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Non-ionization radiation hazard: Effect of mobile phone use on human cognitive functions in data exchange mode

F. Heydari[1], S. Yoosefee[2], P. Khalili[3], F. Ayoobi[4], S.A. Shafiei[5*]

[1]*Qom University of Medical Sciences, Qom, Iran*
[2]*Neuroscience Research Center, Spiritual Health Research Center, Qom University of Medical Sciences, Qom, Iran*
[3]*Social Determinants of Health Research Center, Rafsanjan University of Medical Sciences, Rafsanjan, Iran*
[4]*Occupational Safety and Health Research Center, NICICO, World Safety Organization and Rafsanjan University of Medical Sciences, Rafsanjan, Iran*
[5]*Neuroscience Research Center, Qom University of Medical Sciences, Qom, Iran*

► ***Original article***

Corresponding author:
Seyed Ali Shafiei, Ph.D.,
E-mail: *salishafiei@yahoo.com*

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ABSTRACT

Background: The Cell phones are a major part of people's lives in contemporary societies. Might their radiation be able to affect some cognitive functions while people drive? This study aims to investigate the effect of cell phone radiation on the brain's cognitive functions. ***Materials and Method:*** Forty female students without depression or anxiety volunteered in the cross-sectional study. During one session, the volunteers were randomly exposed to cell phone radiation (20 participants in the first and 20 participants in the second). Participants performed four cognitive tests in each session. A p-value of less than 0.05 was taken as the cut-off point to consider a statistically significant result. ***Results:*** In the congruent part of the Stroop test, the reaction time (RT) was reduced in both groups during the time volunteers were exposed to radiation and there were significant differences between sessions in both groups (P=0.005 and P<0.001). These differences were significant between the two groups in different sessions. However, the number of errors decreased during exposure to radiation and this difference was significant in the first group (P=0.015). In the incongruent part of the Stroop test, the treatment showed that the radiation of mobile phones had a significant effect on the reduction of RT (P<0.001). ***Conclusion:*** Based on this study, it seems that cell phone radiation waves have a limited effect on RT, cognitive and executive function. Therefore, traffic accidents that occur during a mobile phone conversation might be solely due to the division of attention rather than a direct effect of cell phone waves.

INTRODUCTION

Technology development in modern societies has turned the cell phone into an integral part of peoples' lives [1]. Although the expanded use of cell phones is beneficial from a communication point of view, some abrupt biological changes in the human body could be caused by electromagnetic fields [2] . Because of this, numerous studies have explored the impact of electromagnetic radiation, especially on brain function [3].

Some studies have illustrated that brain signals are altered by exposure to the electromagnetic field, even in extremely low frequency and intensity, especially in the frontal regions [4, 5]. Moreover, exposure to electromagnetic radiation may contribute to conflicting results on behavior and cognitive functions [6]. For example, significant effects are sometimes shown on reaction time (RT) and accuracy in contrast to trivial effects on cognitive functions [6] or negative effects on working memory while talking on a cell phone [7] . In a study in 2021, it was shown that long-term exposure to mobile waves decreases memory and performance [8]. In another study, it was shown that mobile waves cause destruction and changes in brain cells and some foods with antioxidants can help prevent the destruction of brain cells [9].

Electromagnetic fields might be able either to increase human error [7] or negatively affect cognitive efficiency [10], RT [11], attention [12] and driving quality as a result of decreasing nerve cells' excitability. Due to the rampant use of cell phones while driving, despite being banned, the effect of radiation on RT and cognitive functions becomes very important. Texting or talking on a cell phone while driving divides the driver's attention which can lead to a disproportionate reaction to external stimuli and increase the risk of accidents. However, what share of the problem belongs to radiation as opposed to conversation is not yet clearly known.

According to the mentioned studies, most of the studies on the effects of mobile phones have been done on different aspects of human attention and cognition, and no study has yet been done on the effect of mobile phone waves on reaction time and

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cognitive functions, especially related to the frontal brain. It was designed to affect mobile waves on special cognitive functions related to the frontal lobe.

MATERIALS AND METHODS

Study population

This study was a randomized crossover single-blind clinical trial among the resident females at the Qom University of Medical Sciences. To begin, 100 surveys were distributed that covered demographic characteristics, along with a depression and anxiety test. Inclusion criteria included being right-handed, living in a dorm (thus eating a similar diet), being female, and having an anxiety score of less than 15 and a depression score of less than 17 based on the Beck Depression Inventory survey. In this study, 40 participants were selected according to the entry criteria. Exclusion criteria included heavy exercise, night shifts, and stimulant agents such as coffee, drugs, and a high-protein diet, at least the night before coming to the lab. Moreover, participants were told not to have a long conversation on a cell phone for at least one hour before the tests, and to ask researchers for a substitute if they were menstruating. The Ethics Committee of Qom University of Medical Sciences granted approval for this study (ID: IR.QUMS.REC.1396.52; Date: 2017/08/01).

Instruments

In this study, an Iranian-made cell phone called Maad + model GLX was utilized. The SAR The specific absorption rate (SAR) and maximum power value of this phone were 0.253 W/kg and 2W respectively. To place the mobile phone on the participants' heads, we used a homemade device (figure 1).



Figure 1. The device used to place a mobile phone on the heads of participants. Connecting the headphones to the mobile phone caused the sound to mute.

Data collection

To evaluate any variations between the two groups (test Group 1 and control Group 2), the standard 2×2 crossover design was employed. Each participant was randomly assigned to either an AB sequence or a BA sequence. Those in the AB sequence were administered treatment A during Period 1 and Treatment B during Period 2. The standard 2×2 crossover design, illustrated in figure 2, served as the model for this study. Participants were exposed to cellphone radiation at one of the sessions, 20 in Group 1 and 20 in Group 2. There was a minimum of one day between the two sessions. The time spent in both sessions was the same for each group. Participants sat on comfortable chairs and cell phones were placed over their left ears. The call from outside the lab was made by another cell phone that was playing a song to send a signal. Silicone mufflers and headphones were utilized to reduce the distracting effect of the music. Therefore, the connection and exchange of information between the two cell phones were not recognizable by participants. After five minutes of exposure to cell phone radiation, all cognitive tests were performed, while the phone call continued during the tests. During the control session, all tests were performed but there was no call from a cell phone outside the lab.

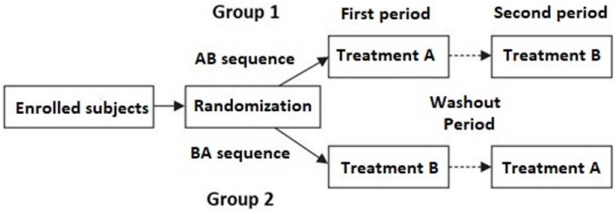


Figure 2. Two-period, two-sequence crossover design.

Cognitive tests

Reaction time test (RTT)

The PEBL Psychomotor Vigilance Test (PPVT) was used to measure the RT. In this test, Participants sat in front of their black-screen computers and pressed the space key immediately after seeing a red point. The time between the appearance of a red point and the pressing of the key was measured by the software. The test consisted of 50 trials, and two red points appeared at completely random time intervals for each trial. The time intervals ranged between 400 and 1000 milliseconds [13].

Stroop test

The Stroop test aimed to evaluate selective attention and cognitive flexibility. The test involved displaying stimuli in red, yellow, green, or blue on a computer screen, while also recording reaction times (RT). Participants went through a practice block and two test blocks, where their main task was to identify the color in which a stimulus appeared by pressing the corresponding button. Stimuli could be congruent, meaning the stimulus name matched the color it appeared in (e.g., "RED" written in red), or incongruent, where the stimulus name differed from the color it appeared in (e.g., "YELLOW" written in blue). The number of errors and RT was measured by the software [14].

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Wisconsin Card Sorting Test

The Wisconsin Card Sorting Test (WCST) or BCST (in PEBL) involved a deck of 64 cards with distinct symbols—triangles, stars, crosses, and circles-embossed in red, green, yellow, and blue. Each card was unique. Participants had to place the cards one by one, considering the feedback (correct or incorrect) they received based on a rule (e.g., R rule). The test assessed attention, working memory, executive functioning, and visual processing. This study analyzed five indices: 1) the number of categories completed (CC); 2) the number of perseverative errors (PE); 3) the number of non-perseverative errors (NPE); 4) trials required to complete the first category (trial 1st); and 5) failure to maintain the set (failure) [15].

Time Wall Test

The Time Wall Test (TWT) was used to measure the perception of time. Participants estimated when a hidden moving object reached a target point. The test consisted of 20 points moving at different speeds landing on the screen at intervals of two to 10 seconds. The points disappear behind a red wall after a certain distance. Participants followed the point through their minds and then pressed a defined key after attempting to place the point in the correct position. Comparing participants' recorded time to the correct time was done through the software. The results were shared with participants in three sentences: Too short, Too Long and Great. If the error rate was less than 5%, the phrase excellent appeared on the screen [13].

Statistical analysis

The data were analyzed employing the conventional approach for an AB/BA crossover trial. For data entry and analysis, the group that was exposed to radiation at the first session (Period 1) was labeled as Group 1 and those exposed to radiation at the second session (Period 2) was labeled as Group 2. Mean and standard deviation were utilized to depict the data. Significant baseline characteristics among participants across groups were compared using the independent t-test for numerical variables. The baseline characteristics compared were age, BMI, depression and anxiety. Independent t-tests were used to evaluate differences between groups in each session, and paired t-tests were used to evaluate differences between sessions in each group. The statistical analysis for the cross-over trial was conducted using the Pkcross package analysis within Stata software version 14 (Stata Corp, College Station, TX, USA). The assessment involved evaluating the overall mean, treatment effects, and period effects. A p-value below 0.05 was considered the threshold for determining a statistically significant result.

RESULT

Demographic Characteristics of Participants

The average age of participants in Group 1 was 21.25 years old, while the mean age for Group 2 was approximately similar at 21.95 years old. The body mass index (BMI) of participants was comparable between both groups, with Group 1 having a BMI of 22.90 and Group 2 having a BMI of 22.32. Analysis comparing the two groups revealed no significant disparities in terms of age, BMI, depression, and anxiety, as indicated in table 1.

Table 1. Comparison of baseline participants' characteristics between groups.

Variables	Group 1 (n=20) Mean± SD	Group2 (n=20) Mean± SD	P-value
Age (years)	21.25±1.45	21.95±6.67	0.272
BMI	22.90±3.59	22.32±2.75	0.568
Depression score	6.90±5.82	7.55±4.17	0.687
Anxiety score	6.85±4.42	8.70±3.85	0.166

Abbreviation: Body Mass Index (BMI)

Reaction Time Test

An analysis was conducted to examine the Reaction Time Test (RTT) between the two groups based on the treatment period. The results indicated that the mean differences in RT between the two groups during Period 1 (P=0.588) and Period 2 (P=0.878) were not statistically significant. However, there was a significant difference between Group 1 and Group 2 when comparing Period 1 and Period 2 (P<0.001 and P=0.002, respectively) as shown in table 2. Additional analysis using the Pkcross package in Stata is presented in table 3. Looking at the effect of radiation, there was some period effect (P=0.006) in the RTT, but it was statistically insignificant (P=0.78).

Stroop test

The Stroop test consisted of two parts-congruent and incongruent. In each part the criteria of RT and the number of errors were measured.

In the congruent part, the RT was reduced in both groups during exposure to cell phone radiation and there were significant differences between Period 1 and Period 2 in both groups (P=0.005 and P<0.001, respectively). These differences were significant between the two groups in Period 1 (P=0.01) and Period 2 (P<0.001). The number of errors decreased during exposure to cell phone radiation for both Period 1, Group 1 and Period 2, Group 2, but the difference was significant only in Group 1 (P=0.015). There was no significant difference in the number of errors between the two groups, as shown in Table 2. Radiation of mobile phones had a significant effect on RT (p=0.001) (table 3).

In the incongruent part, RT decreased in both groups during exposure to cell phone radiation and

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was significant (P<0.001). The statistical analysis demonstrated a significant difference between the two groups during Period 1 (P=0.002). The number of errors in both groups decreased during exposure periods but was not significant (table 2). Cell phone radiation showed a significant effect on the reduction of RT (P=0.003) (table 3).

Table 2. Comparison of cognitive function between and within groups according to treatment period by crossover analyses.

Variable	Group1 (n=20)			Group 2 (n=20)			Between two groups	
	Treatment Period 1	Treatment Period 2	p-value	Treatment Period 1	Treatment Period 2	p-value	p-value (Period 1)	p-value (Period 2)
Reaction time test								
RT (ms)	399.51±29.29	377.58±32.87	<0.001*	393.99±34.36	376.07±28.48	0.002*	0.588	0.878
Stroop test congruent								
RT (ms)	1138.32±133.74	1207.19±130.67	0.005*	999.50±184.06	847.27±112.19	<0.001*	0.01*	<0.001*
Number of errors	2.45±2.26	4.20±3.30	0.015*	4.70±4.99	3.95±4.50	0.204	0.078	0.842
Stroop test incongruent								
RT (ms)	932.39±113.06	1024.23±96.73	<0.001*	1131.47±237.53	994.26±173.54	<0.001*	0.002*	0.505
Number of errors	3.90±4.93	4.25±4.34	0.531	4.30±4.19	2.70±3.18	0.21	0.784	0.205
WCST								
CC	50.85±5.90	53.25±2.88	0.041*	52.45±3.20	53.90±2.77	0.107	0.293	0.472
PE	6.40±2.64	6.15±1.46	0.691	6.30±1.26	5.85±1.46	0.317	0.879	0.520
NPE	6.75±7.05	4.60±3.07	0.104	5.25±3.24	4.25±2.49	0.210	0.393	0.694
Trial 1st	12.45±5.36	12.95±3.86	0.766	13.20±5.00	13.20±4.70	1.00	0.650	0.855
Failure	0.4±0.60	0.35±0.49	0.716	0.35±0.67	0.55±0.69	0.359	0.805	0.296
Time Wall test								
RT (ms)	6.69±2.33	5.12±1.17	0.001*	6.90±3.89	5.20±1.37	0.063	0.831	0.843
Minimum RT(ms)	7.03±3.09	4.97±1.24	0.004*	7.29±3.86	5.17±1.40	0.019*	0.811	0.631
Maximum RT(ms)	6.35±2.14	5.19±1.89	0.003*	6.49±4.37	5.19±1.70	0.200	0.893	0.993

Abbreviations: Wisconsin Card Sorting Test (WCST); the number of categories completed (CC); the number of perseverative errors (PE); the number of non-perseverative errors (NPE); trials to complete the first category (trial 1st); failure to maintain set (failure); and Reaction time (RT). * P-value <0.05

Table 3. Effects of intervention, its period effect and period-by-treatment interaction on the cognitive function in reporting.

Variables		Mean Squares	F-Statistics	P-Value
Reaction time test				
RT (ms)	Treatment effect	80.39	0.08	0.78
	Period effect	7940.40	8.08	0.006*
Stroop test congruent				
RT (ms)	Treatment effect	244437.70	12.01	0.001*
	Period effect	34742.69	1.71	0.195
Number of errors	Treatment effect	31.25	2.04	0.157
	Period effect	5.00	0.33	0.569
Stroop test incongruent				
RT (ms)	Treatment effect	262313.61	9.65	0.003*
	Period effect	10287.68	0.38	0.540
Number of errors	Treatment effect	19.01	1.07	0.303
	Period effect	7.81	0.44	0.509
WCST				
CC	Treatment effect	4.51	0.30	0.588
	Period effect	74.11	4.89	0.03*
PE	Treatment effect	0.20	0.06	0.804
	Period effect	2.45	0.76	0.385
NPE	Treatment effect	6.61	0.35	0.556
	Period effect	49.61	2.62	0.11
Trial 1st	Treatment effect	1.25	0.06	0.815
	Period effect	1.25	0.06	0.815
Failure	Treatment effect	0.31	0.82	0.367
	Period effect	0.11	0.30	0.588
Time Wall test				
RT (ms)	Treatment effect	0.09	0.02	0.900
	Period effect	53.51	8.97	0.003*
Minimum RT (ms)	Treatment effect	0.02	0.00	0.958
	Period effect	87.78	12.56	0.001*
Maximum RT (ms)	Treatment effect	0.12	0.02	0.902
	Period effect	30.17	4.01	0.049

Abbreviations: Wisconsin Card Sorting Test (WCST); the number of categories completed (CC); the number of perseverative errors (PE); the number of non-perseverative errors (NPE); trials to complete the first category (trial 1st); failure to maintain set (failure); and Reaction time (RT). * P-value <0.05** carry-over effect, also known as a treatment – period interaction

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Wisconsin Card Sorting Test

The analysis focused on several parameters in the Wisconsin Card Sorting Test (WCST), including the number of categories completed (CC), the number of perseverative errors (PE), the number of non-perseverative errors (NPE), trials to complete the first category (trial 1st), and failure to maintain set (failure). Results showed CC in the exposure period in Group 1 was reduced and it was significant (P=0.041). There was a period effect observed in the number of CC with a significant p-value of 0.030. However, the treatment effect was found to be insignificant, as indicated in table 3. In terms of other indices, both between and within groups, no significant differences were observed, as demonstrated in tables 2 and 3.

Time Wall Test

In the Time Wall Test (TWT) three variables were measured—RT, minimum and maximum RT. The results showed that the RT in Group 1 increased during the treatment period (Period 1), and this increase was also observed in the minimum and maximum RTs, which were all significant (P=0.001, P=0.004 and P=0.003 respectively). On the other hand, the minimum RT in Group 2 was lower in the exposure period (period 2) than in the control period (Period 1) (P=0.019). In the comparison between the groups, there was no significant difference in the measured criteria in this test (table 2). There was a significant period effect in RT (P=0.003) and minimum RT (P=0.001), but the treatment effect and was insignificant (table 3).

DISCUSSION

Mobile phones are one more essential device in people's modern lives and may have problematic effects on some activities related to cognitive functions of the brain, such as driving, due to radiation. In this study we investigated the effect of cell phone radiation on cognitive functions, especially related to the brain's frontal area in 40 female students living in a college dormitory. Cognitive performance was evaluated by five tests during mobile phone exposure. The findings showed that mobile waves significantly increased RT during the period of exposure and decreased the mean response time and number of errors in both congruent and incongruent Stroop tests (table 2). The results obtained were consistent with the research outcomes of Corbacio *et al*. [16]. In some other studies, the electromagnetic waves [17, 18] or magnetic fields [19, 20] did not effect on the Stroop test, so the results were weaker in more exposed people [20]. The reasons for the inconsistent results may be factors such as the type of electromagnetic fields, the time of exposure, and the performance of cognitive tests after or during exposure [16]. In this study, half of the participants were exposed to mobile waves in the first session and the other half in the second, so the cause of this significant difference was not due to the effect of practice (table 3).

Improved results in the Stroop test may be related to executive performance [21]. This improvement was also observed in the time perception test during the exposure period compared to the non-exposure period in the two groups. Furthermore, radiation may improve working memory because the number of errors in the Stroop test during the exposure period was significantly less than during the non-exposure period in the two groups. According to the WCST, the cognitive function of the frontal brain area was not significantly changed, which can be challenging [22].

Ayoobi *et al*. reported that the mean RT and minimum RT of female participants were significantly decreased by exposure to the magnetic field [11]. Our study confirmed this result. In their study [11], the stimulus appeared between 2 and 12 seconds, while in the current study, the stimulus was less than one second (400-1000ms), As a result, the short interval of the stimuli may have increased attention and alertness in the present study because the mean reaction time (258±57) was significantly lower than in the study by Ayoobi *et al*. (282.5±52). In the assessments of the Extremely Low Frequency-Magnetic Field (ELF-MF) effect on cognitive function that the gender of the participants was not taken into account, these waves had no significant effects on cognitive functions [6, 23].

Many studies found that mobile phone waves with higher frequency than ELF-MF had no effect on the RT which was not consistent with this study [24-29]. An instance of this can be seen in the study conducted by Haarala *et al*., who examined the impact of mobile phone waves on the neurological functions of 32 children between the ages of 10 and 14. Their findings revealed that there was no notable effect on reaction time (RT) and cognitive performance, indicating that the mobile phone waves did not significantly influence these aspects in the children [24]. However, some researchers reported significant effects on RT [10, 12, 30, 31]. The TWT examined the mean response time, minimum and maximum response time. The result showed better performance in the mobile phone exposure session in Group 1. The finding of this study was consistent with studies that used time perception in cognitive function assessment [29, 32].

The WCST was used to measure the frontal lobe performance, working memory and attention [22]. Some studies showed a slight decrease in the number of correct answers in WCST in participants' exposure to electromagnetic fields [33-35]. Negative effects of mobile phone waves on memory, attention and concentration were reported in people who used mobile phones for a longer period of time [20].

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These results were consistent with ours, while other studies showed no effect on attention and working memory [6, 32].

Reduced neuronal cell excitability, changes in some brain signal bands or high activity of alpha and beta waves during exposure to magnetic fields are some possible physiological effects [7, 36, 37]. However, they seem to have no major effect on cognitive processes and do not change behavior [38, 39]. For example, the electroencephalography (EEG) alpha power of the participants was reduced by the radiation of mobile phones, while their cognitive performance in the Stroop test did not change [17]. These effects might be too subtle to be accurately detected using the currently available cognitive tests [40]. In our study, the participants' cognitive performance was evaluated during cell phone radiation, so cognitive changes after exposure were not included.

According to the results of our study, mobile waves do not have a direct negative effect on cognitive performance, so the increase in the risk of accidents while using a mobile phone was probably due to insufficient attention on driving [41, 42]. There seems to be no contribution from mobile phone waves in traffic accidents. Using hands-free cell phones did not reduce the risk of accidents or improve the reaction time of drivers [43, 44], which confirms the validity of our theory about the lack of direct effect of mobile waves on reducing cognitive performance and increasing the risk of traffic accidents [45].

CONCLUSION

Based on this study, it seems that cell phone waves have a limited effect on RT, cognitive and executive function. Therefore, the increase in traffic accidents while using mobile phones may be due to a decrease in driver attention. Understanding the relationship between cell phone radiation exposure and cognition, rationalizes the fear of radiation and directs attention to effective risk factors.

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***Ethics approval*:** This study received approval from the ethics committee of Qom University of Medical Sciences, indicated by the ethical codes ID: IR.QUMS.REC.1396.52; Date: 2017/08/01. Participants willingly contributed to the study after giving written informed consent. The privacy of participants' data was meticulously safeguarded, maintaining strict confidentiality, and limiting access solely to the study investigators.

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***Author contribution*:** SA.S. designed the study and contributed to extraction and analysis, data interpretation, and manuscript editing. P.A. analyzed interpreted and improved the discussion section. S.Y. and F.H. performed the experiments. F.A. wrote the manuscript and edited the final version of the manuscript. All authors have read and approved the published version of the manuscript.

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