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Neurobehavioral effects among inhabitants around mobile phone base stations

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Abstract

Background: There is a general concern on the possible hazardous health effects of exposure to radiofrequency electromagnetic radiations (RFR) emitted from mobile phone base station antennas on the human nervous system.
Aim: To identify the possible neurobehavioral deficits among inhabitants living nearby mobile phone base stations.
Methods: A cross-sectional study was conducted on (85) inhabitants living nearby the first mobile phone station antenna in Menoufiya governorate, Egypt, 37 are living in a building under the station antenna while 48 opposite the station. A control group (80) participants were matched with the exposed for age, sex, occupation and educational level. All participants completed a structured questionnaire containing: personal, educational and medical histories; general and neurological examinations; neurobehavioral test battery (NBTB) [involving tests for visuomotor speed, problem solving, attention and memory]; in addition to Eysenck personality questionnaire (EPQ).
Results: The prevalence of neuropsychiatric complaints as headache (23.5%), memory changes (28.2%), dizziness (18.8%), tremors (9.4%), depressive symptoms (21.7%), and sleep disturbance (23.5%) were significantly higher among exposed inhabitants than controls: (10%), (5%), (5%), (0%), (8.8%) and (10%), respectively ($P < 0.05$). The NBTB indicated that the exposed inhabitants exhibited a significantly lower performance than controls in one of the tests of attention and short-term auditory memory [Paced Auditory Serial Addition Test (PASAT)]. Also, the inhabitants opposite the station exhibited a lower performance in the problem solving test (block design) than those under the station. All inhabitants exhibited a better performance in the two tests of visuomotor speed (Digit symbol and Trailmaking B) and one test of attention (Trailmaking A) than controls. The last available measures of RFR emitted from the first mobile phone base station antennas in Menoufiya governorate were less than the allowable standard level.
Conclusions and recommendations: Inhabitants living nearby mobile phone base stations are at risk for developing neuropsychiatric problems and some changes in the performance of neurobehavioral functions either by facilitation or inhibition. So, revision of standard guidelines for public exposure to RER from mobile phone base station antennas and using of NBTB for regular assessment and early detection of biological effects among inhabitants around the stations are recommended.

Keywords: Neurobehavioral effects; Mobile phone base stations; Radiofrequency radiations (RFR)

1. Introduction

There is a general concern about the possible hazardous health effects of exposure to radiofrequency radiations (RFR) emitted from mobile phone base station antennas. Disturbance of the nervous system leads to behavioral changes and may serve as an early indicator of disturbances in regulatory functions of many systems (Lai and Singh, 1994). Exposure of the neural tissue to RFR can cause electrophysiological changes in the nervous system (Navakatikian and Tomashevskaya, 1994; Velizarov et al., 1999). Some studies have suggested that RFR induce tissue heating leads to tissue damage (Gajsek et al., 2002; Preece et al., 1999). Some effects are observed among mobile phone users at low intensity and after repeated exposure (Hyland, 2000). The efflux of calcium ions from brain tissue is an important neurochemical effect of RFR as calcium ion plays an important role in the functions of the nervous system such as the release of neurotransmitters (Dutta et al., 1989). Experimental studies on

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rats indicated that both cholinergic and endogenous opioid transmitter systems inside the central nervous system are involved in the RFR-induced spatial working memory deficit (Lai et al., 1990, 1994). Moreover, RFR activate endogenous opioids in the brain, which in turn cause a decrease in cholinergic activity leading to short-term memory deficit. The stress hormone ''corticotropin releasing factor'' is also involved (Lai et al., 1994).

The emissions of a mobile phone base station are usually described by its effective radiated power which is given in Watts (W) (Nousir, 2002). The intensity of RFR is called the power density and is measured in (mW/cm^2). However, the specific absorption rate (SAR) that is measured in (W/kg) of tissue is a more reliable determinant and index for RFR biological effects than power densities as SARs reflect what is actually being absorbed rather than the energy quotient in space (Lai, 2000).

There are national and international safety guidelines for public exposure to RFR produced by mobile phone base stations. The Egyptian standard follows the ANSI/IEEE (1992), the permissible level of radiation power density is less than 0.4 mW/cm^2 (Egyptian Protocol of Criteria for Construction of Mobile Phone Base Stations, 2000).

Increased concern by the public about the safety and potential health effects at the appearance of a multitude of cellular transmitter antennas on the buildings and fear of unknown make it necessary to provide an answer to the question about safety of mobile phone base stations. So this study aimed to identify the possible neurobehavioral deficits among inhabitants living nearby the first mobile base station in Menoufiya governorate. To the best of our knowledge, no similar studies were carried out in Egypt till now, but other studies all over the world were performed mainly about safety of cellular phone use.

2. Subjects and methods

This cross-sectional study was conducted during the period from March to December 2003, included inhabitants living in and opposite to the building where the first mobile phone base station was constructed in Shebin El-Kom City (Menoufiya governorate) in 1998 (Fig. 1). The base station consists of three antennas and a shelter which contains an electric power station and the cables for the base station antennas (Fig. 2).

Eighty-five exposed individuals completed the study. Thirty-seven were current inhabitants living under the mobile phone base station antennas, while the other forty-eight were employees and agriculture engineers working in agricultural directorate building approximately 10 m opposite to the station. A control group constituted of 80 employees and engineers of a Shebin El-Kom agricultural administration building located approximately 2 km from the designated mobile phone base station was chosen and completed the study. They were matched for age, sex, occupation (employees and agriculture engineers), education level and mobile phone use. Consent forms were signed by all participants as they were volunteers, they were asked to do their best during testing. Approval and support from the ethical committee at Menoufiya Faculty of Medicine were obtained. None of the participants was informed about the purpose of the study so as to exclude any malingering effects. They were informed about the purpose of the study at the end. The average exposure time for RFR was 8 h for employees in the building underneath the antenna and 15 h for inhabitants of the building opposite the antenna. None of the controls lived near an antenna. The exclusion criteria were based on personal and medical histories including those having epilepsy, psychiatric disorders or specific cause of headache. The tools used to collect data were:

Fig. 1. The mobile phone base station antennas upon the building for agricultural professions.

(A) Questionnaire: included data about personal, occupational and medical histories and neuropsychiatric complaints such as headache, irritability, memory changes, tremors, dizziness, blurred vision, and depressive symptoms (sensation of sadness) (Abdel Gawad, 1972). The questionnaire clearly

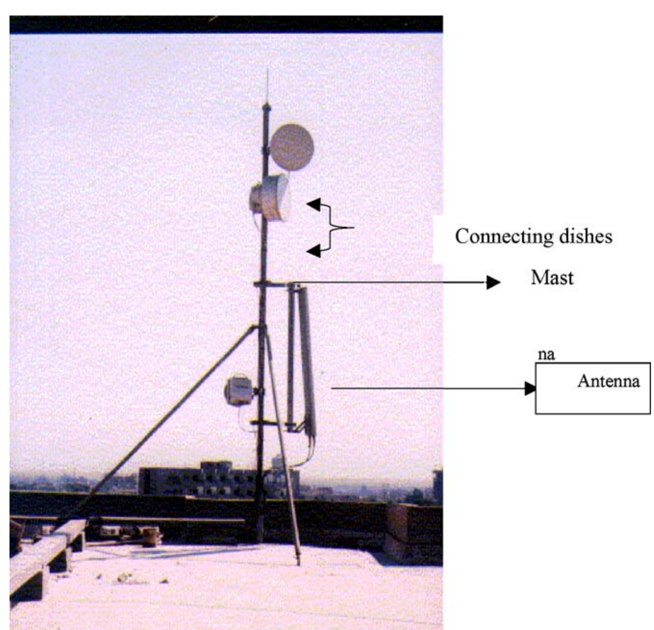

Fig. 2. The antenna of a mobile phone base station upon the building.

Table 1
Personal characteristics of exposed and control participants

Personal characteristics	Exposed ($n = 85$) mean ± S.D.		Controls ($n = 80$) mean ± S.D.		Test of significance	P-value
Age (years)	38.23 ± 14.56		39.88 ± 15.29		t-Test = 0.98	>0.05
	No	%	No	%		
Sex						
Male	48	56.50	47	58.75	$\chi^2 = 0.09$	>0.05
Female	37	43.50	33	41.25		
Education level						
Basic	3	3.50	0	0.00	$\chi^2 = 2.96$	>0.05
Secondary	34	40.00	35	43.75		
University	48	56.50	45	56.25		
Smoking						
Smokers	4	4.70	7	8.75	$\chi^2 = 1.08$	>0.05
Nonsmokers	81	95.30	73	91.25		
Mobile phone use						
Users	10	11.76	8	10.00	$\chi^2 = 0.01$	>0.05
Non-users	75	88.24	72	90.00		

Exposed and controls were of the same age, sex, educational levels, smoking habits and mobile phone use ($P > 0.05$).

stated the confidentiality of the response with no identification of names or contact information.

(B) Clinical examination: including general and local neurological examination.

(C) Neurobehavioral test battery (NBTB) (Lezak, 1995; Wechsler, 1981): a series of eight neurobehavioral tests translated into Arabic by Meleka (1991) was used. They included tests of: (1) Visuomotor Speed (Digit Symbol and Trailmaking B), (2) problem solving (block design), (3) attention and short-term auditory memory (PASAT, Letter Cancellation and Trailmaking A), (4) memory [(Digit Span forward and backward and Benton Visual Retention Test (BVRT)]. In addition to this NBTB, Eysenck Personality Questionnaire (EPQ) (Eysenck, 1990) was used to measure personality domains. Better performance is evaluated by higher scores obtained on tests of Digit Symbol, Block Design, PASAT, Digit Span and BVRT, while lower latency or time to complete Trailmaking parts A and B tests indicated better performance.

(D) Environmental measures: the most recent measures at the start of the study for the power density (mW/cm^2) of mobile phone base station antennas under the study done by the National Telecommunication Institute at the year 2000 were considered.

2.1. Statistical analysis

Data were collected, tabulated and statistically analyzed using chi-square (χ^2) and student *t*-tests and analysis of covariance (ANCOVA) for comparison between groups at 5% level of significance.

3. Results

Eighty-five exposed participants (56.5% males and 43.5% females) with a mean age (38.2 ± 14.5 years) were matched with 80 controls (58.7% males and 43.3% females) with a mean age (39.8 ± 15.2 years) ($P > 0.05$). They were also matched regarding sex distribution, education level, smoking and mobile phone use ($P > 0.05$, Table 1). Although both exposed and control groups did not differ significantly on studying these variables, the analysis of covariance (ANCOVA) was used to adjust for their influence as they are confounders for neurobehavioral performance. ANCOVA confirmed the same deficits as the *t*-test comparisons.

Table 2
Measurements of power density for mobile phone base station antennas upon the building under the study by National Telecommunication Institute (NTI, 2000)

Site of measurement	Power density (mW/cm^2)	The maximum permissible level for continuous exposure (mW/cm^2)
Antenna 1		
1	0.0020	0.0080
2	0.0024	0.0080
3	0.0063	0.0080
Antenna 2		
1	0.0033	0.0080
2	0.0032	0.0080
3	0.0026	0.0080
4	0.0067	0.0080
5	0.0024	0.0080
Antenna 3:		
1	0.0055	0.0080
2	0.0039	0.0080
3	0.0027	0.0080
Inside the shelter	0.0001	0.0080
At different sites	0.0001	0.0080
Within the apartment below antenna 1	0.0001	0.0080

NB: The maximum permissible level for intermittent exposure is 0.4 mW/cm^2 that decreased to 0.0080 mW/cm^2 for continuous exposure (Egyptian Protocol of Criteria for Construction of Mobile Phone Stations, 2000).

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Table 3
Neurological complaints among exposed and controls

Neurological complaints	Exposed ($N = 85$), N (%)	Controls ($N = 80$), N (%)	χ^2	P-value	OR [95% CI]
Headache	20 (23.5)	8 (10.5)	4.44	<0.05	2.77 [1.06–7.4]
Memory changes	24 (28.2)	4 (5.0)	14.19	<0.001	7.48 [2.29–26.98]
Tremors	8 (9.4)	0 (0.0)	Fisher exact	<0.01	–
Dizziness	16 (18.8)	4 (5.0)	6.15	<0.01	4.41 [1.29–16.46]
Depressive symptoms	18 (21.7)	7 (8.8)	4.03	<0.05	2.8 [1.02–7.94]
Blurred vision	19 (22.3)	12 (15.0)	1.02	>0.05	1.63 [0.69–3.91]
Sleep disturbance	20 (23.5)	8 (10.0)	4.44	<0.05	2.77 [1.06–7.4]
Irritability	23 (27.1)	16 (20.0)	0.78	>0.05	1.48 [0.68–3.27]
Lack of concentration	14 (16.5)	8 (10.0)	0.99	>0.05	1.77 [0.65–4.97]

Fischer exact test was used as the calculated expected number in this cell was lower than five.

The last available measures of RFR from the mobile phone base stations antennas from the building in the study were less than the allowable standard level (0.4 mW/cm^2) (Table 2) in the year 2000. The numbers 1–5 indicate the sites at which the measures on a specific antenna were taken. The shelter was an enclosed room containing an electric power station and the cables for the base station antenna. The tower is a building of 12 stories. No measures were available for the buildings across the street or from the control building.

The prevalence of headache (23.5%), memory changes (28.2%), tremors (9.4%), dizziness (18.8%), depressive symptoms (21.7%) and sleep disturbances (23.5%) among exposed subjects were significantly higher than controls (10%, 5%, 0%, 5%, 8.8% and 10%; respectively) ($P < 0.05$, Table 3). The only difference between the exposed participants under the station as opposed to those working opposite it was in the prevalence of sleep disturbance (10.8% and 31.3%, respectively) ($P < 0.05$, Table 4).

The exposed participants exhibited a significantly poorer performance than controls in one test of attention and short-term auditory memory (PASAT), but they exhibited significantly better performance than controls in tests of visuomotor speed (Digit Symbol and Trailmaking B) ($P < 0.01$) and one test of attention (Trailmaking A) ($P < 0.001$). The difference in scores in Trailmaking A was so high and these scores were verified again and no numerical errors were found. There was no significant difference between exposed and controls in the score of EPQ scale ($P > 0.05$, Table 5). The exposed participants opposite to the station exhibited a significantly lower performance in the problem solving (Block Design) than those living under the station ($P < 0.05$, Table 6).

4. Discussion

The extensive use of mobile phones has been accompanied by public debate about possible adverse effects on human health. However, little is known about the effects of long-term exposure that is experienced by people living near mobile phone base stations (Bortkiewicz et al., 2004).

The last available measurements of RFR emitted from mobile phone base station antennas under the study in the year 2000 were less than the Egyptian allowable standard level (0.4 mW/cm^2). However, the level of exposure to RFR increases or decreases according to the number of phone calls from different parts of country or other countries. The number of subscribers in mobile phone service increased approximately four times within 2 years from about 1,575,000 (2.5% of the Egyptian population) in the year 2000 at the time of the previously measured levels to about 7,000,000 (9.5% of the Egyptian population) in the year 2002 (El-Mesairy, 2002) just before the beginning of this study in the year 2003. Consequently, it is expected that the previously mentioned levels of exposure to RFR in the year 2000 were higher at the time of the study.

Table 4
Neurological complaints among inhabitants living under and opposite the station

Neurological complaints	Inhabitants		χ^2	P-value	OR [95% CI]
	Opposite the station ($N = 48$), N (%)	Under the station ($N = 37$), N (%)			
Headache	15 (31.3)	5 (13.5)	2.73	>0.05	2.91 [0.85–10.47]
Memory changes	12 (25.0)	12 (32.4)	0.26	>0.05	0.69 [0.24–1.99]
Tremors	4 (8.3)	4 (10.8)	0.00	>0.05	0.75 [0.14–3.92]
Dizziness	9 (18.8)	7 (18.9)	0.07	>0.05	0.99 [0.29–3.38]
Depressive symptoms	9 (18.8)	8 (21.6)	0.10	>0.05	0.84 [0.25–2.75]
Blurred vision	12 (25.0)	7 (18.9)	0.16	>0.05	1.43 [0.45–4.65]
Sleep disturbance	15 (31.3)	4 (10.8)	3.92	<0.05	3.75 [1.01–15.09]
Irritability	16 (33.3)	7 (18.9)	1.53	>0.05	2.14 [0.7–6.74]
Lack of concentration	9 (18.8)	5 (13.5)	0.12	>0.05	1.48 [0.4–5.71]

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Table 5
Mean ± S.D. of neurobehavioral performance and personality scores of exposed and controls

Neurobehavioral tests	Exposed ($n = 85$)		Controls ($n = 80$)		*t*-Test	*P*
	$\bar{X}$	±S.D.	$\bar{X}$	±S.D.		
Performance tests						
Visuomotor speed						
Digit symbol	41.43	11.91	31.30	11.98	3.19	<0.01
Trailmaking B	84.79	21.88	108.40	39.49	3.16	<0.01
Problem solving						
Block design	24.32	7.23	24.15	5.25	0.10	>0.05
Attention						
PASAT	12.20	4.20	15.47	5.49	4.31	<0.001
Letter cancel	30.28	5.20	31.56	5.92	1.35	>0.05
Trailmaking A (s)	26.10	21.43	88.25	25.46	3.84	<0.001
Memory						
Digit span forward	6.40	1.69	7.05	2.50	1.21	>0.05
Digit span backwards	2.60	0.82	2.37	0.89	1.73	>0.05
Digit span total	9.09	2.82	9.42	3.78	0.38	>0.05
BVRT	4.48	1.62	3.95	0.97	1.36	>0.05
Eysenck personality questionnaire (EPQ)						
P (psychoticism)	7.04	1.73	7.40	2.10	1.20	>0.05
C (criminality)	12.69	3.60	13.58	4.39	0.86	>0.05
N (neuroticism)	10.84	3.93	12.20	4.14	1.29	>0.05
E (extroversion)	10.82	3.62	10.85	3.95	0.38	>0.05
L (lie)	15.45	4.18	10.10	3.45	0.62	>0.05

On studying the prevalence of neurological complaints among exposed subjects and controls, headache, memory changes, tremors, dizziness, depressive symptoms and sleep disturbance were significantly higher among exposed (23.5%, 28.2%, 9.4%, 18.8%, 21.7% and 23.5%, respectively) than controls (10%, 5%, 0%, 5%, 8.8% and 10%, respectively) ($P < 0.05$). These results agree with Santini et al. (2002) who found that the frequency of headache, loss of memory, irritability, dizziness, depression and sleep disturbance was significantly higher among people living near cellular phone base stations (25.4%, 27.6%, 4.5%, 4%, 9.2% and 4.1%, respectively) than controls ($P < 0.05$). Also, Frey (1998) and Leif (2003) observed various complaints mostly of sleep disturbance, irritability, depression, headache, vertigo and concentration difficulties among people living near mobile base stations.

On comparing exposed inhabitants living in the building under the station with those opposite the station regarding

Table 6
Mean ± S.D. of neurobehavioral performance score of inhabitants living under and opposite the station

Performance tests	Inhabitants ($n = 85$)				Student's *t*-test	*P*
	Under the station ($n = 37$)		Opposite the station ($n = 48$)			
	$\bar{X}$	±S.D.	$\bar{X}$	±S.D.		
Visuomotor speed						
Digit symbol	42.24	12.67	40.79	11.72	0.41	>0.05
Trailmaking B	89.52	24.95	81.35	19.16	0.11	>0.05
Problem solving						
Block design	27.57	4.61	21.37	7.97	3.23	<0.01
Attention						
PASAT	11.69	1.73	12.25	2.10	1.80	>0.05
Letter cancel	32.31	5.43	33.15	5.65	0.52	>0.05
Trailmaking A (s)	65.24	24.16	56.96	19.24	0.11	>0.05
Memory						
Digit span forward	6.63	0.57	6.30	1.77	0.63	>0.05
Digit span backward	3.21	1.02	2.90	0.75	1.43	>0.05
Digit span total	9.84	2.29	9.20	2.61	1.68	>0.05
BVRT	4.57	1.33	4.40	1.88	0.35	>0.05

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neurological complaints, there was a significant increase in the prevalence of sleep disturbance among the inhabitants opposite to the station (31.3% versus 10.8%) ($P < 0.05$). This could be explained by the fact that the concrete roof can soak up to 5–30% of the radiation from the antennas, so the levels of radiation in the building under the station may be lower than opposite and pose fewer hazards (El-Mesairy, 2002; Knave, 2001).

On studying the neurobehavioral performance using NBTB and personality domains using (EPQ) scale, the exposed participants exhibited a significantly better performance than controls in tests of visuomotor speed (Digit Symbol and Trail making B) and one test of attention (Trail making A) than controls, but they exhibited a poorer performance in PASAT test (which measures attention and short-term auditory memory) than controls. Better performance is evaluated by higher scores obtained on tests of Digit Symbol, Block Design, PASAT, Digit Span and BVRT, by contrast: lower latency or time to complete Trailmaking parts A and B tests indicated better performance.

The better performance in some neurobehavioral tests in this study agreed with Koivisto et al. (2000) and Lee et al. (2001) who suggested that the electromagnetic field emitted by cellular telephones may have a facilitatory effect on brain functioning. On the other hand, responses of central nervous system to RFR could be a stress response (Duan et al., 1998; Lai and Singh, 1997). Stress effects are well known to accumulate over time and involve first adaptation and then an eventual breakdown of homeostatic processes. Moreover, Lai et al. (1990, 1994) experimental studies on rats indicated that RFR can activate endogenous opioids in the brain, which in turn cause a decrease in cholinergic activity leading to short-term memory deficit. The stress hormone ''corticotropin releasing factor'' is also involved. This may explain the lower performance of exposed subjects in PASAT test in this study. On the other hand, on studying the personality domains using (EPQ) scores, there was no difference between exposed inhabitants and controls in the present study regarding these scores. This may be explained by the fact of the presence of relatively low levels and short duration of exposure (about 5 years) to RFR since the establishment of the base station under the study, a matter which needs a further wide scale research to be verified.

5. Conclusion and recommendations

The inhabitants around mobile base station antennas significantly complain or develop headache, memory changes, tremors, dizziness, depressive symptoms and sleep disturbance than controls. Also, there are some effects of RFR emitted from these antennas on neurobehavioral performance. Therefore, the study recommends:

(1) Annual monitoring of RFR emitted from the mobile phone base station antennas should be carried out as their values may become higher due to the expected extensive future use of mobile phones and hence more activity and more arising emissions leading to increase in incidence and severity of neurobehavioral disorders among inhabitants around these stations. At the same time, this will clarify controversies met with in this study regarding scores of some NB tests for exposed inhabitants.
(2) For inhabitants near mobile phone base station, NBTB can be used as a useful non-invasive tool for assessment and early detection of subtle effects of exposure to RFR.
(3) Further follow up wide scale studies for those inhabitants exposed for longer durations to RFR arising from mobile phone base stations should be done to clarify if there is an actual positive association and/or causation between exposure and either of the development of neurobehavioral complaints or NBTB and personality changes so as to cut off the challenge of presence of controversies in the results done in this field all over the world.

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