

Occupational EMF Exposure From Radar at X and Ku Frequency Band and Plasma Catecholamine Levels

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Workers in certain occupations such as the military may be exposed to technical radiofrequency radiation exposure above current limits, which may pose a health risk. The present investigation intended to find the effect of chronic electromagnetic field (EMF) exposure from radar on plasma catecholamines in the military workforce. In the study, 166 male personnel selected randomly were categorized into three groups: control ($n=68$), exposure group-I (X-band, 8–12 GHz, $n=40$), and exposure group-II (Ku-band, 12.5–18 GHz, $n=58$). The three clusters were further divided into two groups according to their years of service (YOS) (up to 9 years and ≥ 10 years) to study the effect of years of radar exposure. Enzyme immunoassay was employed to assess catecholamine concentrations. EMF levels were recorded at different occupational distances from radar. Significant adrenaline diminution was registered in exposure group-II with no significant difference in exposure group-I when both groups were weighed against control. Nor-adrenaline and dopamine levels did not vary significantly in both exposure groups when compared to controls. Exposure in terms of YOS also did not yield any significant alteration in any of the catecholamines and in any of the exposure groups when compared with their respective control groups. The shift from baseline catecholamine values due to stress has immense significance for health and well-being. Their continual alteration may prove harmful in due course. Suitable follow-up studies are needed to further strengthen these preliminary observations and for now, exposures should be limited as much as possible with essential safeguards. *Bioelectromagnetics*. 36:444–450, 2015. © 2015 Wiley Periodicals, Inc.

Key words: stress; adrenaline; nor-adrenaline; dopamine; electromagnetic field

INTRODUCTION

Technological advancements related to electromagnetic radiations (EMRs) have resulted in expanded utilization of life enhancing instruments. This has radically modified the background electromagnetic field (EMF) levels thus heading us toward a new state commonly called “electromagnetic pollution” or “electro-pollution.” Electromagnetic pollution or electro-pollution is invisible and enveloping us constantly and has been recognized as the greatest menace to health and well-being for all the creatures inhabiting the Earth [Sivani and Sudarsanam, 2012; Singh and Kaur, 2014]. With respect to EMF exposure in humans, in addition to normal exposures in day-to-day life, workers in certain occupations may be exposed to technical radiofrequency (RF) radiation exposure above current limits, which may pose a risk to their health and well-being. In this context, exposures to radio detection and ranging (RADARs) that employ RF (10 MHz–300 GHz) to geographically trace moving and non-moving items thereby exploited by aviation, navigation, defense, weather forecasting and several other sectors, have also been linked with

health effects. Researchers have investigated effects of RF exposure on oxidative stress [Garaj-Vrhovac et al., 2011], fertility [Mollerlokken and Moen, 2008], general health [Goldoni et al., 1993], the endocrine system [Djeridane et al., 2008; Augner et al., 2010; Eskander et al., 2012; Singh et al., 2015] and cytogenetic parameters [Garaj-Vrhovac and Orescanin, 2009]. These radiations have been reported to affect several other aspects of health [Kheiffets et al., 1995; Pfluger and Minder, 1996; Kliukiene et al., 2003; Forsen et al., 2005; Henshaw and Reiter, 2005; Singh and Kapoor, 2014]. The work force deployed in the vicinity of radar usually faces elevated EMFs and is

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threatened with increased incidence of hemolymphatic tumors [Degraeve et al., 2009]. EMF has been implicated to induce stress and affect catecholamine levels as well [Buchner and Eger, 2011]. There are few real-life field studies on EMF interaction due to radar and its effect on catecholamines like adrenaline, nor-adrenaline and dopamine. Since radar utilizes the higher frequencies of the EMF spectrum, workers engaged in its operation might be at risk of exposure to technical RF radiation above current limits. It is not ethically acceptable to conduct controlled human studies at such high frequencies and for long periods of time, thus, the occupational cluster of radar workers represent a suitable group whose exposures and, hence, effects can be appropriately monitored on a long-term basis. Furthermore, chronic effects of radar emissions on catecholamine concentration have not been examined with effects of exposure duration in terms of length of service. To the best of our knowledge, this is the first epidemiological study conducted on radar workers with the objective to determine chronic EMF experience effects on plasma catecholamine concentration.

SUBJECTS AND METHODS

Study Groups

A total of 166 active male military personnel working in two different units of the Indian Army posted at the same site in India at the time of study were randomly selected for this study. All selected personnel from two different units were further categorized into three different groups depending upon their exposure from radar: exposure group I ($n=40$), exposure group II ($n=58$), and control group ($n=68$). The exposure group I individuals worked with X band radar in frequency range 8–12 GHz, whereas exposure group II participants were deployed with the operation and maintenance of Ku band radar in frequency range 12.5–18 GHz. Personnel from the same units not working with or in the vicinity of the radar were put in the control group. They were mostly involved in administrative or clerical duties. Additionally, in order to study radar exposure effect in terms of years of service (YOS), all three sets were further split into two groups (up to 9 years and ≥ 10 YOS). Out of 166, only 155 personnel volunteered for blood draw. The study was undertaken in September 2011 for the three military clusters or groups. The Defence Institute of Physiology and Allied Science (Delhi, India) ethics committee duly approved the study. Participants were informed about study protocol and their written consents were taken. Prior to study

commencement, subject details like personal habits, education, work history, EMF exposure from other sources, health status, and medical history were obtained through a self-administered questionnaire. However, the staff assisted subjects with the questionnaire in case of any doubt. Inclusion criteria for the study were any military personnel with minimum 1-year work experience. Exclusion criteria were subjects suffering from any major health problem; having a history of brain surgery, stroke, and post-trauma; with high exposures to EMF sources other than radar; or having fever or night duty prior to blood collection. In all groups, no participants documented any medicine intake, or existence of any hereditary or chronic disease. All personnel worked a total of 8 h/day with comparable working times for all three groups. They were mostly active during the day with some personnel having a night shift, which was present in all three groups and based on rotation. Apart from this, subjects had a very strict daily schedule with comparable life style and, hence, shared similar sleeping and waking times in addition to working hours. However, they varied on account of EMF exposure from radar. No one reported any unusual EMF exposure other than radar from sources like cellular phone base station, electricity substation, or television or radio broadcast station as none was instituted near the military setup. All personnel belonging to exposure groups worked with the radar on rotation basis with regard to their proximity and all had an equal chance of working at different locations. Additionally, volunteers from all three groups were alike with regard to physical characteristics, age, level of education, lifestyle, and socio-economic status. General details of participants are briefly summarized in Table 1. All staffs followed the same nutritional regime as per the army ration scale without any supplementation. In addition, they adhered to 1-h exercise schedule as per the army physical training protocol in the morning with sport activities (cricket, volleyball) in the evening.

EMF Exposure Level Measurements

EMF levels were determined at various occupational spots in power density (W/m^2) by employing the EME Guard personal exposure meter (Product No. 331 001A, Satimo, Brest, France) (frequency range 27 MHz–40 GHz with upper and lower detection limit of 200 and 5 V/m, respectively) and the Broad Band Field Meter (NBM 520, Narda Safety Test Solutions GmbH, Pfullingen, Germany) (frequency range 100 KHz–60 GHz). Levels were monitored at different locations inside the radar cabin, at the top front of radar vehicle, and at different occupational spots of personnel deployment within the 50 m range of the

TABLE 1. General Characteristics of Volunteers

Characteristics	Control (<i>n</i> = 68)	Group I (<i>n</i> = 40)	Group II (<i>n</i> = 58)
Exposure details			
Radar exposure	Nil	X band, 8–12 GHz	Ku band, 12.5–18 GHz
Years of service, range (in years)	12.2 ± 6.3, 1–28	8.3 ± 5.3, 1–26	11.5 ± 4.1, 1–23
Mean age (in years)	31.9 ± 6.0	27.9 ± 5.2	31.4 ± 4.0
Age range (in years)	21–48	20–45	20–43
Years of education			
Matriculation (10)	58 (85.3)	34 (85)	31 (53.5)
Higher secondary (12)	3 (4.4)	0 (0.0)	10 (17.2)
Graduation or above (≥15)	7 (10.3)	6 (15)	16 (27.6)
Personal habits			
Tobacco (cigarettes)	20 (29.4)	14 (35)	15 (25.9)
Alcohol	25 (36.8)	17 (42.5)	37 (63.8)
Tobacco (smokeless)	14 (20.6)	12 (30)	13 (22.4)

Plus or minus values are mean ± SD or *n* (%) unless otherwise specified.

radar where personnel were supposed to be present during the course of their duty. Instantaneous levels were measured at each location for a period of about 6 min. EMF levels were measured in a similar manner utilizing the same protocol and instruments in both exposure sets. The power density of microwaves inside and outside the radar cabin at various occupational locations of exposure group I varied from 0.24 to 0.77 W/m². Power density measurements in case of exposure group II ranged from 0.1 to 15.6 W/m². Measurements represent instantaneous readings taken at different locations of the personnel's work station/environment in the course of the daily work schedule during radar operations and maintenance. Exposure reference levels have been presented in terms of the range and not averaged reference values.

Chemicals and Kits

Heparin (H0878-100KU, Sigma–Aldrich Chemicals, St. Louis, MO) was purchased. A commercially available enzyme immunoassay kit was employed to quantify the plasma adrenaline (EA604/96, DLD Diagnostika GmbH, Hamburg, Germany), nor-adrenaline (EA610/96, DLD Diagnostika GmbH, Hamburg, Germany), and dopamine (EA608/96, DLD Diagnostika GmbH, Hamburg, Germany) levels. Briefly, the test is based on competitive enzyme linked immunosorbent assay (ELISA) in which the acylated catecholamine from sample and solid phase bound catecholamine contest for a set number of antiserum binding sites. The analytical sensitivity of adrenaline assay was 5 pg/ml with a mean recovery of 97%. The sensitivity in case of nor-adrenaline was 16 pg/ml with a mean recovery of 94% whereas the same for dopamine was 29 pg/ml with a mean recovery of 87%, respectively.

Sample Collection and Processing

Basic information regarding blood collection was given to all participants well in advance. Heparinized tubes were used to collect early morning (0600–0800 h) whole blood samples after overnight fasting (8 h) from the antecubital vein in resting condition. The assembled blood samples after coding underwent similar processing. Blood samples were subjected to centrifugation at 1,000 *g* for 15 min to isolate plasma and were stored in aliquots at –20 °C until their transportation to the laboratory where they were preserved at –80 °C until assayed.

Estimation of Catecholamine Levels

Plasma catecholamine levels were assessed following the manufacturer's directions for commercially available ELISA kits (adrenaline, EA604/96; nor-adrenaline: EA610/96; dopamine: EA608/96) made by DLD Diagnostika GmbH (Hamburg, Germany).

Samples were run blindly in duplicates and in single series to reduce any intra-assay differences. Absorbance was measured by microplate reader (Model Versa_{max}, Molecular Device, Sunnyvale, CA). The result obtained in pg/ml of blood was communicated in percentage assuming value of mean control as 100%.

Statistical Analysis

Values are presented as mean ± SEM (Standard Error of Mean). Readings from duplicate samples were averaged to attain a single reading in case of every assay. Analysis of variance (ANOVA) test was used to find any group difference. Dunnett's multiple comparison test was applied to estimate significance with regard to control population. To test the difference in

TABLE 2. Catecholamine Concentration in Defense Personnel Exposed to Electromagnetic Field From Radar and Control Group

Catecholamine	Control	Exposure Group I	Exposure Group II
Adrenaline	100 ± 13.08%, <i>n</i> = 53	128.42 ± 15.67%, <i>n</i> = 39	55.08 ± 9.16%, <i>n</i> = 44*
Nor-adrenaline	100 ± 18.96%, <i>n</i> = 43	100.22 ± 15.19%, <i>n</i> = 32	114.58 ± 12.03%, <i>n</i> = 52
Dopamine	100 ± 15.04%, <i>n</i> = 46	138.07 ± 19.15%, <i>n</i> = 27	70.81 ± 13.87%, <i>n</i> = 42

Values are mean ± SEM, expressed in percentage, *P* < 0.05.

*Represents significance with respect to control.

catecholamine levels of personnel taking alcohol with those not consuming the same in exposure group II, unpaired *t*-test with Welch's correction was applied. Significance level was set at *P* < 0.05. Statistical analysis was carried out by utilizing the software GraphPad Prism, version 5.00, 2007 for Windows (GraphPad Software, San Diego, CA).

RESULTS

Exposure group II exhibited a significant decrease in plasma adrenaline level, while exposure group I did not exhibit a significant change in comparison to control (Table 2). No significant difference was observed with respect to nor-adrenaline and dopamine in any exposure sets when weighed against the control group. Exposure in terms of YOS up to 9 years and ≥10 YOS also did not produce any significant change in any catecholamines or in any exposure sets when compared with their respective control groups (Table 3). Catecholamine levels of personnel consuming alcohol did not vary significantly from personnel not taking alcohol in exposure group II.

DISCUSSION AND CONCLUSION

In addition to stress retort, the catecholamine system performs vital biological functions like autonomic nervous system regulation, neurotransmission, control of cardiovascular activities, and more. Given

the significance of these adrenal secretions and in light of the observed significant adrenaline diminution, though only in exposure group II in the higher frequency band, our study does imply the EMF exposure potential in combination with mean exposure period of 11.5 years in terms of length of service to influence catecholamine adrenaline in radar workers. Since exposure group II comprised a higher percentage of personnel, taking alcohol as compared to other groups, we further tested whether there was any influence of alcohol consumption on the catecholamine concentration in this set of population. However, statistical analysis ruled out the effect of alcohol intake on catecholamine levels as no significant difference was reached between personnel taking alcohol and those not taking alcohol. With reference to arithmetical means in our study, other catecholamines were also found to be affected though insignificantly despite determined EMF levels well below the occupational limits [ICNIRP, 1998, 2002; NRPB, 2004; Safety Code 6, 2009]. Changes observed in catecholamine levels in exposure groups versus their respective controls might be an effect of EMF stress or the cumulative effect of both EMF and years of experience with radar. However, statistical analysis did not yield any significant variation between the exposure group and their respective control group for any catecholamines, except for adrenaline in exposure group II. This may be due to large difference in the data. No significant difference was found in any of the catecholamines with regard to exposure in terms of

TABLE 3. Catecholamine Concentration in Defense Personnel With Regard to Years of Service (YOS) Category

Service category	Control	Exposure Group I	Exposure Group II
Up to 9 years service			
Adrenaline	100 ± 21.4%, <i>n</i> = 20	108.98 ± 13.07%, <i>n</i> = 27	60.45 ± 15.12%, <i>n</i> = 19
Nor-adrenaline	100 ± 23.23%, <i>n</i> = 17	99.92 ± 17.8%, <i>n</i> = 23	127.44 ± 18.84%, <i>n</i> = 23
Dopamine	100 ± 27.71%, <i>n</i> = 15	121.11 ± 23.58%, <i>n</i> = 15	48.95 ± 15.80%, <i>n</i> = 16
≥10 years service			
Adrenaline	100 ± 16.72%, <i>n</i> = 33	162.22 ± 42.08%, <i>n</i> = 12	49.91 ± 10.97%, <i>n</i> = 25
Nor-adrenaline	100 ± 28.2%, <i>n</i> = 26	92.91 ± 28.08%, <i>n</i> = 9	103 ± 15.12%, <i>n</i> = 29
Dopamine	100 ± 18.02%, <i>n</i> = 31	153.64 ± 31.36%, <i>n</i> = 12	85.07 ± 20.48%, <i>n</i> = 26

Values are mean ± SEM, expressed in percentage, *P* < 0.05.

length of service (up to 9 years and ≥ 10 years). Nevertheless, significant catecholamine adrenaline diminution should not be taken lightly and can be considered an indication of EMF potential to perturb catecholamine levels.

Significant adrenaline suppression found in exposure group II is in concurrence with a previously conducted study in electric utility workers however, at low frequency (50/60 Hz) EMF exposure [Batanjac and Pauncu, 2003]. This study also evaluated the nor-adrenaline concentration and observed significant decline, which is dissimilar to our finding of no significant difference both in terms of exposure with radar band and YOS and with respect to different service categories as well. Braune et al. [2002] also investigated the effect of RF exposure from global system for mobile communication like signals emanating from the mobile phone (900 MHz, pulsed with 217 Hz, 2 W) on the serum levels of hormones adrenaline and nor-adrenaline in healthy male and female individuals and reported null EMF effects. Their findings were in accord with ours except those observed in the exposure group II. An occupational study evaluating the effect on physiotherapists, however, found an increase in adrenaline and nor-adrenaline levels [Vangelova et al., 2007], which is in contradiction to our findings. In a recent study, Buchner and Eger [2011] also assessed catecholamine levels to examine effects of cell phone base station installation in human subjects. They measured catecholamine levels before activation of antennas (start of RF–EMF emissions) and monitored levels every 6 months over a span of one and a half years. They observed an initial post exposure (6 months after activation) increase in adrenaline and nor-adrenaline levels that was followed by decline in subsequent examinations, but normal levels were not restored even at study end. They also observed significant dopamine diminution after activation, which was also not recovered at the end of the study period. The authors suggested the role of adaptation behind their observations. An animal study in rats conducted in this regard documented an immediate rise in the catecholamine system both in the serum as well as in the hippocampus, along with reduction at 8 h and significant rise once again at 24 h exposure when no protection was given by shielding to check the electromagnetic irradiation [Yang et al., 2002]. Further, higher levels of nor-adrenaline and dopamine persisted at 48 h exposure in the hippocampus while in the serum, levels touched control values. They also evaluated the effect of shielding on catecholamine levels and found that whole body shielding was effective in preventing the EMF in eliciting any effect on the catecholamine system as against trunk shielding which was only

effective at the lower and middle power electromagnetic wave. They inferred that the catecholamine system might play a role in damage to the central nervous system (CNS) and cardiovascular system (CVS) post EMF experience and CNS injury may prolong in comparison. In addition, whole body shielding was found to be the most appropriate method in comparison to trunk shielding in imparting protection.

Any environmental amendment, whether physical, chemical, or biological, may stress the living organism, which is believed to be distinguished by the organism through various biological receptors. According to Selye [1950, 1980], this stress triggers a set of general adaptive reactions in all living systems to muddle through these changing situations thereby enabling the body to uphold its homeostasis or internal milieu. Additionally, stress induced demands lead to neuro-hormonal alterations in the organism, which are delicately balanced to boost the organism's ability to endure challenges and in this way adapt to unfavorable conditions. These adaptive modifications mobilize energy and gear up the body to endure “demands” for successful continued existence. High levels of flowing catecholamines in biological tissues are some key stress biomarkers produced in response to stress, which equips the biological organism to maintain homeostasis, by adaptation. However, the biological system cannot sustain elevated levels for long, and tries to regain baseline values to restore normal functioning. In the process of attaining equilibrium, the biological threshold may sometimes break and result in chronic dysregulation of catecholamine levels. In our study in exposure group II, significant adrenaline and non-significant dopamine diminution, respectively, might be a reflection of the adaptation process. In regard to exposure group I, it can be speculated that the exposure paradigm (in terms of both radar frequency band and mean YOS) was not sufficient to induce a stress response as evident by finding no significant difference among the catecholamine concentrations with respect to the reference values. Alternatively, it might also be possible that the biological system had adjusted and restored the near control levels as only single point measurements were taken. Although our results are not in agreement with the findings of Buchner and Eger [2011], which could be attributed to differences in exposure levels, duration of exposure, and the varying experimental design and methodology employed; their study reflected the adaptive mode taken by the body post EMF exposure behind gained results. In our study as well, obtained results can be understood as the outcome of partial habituation and adaptation post chronic radar experience. These preliminary results,

however, need further corroboration and long-term monitoring to reach any definite conclusion.

The body experiences inconsistent variations relating to physiological functions when submitted to stressful circumstances and these changes are depicted by the specific stress condition in real situations [Pacak et al., 1995]. The differences observed with regard to different radar bands in our own study and with previous studies could to some extent be attributed to varying exposure characteristics like frequency, length of exposure, variability in individual sensitivity, experimental design, and protocol used.

In light of these noteworthy results obtained at the two radar bands and lack of comparable studies in this context, it seems quite difficult to reach any firm conclusion. Hence, the results need prudent interpretation. There is lack of sufficient data pertaining to short- and long-term consequences of EMF exposure on stress adaptation mechanisms. Therefore, a long-term monitoring should be undertaken to study the course of these catecholamines' release post EMF contact so as to reach some consequential inference. Studies investigating the same endpoints with similar EMF exposure characteristics are scarce, making it difficult to compare our findings. Besides, inter- and intra-variability in catecholamine levels exhibited by biological systems post stress experience also add to the complexity. Overall, with regard to the arithmetic means and significant adrenaline suppression, the study seems to indicate the EMF exposure potential to alter catecholamine levels. Lack of significant effects with regard to other catecholamines and in connection to different service categories does not eliminate the EMF possibility of influencing catecholamine concentrations and thereby inducing health relevant effects.

Amid all these, the study has several merits. All participants were derived from the same occupational and military cluster. In addition, their diet, exercise protocols, physical characteristics, working hours, lifestyle, education level, and socio-economic status were relatively alike. The blind design, where the experimenter was unaware of the exposed and control status of the samples, further enhances the strength and excludes the chance of one of the confounders. Conducting the study in the same month and year for all the groups excludes the role of any seasonal influence. EMF exposure levels were determined by spot measurements at various occupational sites visited frequently by the soldiers. This could be considered a drawback as long-term personal monitoring by dosimeters is nowadays presumed to be the better and advanced way of exposure assessment [Hutter et al., 2006]. Nonetheless, this technique has

been previously employed for EMF exposure determination [Cocco et al., 2005] and has been observed to yield results with minimum imprecision [Eskelinen et al., 2002]. Being cost-effective, it is better suited for long-term epidemiological investigations versus personal monitoring by dosimeters as subjects voluntarily accept it better [Cocco et al., 2005].

In summation, the shift from baseline catecholamine values because of stress has immense significance for health and well-being, and their continual alteration may prove harmful in due course. Given the relevance of these endocrine secretions, suitable follow-up studies are needed to further strengthen these preliminary observations and for now, the findings should be construed prudently. In the interim, exposures should be limited as much as possible and high exposure zones should be restricted along with taking essential safeguards.

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