



## Alterations of Visual Reaction Time and Short Term Memory in Military Radar Personnel

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### Abstract

**Background:** Radar transmitters emit high-power radiofrequency radiation by creation of a high-voltage and high-frequency alternating electrical current.

**Methods:** Health effects of occupational exposure to military radar were investigated. Visual reaction time was recorded with a simple blind computer-assisted-visual reaction time test. To assess the short-term memory, modified Wechsler Memory Scale test was performed.

**Results:** The mean  $\pm$  SD reaction time in radar works (N=100) and the control group (N=57) were 238.58  $\pm$  23.47 milliseconds and 291.86  $\pm$  28.26 milliseconds ( $P < 0.0001$ ), respectively. The scores of forward digit span in radar works and the control group were 3.56  $\pm$  0.77 and 4.29  $\pm$  1.06 ( $P < 0.0001$ ), while the scores of backward digit span in radar works and the control group were 2.70  $\pm$  0.69 and 3.62  $\pm$  0.95 ( $P < 0.0001$ ). The scores of word recognition in radar works and the control group were 3.37  $\pm$  1.13 and 5.86  $\pm$  1.11 ( $P < 0.0001$ ). Finally, the scores of paired words in radar works and the control group were 13.56  $\pm$  1.78 and 15.21  $\pm$  2.20 ( $P < 0.0001$ ). It can be concluded that occupational exposures to radar radiations decreases reaction time, which may lead to a better response to different hazards.

**Conclusion:** To the best of our knowledge, this is the first study to show that occupational exposure to radar microwave radiation leads to decreased reaction time and the lower performance of short-term memory. Altogether, these results indicate that occupational exposure to radar microwave radiations may be linked to some non-detrimental and detrimental health effects.

**Keywords:** Military radar, Occupational exposure, Radiofrequency, Microwave, Health effects

### Introduction

The rapidly increasing use of microwave radiation, has raised public concern about possible detrimental effects of non-ionizing radiation sources which work in this frequency range (1-3). Radio Detection And Ranging (Radar) equipments send and transmit high-power RF waves by producing a high-vol-

tage and high frequency alternating electrical current. Radar workers are routinely exposed to pulsed high frequency electromagnetic fields, which are produced to locate and identify the presence, direction or range of airplanes, ships, control towers or other, usually moving objects. Nowadays, radar

systems, which operate at radio frequencies (RF) between 300 MHz and 18 GHz, are widely used for navigation, aviation, national defense, weather forecasting and even to speed control (hand-held police radars). As radiations emitted by radar systems must travel long distances in order to detect objects, the power must be relatively high at transmission site. Recent studies conducted on the health effects of occupational exposure to military radar radiations indicate some detrimental effects such as induction of oxidative stress (decreased glutathione concentration vs. increased concentration of malondialdehyde) (4), reduced fertility (5), increased level of DNA damage and chromatid breaks (6). Furthermore, some non-EMF hazards such as radar equipment-related electrical injury are also reported (7). There are also reported risks such as increased incidence of hemolymphatic cancers that can be caused by microwaves generated by radars or ionizing radiation produced by electronic devices producing the microwaves (8). On the other hand, there are published reports that could not show any detrimental effect in radar workers. In a 40-year controlled longitudinal Belgian study, no increase in all-cause mortality in military personnel who were in close contact with radar equipments was found (9). Over the past years our laboratory has focused on studying the health effects of exposure of humans to some common sources of electromagnetic fields such as mobile phones (10-12), MRI (13) and possible implications of pre-exposure to radiofrequency radiations (14-16).

The aim of this study was to assess if occupational exposure of military radar personnel affect their general health.

## Materials and Methods

### Participants

This study was conducted on apparently healthy male and female workers employed in a military radar site with a frequency range of 2-18 GHz. In this study, health effects of this radiation in personnel who routinely work with radar systems are investigated. All required permissions were

obtained from the authorities. As in this study informed consent was essential before enrolling a participant, 100 workers (mean age of  $33.42 \pm 6.87$  years, ranged 24-50 years) including 91 males and 9 females participated in the study, gave their informed consent before beginning the study. Seventy one percent of these workers had university degrees (B.Sc and M.Sc). A previously approved questionnaire (10) including personal information, job status, possibility of exposure to other sources of electromagnetic fields (Mobile phones, CRTs, etc) and adverse health symptoms (self reported) was used.

### GHQ

The 28-item General Health Questionnaire (GHQ) initially developed by Goldberg and Hillier to screen for somatic symptoms, anxiety and insomnia, social dysfunction, and severe depression was used as a self-administered tool for assessment of general mental health and mental distress. Higher scores indicate a worse general health condition. The validity and reliability of the Persian version of this questionnaire, which is understandable to almost every Iranian, was approved previously (17).

### Reaction Time

A modified Bracy simple visual reaction time test (18) that was developed in the Center for Research in Radiation Sciences (CRRS), Shiraz University of Medical Sciences, was used in this study. Visual reaction time (VRT) of all participants was recorded with a simple blind computer-assisted-visual reaction time test. To evaluate participants' sustained attention and response time, the participants were asked to respond as quickly as possible by a single right click on a computer mouse when a red square on the display was replaced by a green one. The students had to perform some preliminary tests for orientation with the test. In this stage, reaction time was not recorded. After orientation, to reduce random variation of measurements, each test was repeated 7 times in both real and sham exposure phases.

### Memory Test

Modified Wechsler Memory Scale test was performed on all participants. The test includes four subtests including forward and backward digit span, paired words and word recognition. After training, to perform the WMS digit span memory test, participants were asked to repeat back a list of digits, which were spoken live-voice, by an expert member of our research team at a rate of approximately one digit per second.

This study was approved by the Research Ethics Committee at the Shiraz University of Medical Sciences and informed consent was obtained from all participants.

### Results

As shown in Table 1, the mean age of the participants was  $33.42 \pm 6.87$  (ranged 24-50) years. Forty eight percent of the participants had worked 8 hours or less than 8 hours per day, while forty-eight and two percent of the participants had worked 9-10 hours per day and more than 10 hours per day, respectively. Only one percent of the participants had worked less than 5 days per week, while 84% and 15% of the participants had worked 5 days per week and 6 days per week, respectively.

**Table 1:** Demographic and occupational characteristics of the sample (n = 157)

	Cases		Controls	
	Frequency (%)	Mean (SD)	Frequency (%)	Mean (SD)
Age				
Male	N = 91 (91.0)	33.85 (7.05)	N = 53 (92.98)	33.17 (7.12)
Female	N = 9 (9.0)	29.11 (1.54)	N = 4 (7.02)	33.19 (7.02)
Total	100 (100)	33.42 (6.87)	57 (100)	33.19 (7.02)
Work Hours/Day				
≤ 8 hours	48 (48)			
9-10 hours	48 (48)			
> 10 hours	2 (2)			
Work Days/Week				
< 5 Days	1 (1)			
5 Days	84 (84)			
6 Days	15 (15)			
Work Experience				
≤ 24 months	20 (20)			
25-48 months	30 (30)			
49-120 months	35 (35)			
> 120 months	15 (15)			
Distance from Antenna				
≤ 4 meters	33 (33)			
5-10 meters	47 (47)			
> 10 meters	20 (20)			

Moving to work experience as a cardinal factor that determines the occupational health effects, 20% of the participants had work experiences of 24 months or less while 30%, 35% and 15% had work experiences in the range of 25-148, 49-120 and more than 121 months, respectively. On the other hand, considering the average distance of the participants from radar antennas, 33% had worked in distances of 4 meters or less, while 47% and 20% had worked in distances of 5-10 meters and more than 10 meters, respectively.

Mean ( $\pm$  SD) GHQ-28 scores of participants in all subsets and the scores in each subsection of somatic symptoms, anxiety/ insomnia, social

dysfunction, and severe depression are shown in Table 2. The mean scores of GHQ for somatic symptoms in radar workers and the control group were  $1.03 \pm 0.49$  and  $1.45 \pm 0.26$  ( $P < 0.0001$ ), respectively. The scores for anxiety/insomnia in radar workers and the control group were  $0.99 \pm 0.58$  and  $1.70 \pm 1.40$  ( $P < 0.001$ ), respectively. For social dysfunction the scores in radar workers and the control group were  $1.08 \pm 0.34$  and  $1.49 \pm 0.29$  ( $P < 0.0001$ ), respectively. Finally, for severe depression these scores in radar workers and the control group were  $0.44 \pm 0.52$  and  $1.66 \pm 0.35$  ( $P < 0.0001$ ), respectively.

**Table 2:** Mean ( $\pm$  SD) GHQ-28 scores of participants in each subsection of somatic symptoms, anxiety/ insomnia, social dysfunction, and severe depression

	<b>Radar Workers (n = 100) males and females Mean<math>\pm</math> SD</b>	<b>Control Group (n= 57) males and females Mean<math>\pm</math> SD</b>
GHQ-28 subscales		
Somatic symptoms	$1.03 \pm 0.49$	$1.45 \pm 0.26$
Anxiety/insomnia	$0.99 \pm 0.58$	$1.70 \pm 1.40$
Social dysfunction	$1.08 \pm 0.34$	$1.49 \pm 0.29$
Severe depression	$0.44 \pm 0.52$	$1.66 \pm 0.35$

$P$  value < 0.0001

Interestingly, the number of work hours was associated with GHQ-28 scores of participants. The mean scores of GHQ for somatic symptoms in the control group and radar workers who worked  $\leq 8$  hours, 9-10 hours and more than 10 hours per day were  $1.45 \pm 0.26$ ,  $1.07 \pm 0.50$ ,  $1.03 \pm 0.48$  and  $0.61 \pm 0.07$  ( $P < 0.0001$ ), respectively. For anxiety/insomnia, the mean scores in the control group and radar workers who worked  $\leq 8$  hours, 9-10 hours and more than 10 hours per day were  $1.70 \pm 1.40$ ,  $1.02 \pm 0.62$ ,  $0.99 \pm 0.56$  and  $0.82 \pm 0.36$  ( $P < 0.001$ ), respectively. For social dysfunction, the mean scores in the control group and radar workers who worked  $\leq 8$  hours, 9-10 hours and more than 10 hours per day were  $1.49 \pm 0.29$ ,  $1.08 \pm 0.36$ ,  $1.09 \pm 0.34$  and  $0.93 \pm 0.25$  ( $P < 0.0001$ ), respectively. For severe depression, the mean scores in the control group and radar workers who worked  $\leq 8$  hours, 9-10 hours and

more than 10 hours per day were  $1.66 \pm 0.35$ ,  $0.52 \pm 0.54$ ,  $0.40 \pm 0.51$  and  $0.07 \pm 0.08$  ( $P < 0.0001$ ), respectively. Altogether, the total scores of GHQ for all 4 subsets in the control group and radar workers who worked  $\leq 8$  hours, 9-10 hours and more than 10 hours per day were  $1.53 \pm 0.22$ ,  $1.82 \pm 0.38$ ,  $1.77 \pm 0.49$  and  $2.08 \pm 0.64$  ( $P < 0.0001$ ), respectively.

On the other hand, work experience played a significant role in GHQ scores. The mean scores of GHQ for somatic symptoms in the control group and radar workers who had work experiences of  $\leq 24$  months, 25-48, 49-120 and more than 120 months were  $1.45 \pm 0.26$ ,  $1.04 \pm 0.40$ ,  $1.01 \pm 0.48$ ,  $0.91 \pm 0.49$  and  $1.18 \pm 0.59$  ( $P < 0.0001$ ), respectively. For anxiety/insomnia, the mean scores in the control group and radar workers who had work experiences of  $\leq 24$  months, 25-48, 49-120 and more than 120

months were  $1.70 \pm 1.40$ ,  $0.97 \pm 0.47$ ,  $1.08 \pm 0.53$ ,  $0.89 \pm 0.70$  and  $1.08 \pm 0.60$  ( $P < 0.001$ ), respectively. For social dysfunction, the mean scores in the control group and radar workers who had work experiences of  $\leq 24$  months, 25-48, 49-120 and more than 120 months were  $1.49 \pm 0.29$ ,  $0.96 \pm 0.29$ ,  $1.13 \pm 0.34$ ,  $1.11 \pm 0.41$  and  $1.07 \pm 0.25$  ( $P < 0.0001$ ), respectively. For severe depression, the mean scores in the control group and radar workers who had work experiences of  $\leq 24$  months, 25-48, 49-120 and more than 120 months were  $1.66 \pm 0.35$ ,  $0.40 \pm 0.55$ ,  $0.47 \pm 0.47$ ,  $0.49 \pm 0.56$  and  $0.35 \pm 0.52$  ( $P < 0.0001$ ), respectively.

On the other hand, the distance from the antenna played also a significant role in mean GHQ-scores of the participants. The mean scores of GHQ for somatic symptoms in the control group and radar workers who had worked at an average distance of  $\leq 4$  meters, 5-10 and more than 10 meters were  $1.45 \pm 0.26$ ,  $1.06 \pm 0.40$ ,  $1.05 \pm 0.54$  and  $0.95 \pm 0.50$  ( $P < 0.0001$ ), respectively. For anxiety/insomnia, the mean scores in the control group and radar workers who had worked at an average distance of  $\leq 4$  meters, 5-10 and more than 10 meters were  $1.70 \pm 1.40$ ,  $1.10 \pm 0.55$ ,  $0.97 \pm 0.62$  and  $0.89 \pm 0.54$  ( $P < 0.001$ ), respectively. For social dysfunction, the mean scores in the control group and radar workers who had worked at an average distance of  $\leq 4$  meters, 5-10 and more than 10 meters were  $1.49 \pm 0.29$ ,  $1.13 \pm 0.34$ ,  $1.04 \pm 0.29$  and  $1.10 \pm 0.47$  ( $P < 0.001$ ), respectively. For severe depression, the mean scores in the control group and radar workers who had worked at an average distance of  $\leq 4$  meters, 5-10 and more than 10 meters were  $1.66 \pm 0.35$ ,  $0.43 \pm 0.42$ ,  $0.43 \pm 0.60$  and  $0.49 \pm 0.50$  ( $P < 0.0001$ ), respectively. Altogether, the total scores of GHQ for all 4 subsets in the control group and radar workers who had worked at an average distance of  $\leq 4$  meters, 5-10 and more than 10 meters were  $1.53 \pm 0.22$ ,  $1.54 \pm 0.22$ ,  $1.49 \pm 0.23$  and  $1.49 \pm 0.43$ , respectively. These differences were not statistically significant ( $P = 0.77$ ).

The relationship between reaction time and the participants' work experience is shown in Table 3.

**Table 3:** The relationship between reaction time and the participants' work experience

Work Experience	Frequency (# of samples)		Total
	Reaction Time (msec)		
	$\leq 225$ msec	$> 225$ msec	
$\leq 48$ months	0	50	50
$> 48$ months	33	17	50
Total	33	67	100

Chi-square  $P$ -value  $< 0.001$

Chi-square test revealed a statistically significant relationship between work experience and reaction time ( $P < 0.001$ ). On the other hand, there was a significant relationship between participants' age and the reaction time ( $P < 0.001$ ). After adjustment for age, reaction time remained associated with work experience. The reaction time of the radar workers and the control group in different age categories is shown in Table 4.

**Table 4:** Mean ( $\pm$  SD) reaction time of the radar workers and control group

Age group (yr)	Radar Workers Reaction time m sec (Mean $\pm$ SD) (# of participants)	Control Group Reaction time m sec (Mean $\pm$ SD) (# of participants)
20-30	246.81 $\pm$ 21.65 (N = 48)	298.44 $\pm$ 30.03 (N = 27)
31-40	233.71 $\pm$ 22.34 (N = 35)	291.75 $\pm$ 23.96 (N = 20)
41-50	225.35 $\pm$ 23.02 (N = 17)	275.91 $\pm$ 26.87 (N = 11)
Total	238.58 $\pm$ 23.47 (N = 100)	291.86 $\pm$ 28.26 (N = 57)

$P$  value  $< 0.0001$

This table clearly shows that regardless of the age category, there is a statistically significant difference between reaction time of the radar workers and the control group.

The scores of the short-term memory of radar workers and the control group for each subtest are shown in Table 5. According to this table, for all subtests (forward and backward digit span, paired words and word recognition), the scores of

the radar workers are significantly higher than those of the control group.

**Table 5:** Mean ( $\pm$  SD) short term memory scores of participants in each subtests including forward and backward digit span, paired words and word recognition

	<b>Radar Workers (Mean<math>\pm</math> SD) (n = 100)</b>	<b>Control Group (Mean<math>\pm</math> SD) (n = 57)</b>
Forward digit span	3.56 $\pm$ 0.77	4.29 $\pm$ 1.06
Backward digit span	2.70 $\pm$ 0.69	3.62 $\pm$ 0.95
Word Recognition	3.37 $\pm$ 1.13	5.86 $\pm$ 1.11
Paired words	13.56 $\pm$ 1.78	15.21 $\pm$ 2.20

$P$  value < 0.0001

## Discussion

Results showed that the mean reaction time in radar works was significantly lower than that of the control group (238.58  $\pm$  23.47 milliseconds vs 291.86  $\pm$  28.26 milliseconds,  $P$ <0.0001). These results may lead us to this conclusion that occupational exposure to radar radiations decreases reaction time, which may lead to a better response to different hazards. On the other hand, the scores of forward digit span, backward digit span, word recognition and paired words in radar workers were significantly lower than those of the control group (3.56  $\pm$  0.77 vs. 4.29  $\pm$  1.06,  $P$ <0.0001; 2.70  $\pm$  0.69 vs. 3.62  $\pm$  0.95,  $P$ <0.0001; 3.37  $\pm$  1.13 vs 5.86  $\pm$  1.11,  $P$ <0.0001; 13.56  $\pm$  1.78 vs. 15.21  $\pm$  2.20,  $P$ <0.0001, respectively).

Findings of reaction time in this study generally confirm the findings of our previous study that indicated exposure to mobile phone radiations caused decreased reaction time in university students (12). Generally speaking, our findings are in contrast with those of other investigators who have reported detrimental health effects of the occupational exposure to radar radiations such as decreased sperm motility and viability in highly

exposed group compared to those of the lowly exposed and control groups (19), increased sperm dysmorphia and alteration in quality of semen in response to changes in microwave frequency, distance, intensity, exposure time and quality of shielding (20), increase in frequency of micronuclei (21). On the other hand these findings are not in line with those reports that showed biological alterations without major clinical implications such as increased IgG, IgM and IgA level and decreased count of lymphocytes and T8 cells (22) or even some beneficial bioeffects such as lower all-cause mortality rate in military conscripts who served in battalions with anti-aircraft radars versus controls (9).

Investigation of the general and more specifically mental health that is believed to be an integral and essential component of health was among the main goals of this study. The WHO constitution states: "Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity". In this light, mental health is more than the absence of mental disorders or disabilities (23). Exposure to radiofrequency radiation has not consistently been shown to have an effect on well-being or self-reported symptoms such as headache, fatigue, dizziness and concentration difficulties (24). In this light, our study interestingly showed that the scores of GHQ for all 4 subsets in the control group were higher than those of radar workers. This clearly indicates that the levels of psychological distress in radar workers are less than those of the control group.

In the former Soviet Union anecdotal reports of symptoms such as insomnia, memory loss, and headache led to some early reports indicating possible psychiatric or psychological effects of exposure to electromagnetic fields (25). However, after several decades, these reports are still unconfirmed but recently, hypotheses relating EMF to problems such as neurodegenerative disorders have attracted a worldwide interest (26). In our study, the short-term memory scores in radar workers were less than those of the control group. This finding is in line with the results obtained in a study on 317 seventh grade students (144 boys,

173 girls, median age 13 years). In this study, in children who reported more mobile phone voice calls, the accuracy of working memory was poorer and reaction time for a simple learning task was shorter (27).

Despite much dissimilarity, some of our findings are clearly in contrast with some recent studies that report lack of evidence for a direct association between frequency and severity of non-specific physical symptoms and higher levels of EMF exposure (10, 11, 28).

## Conclusion

Altogether, the results obtained in this study indicate that occupational exposure to radar microwave radiations are not linked to major adverse health effects. However, as the short-term memory scores in radar workers were less than those of the control group, attempts for reducing exposure of radar workers to radiofrequencies generated by radar systems should be performed.

## Ethical considerations

Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc) have been completely observed by the authors.

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