



Brief Report

Acute effects of the electromagnetic waves emitted by mobile phones on attention in emergency physicians

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ABSTRACT

Study objective: The purpose of this study was to investigate the acute effects of the electromagnetic waves (EMW) emitted by mobile phones on attention in emergency physicians.

Methods: This single-center, prospective, randomized, double-blinded clinical study was performed among emergency physicians in a tertiary hospital. Thirty emergency physicians were enrolled in the study. Initial d2 test was applied in the evaluation of attention and concentration of all the physicians, who were randomly assigned into one of two groups. The control group members hold mobile phones in 'off' mode to their left ears for 15 min. The members of the intervention group hold mobile phones in 'on' mode to their left ears for 15 min, thus exposing them to 900–1800 MHz EMW. The d2 test was re-applied to both groups after this procedure. Differences in attention and concentration levels between the groups were compared.

Results: Difference between initial and final d2 test in total performance (TN-E, $p = 0.319$), in total number of figures marked (TN, $p = 0.177$), in test performance percentile (PR, $p = 0.619$) and in attention fluctuation (FR, $p = 0.083$) were similar between the groups. However, difference in the number of figures missed (E1 selective attention, $p = 0.025$), difference between numbers of incorrectly marked figures (E2, $p = 0.018$) and difference in focus levels (E, $p = 0.016$) were significantly in favor of the intervention group.

Conclusion: According to our study findings, the EMW emitted by mobile phones has no deleterious effect on the attention and concentration levels of emergency physicians, and even has a positive impact on selective attention levels.

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1. Introduction

1.1. Background

The effects of electromagnetic waves (EMW) on humans have become a major source of interest and concern in recent years. Mobile phone technology, together with Wireless Local Area Network (WLAN), bluetooth, and Digital Enhanced Cordless Telecommunications (DECT), has become one of the most commonly used sources of EMW to which modern humans are exposed.

Concerns over the effects of EMW (at a 900–1800 MHz range) emitted by mobile phone receivers may be associated with carcinogenic

and neuronal activity [1,2]. Excessive use of mobile phones is known to cause headache, a feeling of discomfort and a sensation of warmth around the ear, and this is also thought to cause additional deleterious effects on concentration and attention, memory loss and depression [1].

1.2. Importance

As in all areas of life and all occupational groups, mobile phone use is widespread among emergency physicians. Environmental factors that impair the individual's mental concentration and attention are thought to play a significant role in medical errors that occur in emergency departments. The importance of attention and concentration in emergency departments, where vital decisions are made concurrently and medical procedures need to be performed without error and in a race against time, is obvious. This study was planned based on the

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hypothesis that EMW emitted by mobile phones may affect emergency physicians' attention and concentration levels.

1.3. Goal of this investigation

Our study was planned to investigate the acute effects on emergency physicians' attention and concentration of EMW emitted by mobile phones.

2. Methods

2.1. Study design and setting

This single-center, prospective, randomized, double-blind clinical study was performed between 15.11.2016 and 15.02.2017 in The Health Sciences University Trabzon Kanuni Training and Research Hospital Emergency Medicine Department, Turkey, in order to investigate the acute effects of EMW associated with mobile phone use on emergency physicians' attention and concentration levels. The study was approved by the Health Sciences Trabzon Kanuni Training and Research Hospital Clinical Research Ethical Committee under protocol number 2016-49. Written, informed consent was obtained from all the emergency physicians included in the study. The trial protocol was registered at [ClinicalTrials.gov](https://clinicaltrials.gov/ct2/show/study/NCT03239925) (NCT03239925).

2.2. Selection of participants

Our single-center study was performed with emergency department physicians serving in The Health Sciences University Trabzon Kanuni Training and Research Hospital emergency department, a tertiary department receiving 400–600 patient presentations a day. Physicians working in the emergency department for at least one year, expressing willingness to take part and giving written consent to do so, and aged between 18 and 60 were included. Left-handed subjects, those who had consumed alcohol or coffee in the previous 24 h, pregnant subjects, or with a history of substance abuse or dependence, with cancer or any psychiatric disease and those using medication for sleep disorder were excluded from the study.

2.3. Intervention

Thirty emergency physicians were enrolled in the study following pre-assessment based on the inclusion and exclusion criteria. The d2 test of attention, widely employed in the literature in the evaluation of attention and concentration, was applied to the physicians enrolled before the study began [3].

In determining the groups, participants were ranked from highest to lowest on their initial TN-E scores on the d2 test of attention. Following that ranking process, two similar groups (intervention and control) were established using the head-and-tails method of binary randomization.

The control group members were asked to hold a mobile phone in 'off' mode to their left ears in their left hands for 15 min.

The members of the intervention group were asked to hold a mobile phone in 'on' mode to their left ears in their left hands for 15 min, and were thus exposed to 900–1800 MHz EMW for 15 min.

For blinding purposes, the screen of the mobile phone used in the experiment was covered with a black leather sheath. In this way all the participants, and later the specialist psychologist who would perform the attention assessment, would be unaware whether the mobile phone was in 'on' or 'off' mode.

Following this 15-min procedure, the d2 test of attention was applied to both groups by a specialist psychologist, and differences in attention and concentration levels in the intervention group exposed to EMW via mobile and the control group not exposed to EMW since the mobile phone was in 'off' mode were subjected to statistical comparison. The study flow chart is shown in Fig. 1.

2.3.1. The attention evaluation test used in the study – the d2 test of attention [2]

The d2 test of attention measures selective attention and mental concentration in a time-based manner. Other parameters measured are processing speed, rule compliance and quality of performance. The test can be administered to subjects aged 9–60, individually or in groups. The test form contains 14 lines with 47 characters on each line. The letters 'd' and 'p' are used in the test. Up to four small dashes appear beneath, above, or both beneath and above some letters. Based on the dashes beneath and/or above the letters, there are 16 different possible patterns.

The basic task of the subject taking the test is to find all the letters 'd' accompanied by two dashes. The person taking the test is given 20 s to fulfill the task in each line by marking each letter 'd' with two dashes. The test takes approximately 8 min to complete. Evaluation of the test is based on TN, E1, E2, CP, TN-E and FR scores. [TN, the total number of characters marked (reflects psychomotor speed-understanding); E1, the number of characters missed without being marked (reflects selective attention); E2, the number of characters marked incorrectly (reflects special learning difficulty); CP, total number of correct marks; TN-E, difference between the total number of items scanned minus error scores (reflects test performance); FR, the difference between the maximum number of characters marked and the minimum number of characters marked (reflects distractibility)].

2.4. Outcome measures

The primary outcome of our study was to determine whether or not changes in d2 test of attention scores measured at the beginning and end of the study would differ between emergency physicians exposed to EMW and emergency physicians not exposed to EMW.

2.5. Primary data analysis

Internet-based power analysis software (UCSF Biostatistics: Power and sample size programs) was used in calculating the sample size in our study (contact address www.stat.ubc.ca/rollin/stats/ssize/). Mean attention levels of emergency physicians was determined in a preliminary study before EMW exposure, and a sample size was calculated based on a prediction of a 50% decrease in attention level scores of emergency physicians exposed to EMW. Accordingly, we targeted a minimum of 30 participants, 15 in both groups, for 80% power.

The data obtained from the study were recorded onto Windows Excel 2013 software and subjected to statistical analysis on SPSS 23.0 software. Compatibility with normal distribution was analyzed using the Shapiro-Wilk test, and normally distributed data were expressed as mean and standard deviation, while non-normally distributed data were expressed as median and min-max values. Student's *t*-test was used to compare normally distributed constant variables between two groups, while the Mann Whitney *U* test was used for non-normally distributed constant variables. The chi square test was used for categorical variables in comparisons between two groups. The paired *t*-test was used for normally distributed data in comparing initial and final attention scores at repeat measurements in the groups, while the Wilcoxon test was used for non-normally distributed data. $p < 0.05$ was regarded as statistically significant.

3. Results

All emergency physicians working in the emergency department where our study was performed were evaluated ($n = 35$). Five of these were subsequently excluded for various reasons (left hand use $n = 3$; psychiatric medication use $n = 1$; malignancy $n = 1$). Thirty emergency physicians, the minimum target, were thus finally included in the study.

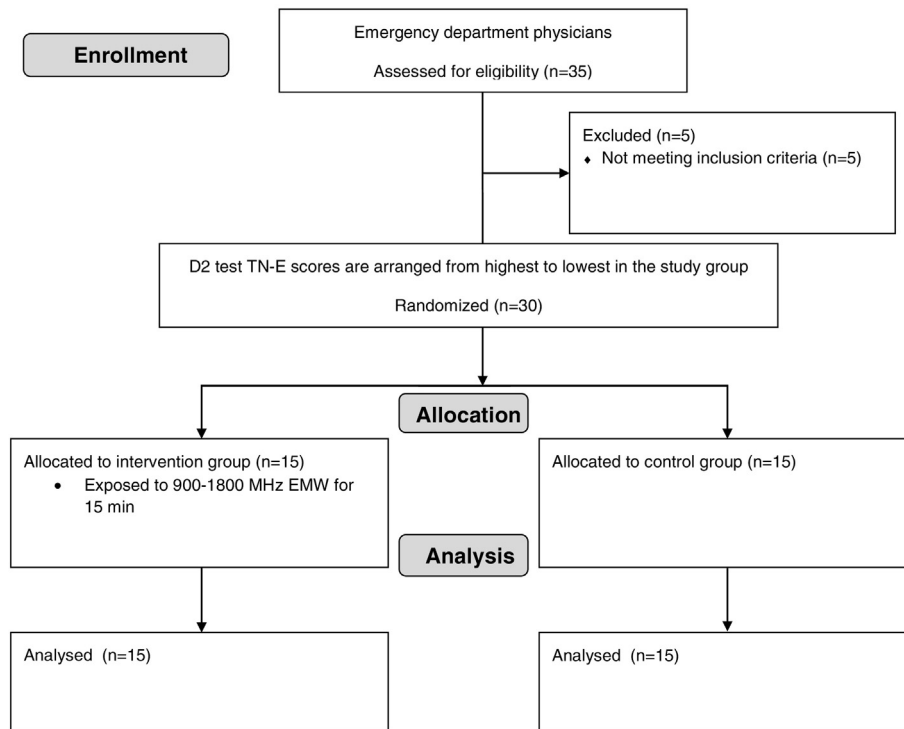


Fig. 1. The study flow chart.

Control and intervention groups were established by randomizing all the physicians included in the study on the basis of their initial TN-E scores (Test performance, total number of items minus error scores) on the d2 test of attention. The basic demographic characteristics of the study groups are shown in Table 1.

Analysis of the control and intervention groups' initial and final d2 tests is shown in Table 2. Although the establishment of the study groups in our study was based on TN-E scores, one component of the d2 test of attention, the groups were constituted with binary randomization using the head and tail method after TN-E scores had been ranked from highest to lowest. Although there was no difference between the two groups in terms of initial scores, a significant difference was determined in some other components of the test (E1: selective

attention, E: focusing level). Accordingly, the initial selective attention of the subjects in the control group was lower than that of the intervention group, while the focusing level was higher than in the intervention group.

There was no difference between the two groups in terms of final values after the d2 test of attention.

According to the initial and final d2 test of attention results in the control group, initial total number of characters marked (TN) and total test performance and percentile (TN-E and PR) increased, while distractibility decreased. In the intervention group, the group exposed to EMW, total number of characteristics marked (TN), number of symbols marked incorrectly (E2), and total test performance and percentile (TN-E and PR) increased.

Table 1
Basic demographic characteristics of the study groups

	Group I-control	Group II-intervention	p value
Age (Mean $\pm$ SD)	32.73 $\pm$ 4.41	33.46 $\pm$ 5.55	0.692
Sex			
Male n, (%)	10, (66.7)	9, (60.0)	1.000
Female n, (%)	5, (33.3)	6, (40.0)	
Marital status			
Married n, (%)	9, (60.0)	10, (66.7)	1.000
Single n, (%)	6, (40.0)	5, (33.3)	
Coffee drinkers n, (%)	2, (13.3)	4, (26.6)	0.651
Tea drinkers n, (%)	15, (100.0)	15, (100.0)	1.000
Smokers n, (%)	8, (53.3)	9, (60.0)	1.000
Number of years using mobile phones (year)	16 (12–18)	15 (9–18)	0.296
Median (min-max)			
Daily mobile phone usage (min/day)	45 (10–60)	30 (15–60)	0.274
Median (min-max)			
Total length of experience as a physician (year)	6.1 $\pm$ 4.2	7.6 $\pm$ 5.9	0.432
Mean $\pm$ SD			
Length of experience as an emergency physician (year)	4.9 $\pm$ 3.5	5.5 $\pm$ 4.4	0.682
Mean $\pm$ SD			
Mean hours worked per month	222.9 $\pm$ 29.8	213.9 $\pm$ 32.4	0.431
Mean $\pm$ SD			

Table 2
Initial and final d2 test scores of the control and intervention groups.

	Group I-control		Group II-intervention		p value
	Initial	Final	Initial	Final	
TNE score (Mean $\pm$ SD)	469.06 $\pm$ 69.30 ^a	510.13 $\pm$ 78.75 ^a	468.80 $\pm$ 64.48 ^b	511.53 $\pm$ 71.89 ^b	a, p < 0.001 b, p = 0.027
E1 score (Mean $\pm$ SD)	32.46 $\pm$ 17.35 ^a	25.33 $\pm$ 19.14	15.80 $\pm$ 9.90 ^a	19.40 $\pm$ 14.23	a, p = 0.003
E2 score (Mean $\pm$ SD)	2.00 (0.00–6.00)	1.00 (0.00–3.00)	0.00 (0.00–4.00) ^a	1.00 (0.00–3.00) ^a	a, p = 0.022
E score (Mean $\pm$ SD)	6.94 $\pm$ 3.23 ^{a,b}	4.92 $\pm$ 3.48 ^b	3.69 $\pm$ 2.49 ^a	3.84 $\pm$ 2.57	a, p = 0.005 b, p = 0.008
TN score (Mean $\pm$ SD)	500.60 $\pm$ 72.24 ^a	536.33 $\pm$ 78.41 ^a	485.26 $\pm$ 63.06 ^b	532.33 $\pm$ 75.19 ^b	a, p = 0.003 b, p = 0.021
PR score (Mean $\pm$ SD)	945.00 (500.00–999.00) ^a	992.00 (579.00–999.00) ^a	945.00 (500.00–999.00) ^b	986.00 (540.00–999.00) ^b	a, p = 0.004 b, p = 0.016
FR score (Mean $\pm$ SD)	7.66 $\pm$ 1.87 ^a	6.33 $\pm$ 1.98 ^a	7.00 $\pm$ 2.39	7.86 $\pm$ 2.66	a, p = 0.029

TN, the total number of characters marked (reflects psychomotor speed-understanding); E1, the number of characters missed without being marked (reflects selective attention); E2, the number of characters marked incorrectly (reflects special learning difficulty); CP, total number of correct marks; TN-E, difference between the total number of items scanned minus error scores (reflects test performance); FR, the difference between the maximum number of characters marked and the minimum number of characters marked (reflects distractibility).

3.1. Main results

The most important endpoint of our study was whether change and difference in d2 test of attention parameters measured initially and at the end of the study would vary between emergency physicians exposed to EMW and emergency physicians not exposed to EMW. Difference in initial and final d2 test of attention parameters is shown in Table 3.

Accordingly, difference in the total number of characters marked (TN) in the initial and final d2 tests, difference between test performances (TN-E), difference in test performance percentiles (PR) and difference in distractibility (FR) were similar between the intervention and control groups. In contrast, significant differences were determined between the groups in terms of difference in the number of characters skipped without being marked (E1 selective attention), difference in number of characters marked incorrectly (E2) and difference in focusing levels (E).

4. Limitations

This research was carried out with data obtained from 30 emergency physicians working at the The Health Sciences University Trabzon Kanuni Training and Research Hospital. The number of participants was therefore relatively low. This research was not carried out with cross over design, which would have been more effective. Data from the d2 test of attention alone were used as an attention measurement tool. However, different findings might be obtained from other tests assessing attention. Data obtained from restriction of exposure to

EMW to 15 min were also used. The effects of longer exposure to EMW on attention could not, therefore, be evaluated. Attention levels were evaluated from data obtained on the assumption that the emergency physicians completed the d2 test of attention honestly. We assumed that the emergency physicians included in the study completed the inclusion and exclusion criteria form prior to the main research in an objective manner, and evaluated the attention levels of the physicians meeting the inclusion criteria, while the attention levels of emergency physicians meeting exclusion criteria were not evaluated. Attention levels were analyzed with data obtained on the assumption that the pre-d2 test of attention physical and psychological status of the emergency physicians would have no positive or adverse effect on the attention test. Attention and concentration are only two aspects of performing as an emergency physician, other parameters measured by neuropsychological testing such as concentration, short term memory, recall of medical knowledge were not assessed. Additionally, there were more coffee drinkers in intervention group which may have explained why the intervention group had improved performance on some tests.

5. Discussion

On the basis of our study findings, the difference between the total number of characters marked (TN) in the initial and final d2 tests of attention, the difference between test performance scores (TN-E, total number of items minus error scores), difference between test performance percentiles (PR) and difference between distractibility (FR) were similar between the control and intervention groups. In addition,

Table 3
Differences between initial and final d2 tests in control and intervention groups

Initial-final d2 test scores	Group I-control	Group II-intervention	p value
TNE difference Median (min-max)	−40 (−101,11)	−66 (−97,171)	0.319
E1 difference (Mean $\pm$ SD)	7.13 $\pm$ 14.30	−3.60 $\pm$ 10.11	0.025
E2 difference (Mean $\pm$ SD)	0.86 $\pm$ 2.23	−0.73 $\pm$ 1.03	0.018
E difference (Mean $\pm$ SD)	2.02 $\pm$ 2.52	−0.15 $\pm$ 2.09	0.016
TN difference Median (min-max)	−31 (−104,42)	−71 (−119,173)	0.177
PR difference Median (min-max)	−24 (−218,39)	−30 (−393,455)	0.619
FR difference (Mean $\pm$ SD)	1.33 $\pm$ 2.12	−0.86 $\pm$ 4.24	0.083

difference in the number of characters skipped without being marked (E1 selective attention), difference in the number of characters incorrectly marked (E2), and difference in focusing levels (E) were better in the intervention group exposed to EMW via mobile phone. To summarize, exposure to EMW via mobile phone had no adverse effect on the attention performance of emergency physicians, who need to make critical decisions rapidly and expertly, while it exhibited a positive effect on some sub-parameters, such as selective attention. From that perspective, we may conclude that telephone use before critical decisions that emergency decisions have to make very rapidly has no deleterious impact on their attention levels.

The d2 test of attention used in our study possesses proven scientific validity. The d2 test has been used to assess attention in several previous studies, and has been widely accepted [3]. The TN and TN-E components of the d2 test indicate psychomotor speed. Psychomotor speed indicates the speed at which the individual converts perception into action, the ability to respond to perception and speed of comprehension. Perception and comprehension of a stimulus and giving a swift and appropriate response are exceedingly important for emergency physicians. This is because vitally important and critical decisions that generally have to be made in a limited time frame by emergency physicians may affect the patient's future in a positive or adverse manner. From that perspective, our study results show that EMW emitted by mobile phones do not have a deleterious effect on psychomotor speed, speed of comprehension or continuity of attention.

E1, another important component of the d2 test of attention, reflects selective attention. A large number of E1-type errors and thus a high E1 score indicate low selective attention. Selective attention involves concentration on one stimulus while ignoring others in the presence of several stimuli. It may also be described as the ability to focus on a desired stimulus or task while resisting distractions [3–5]. Selective attention is therefore of considerable importance for the management of a department exposed to crowding and numerous different stimuli, and to emergency physicians who have to make decisions vital to the lives of several critical patients both rapidly and accurately and to implement numerous life-saving procedures in an expert manner. Based on our study findings, it may be concluded that the mobile phone has no deleterious effect on the selective attention of emergency physicians exposed to EMW through mobile phones, and even increases selective attention.

As the number of mobile phone users increases, the potential health risks involved have also become an important object of focus. Several studies have investigated the probable neurophysiological effects of EMW emitted with signals such as receivers on the central nervous system [6,7]. However, there is still uncertainty concerning which functions of the central nervous system are affected by EMW [8]. There are also inconsistent views regarding the effects of EMW on attention, whether these are adverse or positive, or whether there is no effect at all [9].

In one study, Lee et al. investigated the effect of mobile phones on attention, with participants being exposed to EMW by holding the telephone to their right ears in their right hands. Similarly to our own study, attention levels in the group using mobile phones in 'on' mode increased slightly compared to the control group [8]. Edelstyn et al. investigated the effect of acute exposure to mobile phones on processing speed and touch capacity in the attention system, and concluded that EMW increased processing speed [1]. Koivisto et al. determined that EMWs caused an increase in human wakefulness tests and a shortening in short term memory response times. Based on those findings, they concluded that mobile phones had a positive impact on attention. Although they were unable to fully account for this, they suggested that it might be due to mobile phones causing a local temperature increase in the frontal or parietal cortex [10]. Preece et al. investigated the effects of EMW on cognitive functions and observed a slight shortening in selection and reaction tasks. They therefore suggested that EMW exposure via mobile phones has a positive effect on attention. However,

similarly to Koivisto et al., Preece et al. were also unable to fully explain this effect and suggested it might be caused by a local temperature increase occurring with mobile phone use [11]. Both teams thought that with the antenna of the mobile phones they used being close to the prefrontal cortex, which is responsible for attention, the EMW emitted by the phone gives rise to a temperature increase in the prefrontal cortex, and that attention is positively affected by this. Although the mobile phone employed in our study was applied inside a black leather sheath, it may still be concluded that it established a similar local temperature increase due to being held close to the prefrontal cortex.

In contrast to these studies reporting positive effects on attention from EMW with mobile phones, other research has suggested that mobile phones have no or else deleterious effects on attention. Haarala et al. concluded that EMW had no distinct effect on human cognitive functions and responses [12]. Besset et al. examined neuropsychological categories including information processing, attention capacity, memory function and executive function and showed that EMW had no effect on these four functions [13]. Terao et al. investigated whether high-frequency EMWs emitted by mobile phones would have any impact on choice reaction time and movement time, but determined no significant variations [14]. Russo et al. reported no variation in performance levels obtained during attention tasks [15]. In our study, mobile phone exposure had no significant effects on TN or TN-E components of the d2 test of attention. From that perspective, our findings are similar to these data from the previous literature.

To the best of our knowledge, the only study showing an adverse effect on attention of EMW emitted via cell phone was published by Eliyahu et al. In that study, the authors employed a different attention test, and assessed the spatial recognition, verbal recognition and spatial compatibility tasks as subcomponents of that test, and reported a slowing in reaction times [16]. We observed no adverse effect on attention levels of EMW emitted by mobile phones in emergency physicians we assessed using the d2 test of attention and its subcategories.

Cognitive functions can be considered under the headings of attention, executive functions, visual-mechanical functions, and verbal and non-verbal memory [17]. An effect of EMW on cognitive functions has been reported in some studies, some reporting that mobile phone use has a positive impact on cognitive functions, and others reporting a deleterious effect. However, no logical biological mechanism capable of explaining these effects has been reported [9].

To summarize these data from the literature and our own study, the evidence concerning the effect on attention and cognitive performance of EMW emitted by mobile phones is not definitive, but if there is such an effect, it may be concluded that the effect is positive.

6. Conclusion

On the basis of our study findings, the EMW emitted by mobile phones has no deleterious effect on the attention levels of emergency physicians, and even exhibits a positive effect on selective attention levels. From that perspective, emergency physicians who have to make instantaneous vital decisions in a rapid and accurate manner and perform critical procedures carefully and scrupulously, can use mobile phones prior to these decisions because they have no deleterious impact on attention and concentration levels during them.

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Conflicts of interests statement

The authors declare that they have no significant competing financial, professional or personal interests that might have influenced the performance or presentation of the work described in this manuscript.

Author contributions

GA, DS, ST: substantial contributions to conception and design, acquisition of data, analysis and interpretation of data, drafting the article or revising it critically for important intellectual content and final approval of the version to be published; SA, HY, MI: acquisition of data, interpretation of data, drafting the article or revising it critically for important intellectual content and final approval of the version to be published.

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