to the number of years served between 1963 and 1994

No. of years in battalions (1963–1994)	Radar			Control		
	Alive	Death	Total	Alive	Death	Total
0–4	2080	192	2272	1821	171	1992
5–9	1066	102	1168	568	45	613
10–14	574	64	638	222	17	239
15–19	223	25	248	67	9	76
20–24	57	10	67	18	2	20
25–29	25	5	30	5	2	7
30+	4	0	4	0	0	0
Total	4029	398	4427	2701	246	2947

vice in radar battalions after 1977 was 1.05 (95% CI: 0.92–1.22).

After the age of 29, mortality rates observed in the radar and in the control groups of professional militaries were always lower than age-specific mortality rates in the 1994 Belgian population (Table 3). Compared to the 1994 Belgian population, the SMR in professional militaries was 0.77 (95% CI : 0.70–0.85) for the radar group and 0.75 (95% CI:0.66-0.85) for the control group.

Military conscripts

In military conscripts, during the entire observation period, the annual mortality rate was 158/100,000/year in the radar group, and 212/100,000/year in the control group (Table 5), and the SMR of radar vs. the control group was 0.80 (95% CI: 0.75–0.85). Hence, among conscripts the number of death observed in the radar group was significantly lower than in the control group.

Table 5. Conscript Belgian Militaries: Mortality rates in the radar and in the control group

Age	Radar			Control		
	Person-years	No. of deaths (1968–2003)	Death rate*	Person-years	No. of deaths (%, 1968–2003)	Death rate*
10–19	10,165	12	118	5925	2	34
20–29	207,689	198	95	117,951	126	107
30–39	205,046	245	119	117,964	180	153
40–49	136,580	304	223	89,323	264	296
50–59	40,640	185	455	32,864	197	599
60–69	643	6	933	746	3	402
Total	600,763	950	158	364,773	772	212

* Annual death rate/100,000 persons.

After the age of 29, mortality rates observed in the radar and in the control groups of military conscripts were always lower than age-specific mortality rates in the 1994 Belgian population (Table 3). Compared to the 1994 Belgian population, the SMR in military conscripts was 0.68 (95% CI: 0.64–0.73) for the radar group, and 0.84 (95% CI: 0.79–0.90) for the control group.

Discussion

During a 36-year period of observation of mortality (no mortality data were available for 1963–1968), we found no difference in all-cause mortality between Belgian militaries that were in close contact with radar equipments of anti-aircraft defence battalions, and militaries who never served in units equipped with radars. In professional militaries no difference in mortality was found according to the duration or the period of the service. The radar and the control groups of militaries were very similar, as they served in the same area in Germany during the same period of time.

Mortality rates in militaries were often lower than in the 1994 Belgian population, most probably because people admitted to the military service are on average in better health than people who never join the army (i.e., a 'healthy worker' effect). Also, deaths could be more frequent in militaries for which we could not retrieve correct identification, but we have no clue for confirming this hypothesis. The apparently higher mortality rate observed before 20 years old in some groups (when compared with the 1994 Belgian population) could be the result of statistical fluctuations due to small number of deaths observed before that age. Also, traumatic deaths were probably higher than in the general population of same age. Nevertheless, procedures for identifying militaries were the same for the radar and the control groups. Secretaries and data managers who constituted lists of National Numbers from lists of names, birthdays and battalions numbers were not aware of the exposure status of militaries, and proportions of militaries with correct identification were similar in radar and in control groups. If underreporting of deaths existed, then there is no reason to believe it was not the same in the radar and in the control groups. As a result, selection bias is not likely to explain the lack of difference in mortality between radar and control battalions.

As we do not have individual data on exposure to radars, the possibility remains that an eventual increase in mortality in the most heavily exposed militaries could be masked by militaries with low exposure to radars. However, the similar duration of stay in radar battalions of professional militaries who died or were alive in 2003 does not support that hypothesis.

In the Belgian Army, norms for maximal exposure to electromagnetic fields are those prescribed by the NATO, who recommended minimal safety distances for continuous exposure depending on the power of radars.

Generators of microwaves in radars emit some parasitic radiation under the form of low doses of X-rays. A light metallic shield installed on radars prevents irradiation outside the generator. In 2001, a study on wave generator of the Hawk system was commissioned by the German Ministry of Defense and conducted in total independence from the German army and of the NATO [3]. According to that study, a person working for one hour at a 5 cm distance of the unshielded wave source, 250 days/year, would receive 15 mSv per year, a dose largely below the maximum dose of 50 mSv per year allowed for Belgian workers in 1994.

Only two studies compared all-cause mortality of militaries that were exposed to radars with mortality of militaries that were less or not exposed to radars [4, 5] These studies were conducted in US militaries, and found no increase in all-cause mortality. There is thus in 2005 no evidence that occupational exposure to radars of militaries influences all-cause mortality.

Acknowledgements

We would like to thank Mrs V. De Leener (secretary), J. Ducci (secretary) and Mr A. Vanderbruggen (of the Human Resources Department of the Belgian Defence) for their skilful collaboration.

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