Arh hig rada toksikol 1993;44:223-228

Communication
UDC 613.168'648

HEALTH STATUS OF PERSONNEL OCCUPATIONALLY EXPOSED TO RADIOWAVES

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Received July 2, 1993

The findings of medical examinations performed in two groups of persons occupationally exposed to microwaves and radiofrequency radiation are presented in comparison with control findings. A group of 49 radar operators from the Zagreb Air Traffic Control was examined twice within a period of 18 months. The other group comprised 46 workers employed in radio relay stations. The control group were 46 workers from the Zagreb Airport. A follow-up study showed significant changes in haematological and biochemical parameters, in electrical brain activity and in capillaroscopic and ophthalmological findings in the group of radar operators within the followed period. For that group a cross-sectional study of the differences in general health status also showed the highest rate of changes. The results indicate that long-term occupational exposure to microwaves and radiofrequencies may damage sensitive organic systems.

Key terms: electromagnetic fields, medical examinations, microwave radiation, radar operators, radiofrequency radiation, working conditions

The growing use of electrical and electronic devices, along with the rapid growth of telecommunication systems, radiobroadcasting, television transmitters, and radar installations has increased the risk of human exposure to electromagnetic energy and, at the same time, concern about possible health effects (1, 2).

Results of *in vitro* and animal studies are difficult to extrapolate to man, and these studies alone do not constitute a satisfactory basis for the establishment of health protection criteria (1, 3). They should, therefore, be supplemented by appropriate epidemiological studies in man.

The available data concerning the health effects of microwave radiation in man are insufficient, although surveys of the health status of personnel occupationally exposed to microwaves have been carried out (3–6). One such survey was performed by the Institute for Medical Research and Occupational Health, University of Zagreb, Zagreb, Croatia. The main purpose of the study was to stimulate scientific investigation in this field, and to contribute to the knowledge of the actual risk of exposure to microwave radiation.

SUBJECTS AND METHODS

Two groups of exposed workers and a control group were medically examined. One group consisted of 49 radar operators from the Zagreb Air Traffic Control (ATC group). They were examined twice within a period of 18 months (ATC 1 = the first measurement, ATC 2 = the second measurement). The other group comprised 46 workers employed in radio relay stations (RRS group). The control group (CON) were 46 workers from the Zagreb Airport, not exposed to microwaves. The programme of medical examinations and check ups included:

- haematological and biochemical blood and serum tests
- structural chromosome aberration analysis
- electroencephalogram (EEG)
- psychological tests - Cornell index, Wechsler' s memory scale, CRD (Complex Reactiometer Drenovac) tests
- ophthalmological examination
- otorhinolaryngological examination and audiometry
- electrocardiogram, blood pressure measurement, pulse rate in steady state and after exertion
- Astrand's test
- respirometry in steady state and after exertion
- internist's examination
- capillaroscopy
- anthropometry.

Working conditions of the subjects in the study were analysed. Power density of electromagnetic fields was measured with a Raham model 4A, an isotropic wideband electromagnetic radiation hazard meter. The measurement of weak X-radiation was carried out by Victoreen model 471, an ion chamber survey meter. Analysis of various environmental factors, such as noise, air temperature, humidity, etc, showed good working comfort according to ISO (International Standard Organization) standards.

Statistical analysis was carried out in two separate parts. One was an analysis referring to the differences between the results of the first and second measurements in the ATC group (ATC 2–ATC 1) by model of differences, in order to establish possible changes in selected health parameters as the function of time (follow-up study). The other was an analysis of the health status of the three examined groups (ATC 2, RRS and CON) aimed at detecting differences in exposure levels (cross- sectional study). The statistical methods applied were factor analysis, analysis of quantitative variations in a model of difference, and discriminant analysis (6, 7). For both studies the total number of variables analysed was the same - 24 variables of general health status, 10 haematological variables and 16 biochemical variables. A detailed description of the biostatistical models used, the criteria for the selection of significant latent dimensions and the structure of chosen dimensions are given in reference 9. Statistical evaluation was performed by standard statistical software SS on a UNIVAC 1100 at the University Computor Centre in Zagreb.

RESULTS

Results of the follow-up study are presented in Table 1 which shows that the changes in latent dimensions HAEM-4, BAS-5, BIO-3, BIO-2 and BAS-2 were the most marked ones. The standardized structure of discriminant function K1 shows that all of these dimensions had the minus sign. The other significantly changed dimensions (BIO-4, BAS-

3, HAEM-1, HAEM-3) had a weaker effect on the differences between the two examinations.

Table 1. *Analysis of quantitative changes in the model of differences (ATC 2 – ATC 1)*

Latent dimensions	F-test in K1	K1 standard structure
BIO–1	0.75	0.08
BIO–2	11.82*	–0.32
BIO–3	14.00*	–0.35
BIO–4	7.40*	–0.25
HAEM–1	3.11*	–0.16
HAEM–2	1.51	–0.11
HAEM–3	2.84*	–0.15
HAEM–4	27.41*	–0.49
BAS–1	10.71*	–0.30
BAS–2	8.19*	0.27
BAS–3	4.70*	–0.20
BAS–4	1.10	–0.09
BAS–5	19.39*	–0.41

*F-test significant with P<0.01
K1 – discriminative functions between parameters in the second and first measurements
BIO 1–4 biochemical parameters
HAEM 1–4 haematological parameters
BAS 1–5 basic parameters of the health status

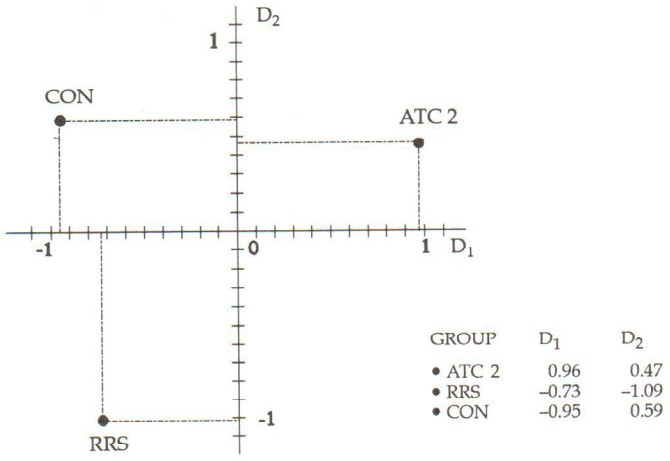

Figure 1. *Differences between ATC, RRS and CON groups in all analysed parameters*

Final results of the cross-sectional study are shown in Figure 1. By factor analysis two significant discriminant variables were isolated. The discriminant variables D1 and D2 account for 54% and 46% of the differences among the examined groups. Their structure is presented in Table 2. The projections of the groups' centroids is shown in Figure 1.

Table 2. *The structure of the discriminant variables D1 i D2*

Dimensions	D1	D2	Communalities
BAS-1	0.04	0.23	0.05
BAS-2	0.57	0.23	0.39
BAS-3	0.13	-0.10	0.02
BAS-4	0.37	0.72	0.67
BAS-5	-0.10	0.27	0.08
BAS-6	0.65	-0.47	0.64
HAEM-1	-0.13	0.11	0.03
HAEM-2	0.15	-0.30	0.11
HAEM-3	-0.10	-0.30	0.10
HAEM-4	-0.04	-0.02	0.00
BIO-1	-0.24	0.01	0.06
BIO-2	-0.35	0.31	0.22
BIO-3	-0.64	0.06	0.42

BAS 1-6 basic parameters of the health status
HAEM 1-4 haematologic parameters
BIO 1-3 biochemical parameters

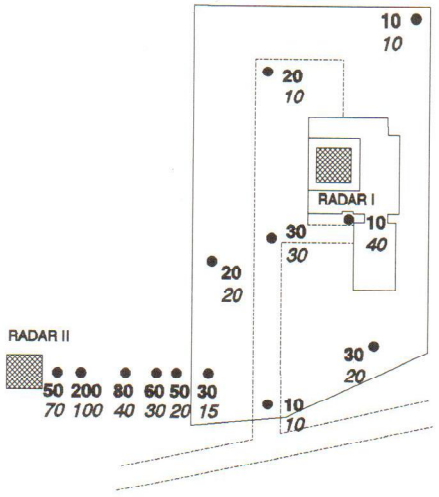

Figure 2. *Microwave fields around terminal and surveillance radar (in μW cm^{-2}). First measurement – bold; second measurement – italic.*

Figure 2 presents the results of the microwave power density measurement in the worksetting of the ATC group. Measurements taken in the radio relay stations showed a lower exposure level for the RRS group, and were mostly around few tens of μWcm^{-2}. The other measured parameters: weak X-radiation, thermal and noise parameters were within permissible levels.

DISCUSSION

The meagre evidence available on exposure effects in man has been obtained from incidents of accidental acute over-exposure to microwaves and radiofrequencies (2, 10). Not enough attention has been given to the conduct of epidemiological investigations (3, 6). Our study indicates that long-term occupational exposure may damage sensitive organic systems.

The results of the follow-up study, presented in Table 1, show the HAEM-4 dimension to be the most significantly changed one within the observed period of time. HAEM-4 was saturated with variables »platelet count«, »reticulocyte count«, »leucocyte count, total«, »non-segmented granulocyte percentage« and »monocyte percentage«. The minus sign means that all haematological parameters significantly decreased between the two examinations. The BAS-5 and BAS-2 dimensions were saturated with variables concerning the electrical brain activity, ophthalmological finding and capillaroscopic changes. In the second measurement these variables changed and showed significantly more disturbances. Dimensions BIO-3 and BIO-2 were saturated with biochemical parameters: serum iron, UIBC, TIBC and serum glucose were projected in BIO-3, while BIO-2 was saturated by serum immunoglobulin concentration and electrophoresis of serum proteins. In the second measurement UIBC, TIBC and serum glucose concentrations were lowered. So were those of IgG, IgA, gamma globulins and total serum proteins.

The results of the cross-sectional study can be discussed from Figure 1. According to the magnitude and direction of the centroids' projection on the first and the second discriminant variables, it is possible to analyse the differences in the health status among the examined groups. The findings were most frequently changed in the group of radar operators. In those subjects ophthalmological and capillaroscopic changes were most marked and subjective complaints related to the workplace most frequent. In the exposed groups alcohol consumption was significantly more often reported, followed by changes in electrocardiogram, frequent chorioretinitis and poor dosimetric finding. In the ATC 2 group changes in serum protein electrophoresis and lowered immunoglobulin concentrations were found. The ATC 2 and control groups had a significantly lower score of erythrocytes, reticulocytes, leucocytes, monocytes and basophiles, and a higher score of thrombocytes and non-segmented granulocytes than the RRS subjects.

Quantitation of exposure during work is extremely difficult because of lack of personal dosimeters. This is especially true of workplaces where the personnel move around in the course of their duties, and are exposed to stationary and non-stationary fields, and both near- and far-field exposures. Our results indicate that long-term occupational exposure to microwaves may damage sensitive organic systems and point to the need to establish a continuous, directed medical surveillance of the subjects occupationally exposed to microwave radiation.

REFERENCES

1. *World Health Organization.* Radiofrequencies and microwaves. Geneva, World Health Organization. Environmental Health Criteria 1981;16.
2. *International Labour Organization, ILO.* Occupational hazards from nonionizing electromagnetic radiation. Occupational Health and Safety Series 1985; No 3.
3. *Saunders RD, Kowalczuk CI, Sienkiewicz ZJ.* Biological effects of non-ionizing electromagnetic fields and radiation: III. Radiofrequency and microwave radiation. Chilton, NRPB-R240; 1991.
4. *Broadbent DE et al.* Health of workers exposed to electric fields. Br J Ind Med 1985:42:75-84.
5. *Grandolfo M.* Occupational exposure limits for radiofrequency and microwave radiation. Applied Industrial Hygiene 1986;1:81-97.
6. *Roberts NJ, Michaelson SM.* Epidemiological studies of human exposures to radiofrequency radiation - a critical review. Int Arch Occup Environ Health 1985;56:169-78.
7. *Armitage P.* Statistical methods in medical research. London: Blackwell Scientific Publishers, Oxford Press, 1971.
8. *Checkoway H, Neil EP, Crawford-Brown DJ.* Research methods in occupational epidemiology. Oxford: Oxford University Press, 1989.
9. *Goldoni J.* Biomedical effects of occupational exposure to microwaves and radiofrequencies. (PhD Thesis) Zagreb: Institute for Medical Research and Occupational Health, University of Zagreb, 1988, 217 p.
10. *Allen SG et al* Proposals for basic restrictions for protection against occupational exposure to electromagnetic non-ionizing radiations. Physica medica 1991;7:77-89.

Sažetak

ZDRAVSTVENO STANJE OSOBA PROFESIONALNO IZLOŽENIH RADIOVALOVIMA

U radu su analizirani i komentirani nalazi medicinskih pretraga dviju skupina osoba izloženih mikrovalnom i radiofrekventnom zračenju i usporedive kontrolne skupine. Prvu izloženu skupinu čini 49 radarskih tehničara Kontrole leta. Oni su pregledani dva puta u razmaku od 18 mjeseci. Drugu izloženu skupinu čini 46 radnika zaposlenih u poštanskim radiorelejnim stanicama. U kontrolnoj je skupini 46 radnika aerodromskih službi. Longitudinalna studija pokazuje značajne promjene u hematološkim i biokemijskim parametrima, električnoj aktivnosti mozga te u kapilaroskopskom i oftalmološkom statusu tijekom praćenog razdoblja. Transverzalna studija razlika u općem zdravstvenom stanju pregledanih skupina pokazuje da nalazi medicinskih pretraga najčešće odstupaju od normalnih u skupini radarskih tehničara. Rezultati rada upućuju na mogućnost da dugotrajna profesionalna izloženost mikrovalovima i radiofrekvencijama može oštetiti osjetljive organske sustave.

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Ključne riječi: elektromagnetska polja, medicinske pretrage, mikrovalno zračenje, radarski operateri, radiovalno zračenje, radni uvjeti