Effect of Mobile Phone Electromagnetic Field on Non-spatial Working Memory

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The MP-EMF effect on human cerebral function' which belongs to Southeast University

Abstract: As the number of mobile phones (MP) usage grows exponentially, more and more researchers have focused on the effect of electromagnetic field (EMF) radiated by MP on humans. So far several studies concerning the effect of MP-EMF (mobile phone electromagnetic field) on human brains have been published, and they have led to various results. While very few of them have studied the influence of MP-EMF on color-related working memory (WM) during different WM periods. Our current study investigates the effect of the MP-EMF on non-spatial WM between central executive (CE) and one of its sub-systems visual-spatial sketchpad (VS) utilizing eleven focal colors and a GSM-like mobile phone. A total of 15 physical and mental health subjects (five of them were female) performed the WM task under three MP conditions: close status (shutdown status, MP was turned off), standby status (MP was turned on and kept in the idle state) and corresponding status (connected status, MP was kept in the state of call connection). The result shows that there are no significant behavioral differences among the varying conditions of MP-EMF. However, several ERP (Event-related Potential) components are significantly changed under different levels of MP-EMF. During the recollection period, the increasing amplitude of ERP components in frontal, parietal and occipital cortexes indicates that it may cost more cerebral resource for us to complete working memory task while using mobile phones (under the corresponding condition). This interesting discovery will be helpful for future studies about working memory and color-related cognition.

Key words: cell phones; GSM; ERP; focal colors; visual information

Introduction

With the development of mobile telecommunication networks, people's daily life has been significantly influenced by mobile phones more greatly than any other time in history. According to the investigation of the International Telecommunications Union (ITU), the estimated number of cellphone subscriptions worldwide reached 5.28 billion at the end of 2010 [ITU, 2011]. In particular, the effect of EMF on human beings has become the most concerned issues for MP users. The study of Gandhi points out that nearly 40 to 55 percent of EMF energy is absorbed by users' brains.[Gandhi, 2002]

Working memory (WM) refers to a special cognitive system that maintains and stores information to support human cognition processes [Baddeley and Hitch, 1974; Baddeley et al., 1988, 1996] and could be considered as "a workbench of cognition"[Klatzky, 1980]. At the same time, many exclusive cerebral functions such as general reasoning skills also depend on WM.[Kyllonen and Christal, 1990] WM is a multi-system consisting of three functional parts: one of them is the "central executive" (CE), the other two are the "phonological loop (PL)" and the "visual sketchpad (VS)". CE controls these two subsystems (PL and VS) and distributes cerebral resources to them. PL processes verbal and linguistic information, while VS handles the information obtained by our visual system. Additionally, some researches[Baddeley, 2000] suggested that there is another subsidiary system called episodic buffer which is related to the long-term memory.

The whole procedure of working memory associates with several cerebral cortexes. Several studies have shown that spatial and non-spatial WM are dissociable and associate with frontal, parietal and occipital regions. [Vergauwe et al., 2009]. Some other studies proved that CE is implemented by Pre-frontal Cortex (PFC) and the storage procedure of WM could be dissociated. [Fuster, 1989; Carpenter et al., 1990]. It is also proved that visual information associated with

parietal lobes and damage of occipital lobe would lead to visual impairment.[Hanley et al., 1991] Recently, the cognitive research of nine girls (11-13 years old) indicated that spatial (e.g., location) and non-spatial (e.g., colors) information were processed differently both in visual attention and working memory tasks. [Vuontela et al., 2009] However, these subjects were too young to have a sturdy cognitive function and the gender radio was not counterbalanced.

MP influence could also change the brain activity recorded by EEG (electroencephalogram) recorder on the scalp and it is supported by several published studies. After several minutes of exposure, there will be a significant increase of spectral power in fast alpha, slow/fast beta, and delta rhythm.[Reiser et al., 1995; Huber et al., 2002; Curcio et al., 2005] During the past decades, many studies have focused on MP influence on cerebral cognitive functions. There were some alterations of EEG oscillatory responses around 6-8 Hz and 8-10 Hz while the subjects doing the visual and auditory working memory tasks. [Krause et al., 2000a, 2000b] Hamblin et al. found that amplitude and latency of N100 decreased and amplitude of P300 increased with the exposure of MP.[Hamblin et al., 2004] However, he could not replicate the previous positive findings with a larger group of subjects.[Hamblin et al., 2006] The research which investigated the effect of EMF (GSM and Universal Mobile Telecommunications System, UMTS) on visual and auditory evoked potentials with an oddball task showed that there were not any significant changes of them.[Kleinlogel et al., 2008] The same result applies to the research on 3G mobile phones.[Stefanics et al., 2008] In a research related to daily EMF, the experiment period was divided into three parts: baseline, exposing and recovery period. No significant difference was found with or without EMF exposure.[Besset et al., 2005] In a memory load experiment, MP-EMF accelerates the response times when the memory load is three items, however, the same result could

not be found for the rest period.[Koivisto et al., 2000] It is claimed that the EMF effect on the EEG might be variable and could not be easily replicated for unknown reasons such as individual difference.[Daneman and Carpenter, 1980; Krause et al., 2006]

So far, due to our limited knowledge, few researches have been carried out to study the MP-EMF effect on visual information WM processing especially on color materials. Our experiment concentrates on color recognition which is one of the most important factors for visual information working memory, and we attempt to explore the MP-EMF effect on it. Our study aimed at investigating the influence of EMF produced by GSM-900 exposure on non-spatial working memory especially for color materials. Both behavior and ERP results are analyzed and discussed among three MP conditions (close, standby and corresponding).

Materials and Methods

Participants

Our experimental available group contains fifteen college students (aged 19 to 24, mean 22.5, 5 female, from southeast university, Nanjing, China) who were psychiatrically and medically healthy. In order to improve the precision of the result, we arranged each subject to participate the experiment at a fixed time of day (9:30 am). The protocol of the study was approved by the Research Center for Learning Science Key Laboratory of Child Development and Learning Science of Ministry of Education of Nanjing China. In order to maintain the consistency of our research, all subjects were asked to copy the test pictures in their mind and avoid using verbal information to complete the task (We had inquired the strategy of each subject after they finished all the tasks. The one who tried to use verbal information would not be included into the available group). The accuracy for each subject should be up to 75 percent, or he/she would be selected out.

Experiment devices and Exposure condition

The experimental mobile phone was Nokia 5200 (NOKIA (China) INVESTMENT CO., LTD. Pulse modulated at 217 Hz, 903.85 MHz output) and the only modification was the removal of audio transducer. At the beginning of the experiment, all the functions of the mobile phone were turned to mute model. The exposure details were detected and analyzed with the help of Electromagnetic radiation spectrum analyzer (Aaronia HF-60105, German Aaronia Inc.). The environmental EMF average power was -40 dBm and could be also regarded as the power set for the close condition (power off). Compare to this, while the mobile was under corresponding condition, the power will increase to 10dBm which suggested that MP-EMF has a main effect on corresponding conditions. Measurements and computational modeling of specific absorption rate (SAR) were conducted and result is shown in Table 1(σ=0.97 S/m, ρ=1.06 g/cm^3).

In our current experiment, we try to simulate the daily MP process to make the result more helpful for daily life. At the beginning of the experiment, the experimental MP would be completely charged and settled on the subject's right ear with the help of a specific hanging-earphone (Fig.1.A). During the exposure period, all functions of the experiment MP were turned to mute model to avoid acoustic disturbance. The EEG signal is recorded by NeuroScan1.0 device (NeuroScan Inc. Herndon, Virginia, USA) which has 64-channel Quick-cap with Ag/AgCl electrodes according to international 10-20 system.[Chatrian et al., 1988] The electrode impedances were kept below 5 kohm all the time during the experiment (they had been checked during every break). An analog band-pass filter ranging from 0.16 Hz to 150 Hz is applied for recording. The sampling rate is 500 Hz. The visual stimulation program is designed using E-prime 1.0 (Psychology Software Tools, Inc.).

Auxiliary equipment (Fig.2) consists of a Single Chip Micyoco (SCM) system which was controlled by E-prime to alternate MP’s condition without arouse subjects’ attention and a LCD

screen to show the current condition of the experiment MP. The EEG participants were seated 100 cm in front of a Dell 22-in. Cathode Ray Tube (CRT) display (screen resolution: 1024×768, refresh rate: 120 Hz, color quality: highest 32 bit).

Design of the experiment

We chose color pictures as the experimental materials to investigate the MP-EMF effect on non-spatial working memory. In order to enlarge the discrepancy among different MP-EMF conditions, subjects were asked to remember six colors in a trial, because human could only successfully capture 3-4 colors in visual working memory at one time.[Luck and Vogel, 1997]

Eleven colors (yellow, white, black, purple, blue, green, orange, red, pink, brown, and gray) which have the same gradation (1) and saturation (0.5) are selected in the whole experiment. These basic and salient colors are known as focal colors which can be remembered accurately than non-focal colors.[Regier et al., 2005] The details of one trial are shown as Fig.1.C. At the beginning of our experiment, the screen showed six different pure color-pictures (train pictures) and it lasted 1.5 s. During that period, subjects should try their best to copy the screen in their mind. And then, 500 ms rest was supplied. After another attention point, a single color picture (test picture) appeared. During the experiment, subjects should try to recollect the training pictures which were copied before and decide whether this test picture had presented in the six-picture screen or not. At the same time, the subjects should give their responses through keyboard (Press ‘A’, if the test picture had been appeared in the train pictures. Press ‘L’ if not.). Keyboard reactions (left and right) had already been counterbalanced (Half of the subjects will press ‘A’ if the answers is ‘Yes’, the other part is ‘L’.).

Data analysis

For ERP analysis, all the data were EOG (Electro-Oculogram) corrected, and they were epoched from -0.3 s pre-stimulus to 1 s post-stimulus. After that, epochs with voltage exceeding 80 μV or below -80 μV would be rejected. Then the epochs were baseline corrected for 0.3 s pre-stimulus period and then the signal went through a band-pass filter (0-30 Hz) with zero phase shifts. The accepted target trial number was above 50.

Many WM studies have proved that CE is implemented by frontal region, and visual information is processed by parietal and occipital lobe.[Fuster, 1989; Carpenter et al., 1990; Hanley et al., 1991; Pisella et al., 2004] In this experiment, we focus on three important cortex areas: frontal, parietal and occipital cortex (FC, PC and OC) which represented by Fz, Cz, POz. (Fig.1.B). The Positron Emission tomography (PET) experiment done by some researchers[Smith and Jonides, 1999] has proved that WM consists of a phonological store and a rehearsal mechanism are independent with each other. As for the non-spatial visual information, WM could also be separated into two parts: storage period (input period) and recollection period (output period) (it was supported by the experimental result). All data was analyzed with three-way repeated-measures ANOVA (ANOVA of PERIOD [storage vs. recollection] ×CONDITION [shutdown status vs. standby status vs. connected status]×ELECTRODE [Fz vs. Cz vs. POz]) Greenhouse-Geisser correction of the degrees of freedom was applied and where appropriate and P-value will be regarded as significant when it was above 0.05. The software we used in the experiment was SPSS statistical package 16.0 (SPSS. Inc.).

Result

Behavioral result

To make a counterbalance, all condition sequences were assembled by computer. Subjects were asked to guess the present MP-condition before the coming experiment. The accuracy for this speculation was 0.389 (approximate to 1/3) which guaranteed that subjects did not know the condition sequence before the experiment. After calculating the accuracy and RT for each subject, we can see from Table 2 that MP-EMF has no effect on WM behavior among different conditions (P-value> 0.05).

ERP result

Period Separation

Results of ANOVA analysis are listed in Table 3 and the Grand-Average ERPs is shown in Fig. 3. During 200-300 ms, the main effect of the PERIOD factor was observed as marginally significant ($F(1, 14)=3.375$, $p=0.088$). The interaction PERIOD×ELECTRODE was also significant ($F(2, 28) =18.702$, $p<0.001$) and that of PERIOD×CONDITION could be considered as marginally significant ($F(2,28)=2.743$, $p=0.082$). Simple effect test showed that PERIOD factor was significantly different at Cz ($F(2,28)=9.44$, $p=0.008$) and Fz ($F(2,28)=7.42$, $p=0.016$) or under the condition of corresponding ($F(2,28)=7.22$, $p=0.018$). When the time window is 50-80 ms, the PERIOD×CONDITION interaction has the significant result ($F(2,28)=3.587$, $p=0.044$) especially when the MP condition was close ($F(2,28)=10.4$, $p=0.006$). However, no significant result was observed for the main effect of PERIOD and interaction between PERIOD and ELECTORDE. The above results suggest that color information WM procedure may be separated into two parts: storage and recollection.

MP-EMF effect

Focus on the storage period, we selected three time windows: 50-100 ms, 70-170 ms and 200-300 ms. However, none of them existed significant difference. For the recollection period, we also chose and analyzed three time windows: 50-100 ms, 100-150 ms, and 200-300 ms. The results are shown in Table 4 and Fig. 4.

During 50-100 ms, both CONDITION ($F(2,28) = 2.707$, $p=0.087$, marginally significant) and ELECTRODE ($F(2,28) = 4.482$, $p=0.044$) have main effect respectively and no interaction effect could be observed. During 100-150 ms, a marginally significant ELECTRODE×CONDITION interaction ($F(2, 28) = 2.53$, $p=0.084$) could be found. And the Simple effect test showed that the ELECTRODE factor under standby condition and the CONDITION factor at Fz had simple effect respectively. When it comes to the period 210-280 ms, both ELECTRODE ($F(2, 28) = 7.653$, $p=0.008$) and CONDITION ($F(2,28) = 4.518$, $p=0.023$) had main effect, and the ELECTRODE× CONDITION interaction was also marginally significant ($F(2,28) = 2.284$, $p=0.087$).After simple effect test, we could find that ELECTORDE factor in all conditions had the significant simple effect. (ELECTORDE within close condition ($F(2,28) = 6.65$, $p=0.004$); ELECTORDE within standby condition [$F(2,28) = 5.17$, $p=0.012$]; ELECTORDE within corresponding condition [$F(2,28) = 10.6$, $p=0.001$]). These results show that the corresponding condition has a higher effect on all the electrodes. At Fz ($F(2,28) = 6.41$, $p=0.005$) and Cz ($F(2,28) = 3.85$, $p=0.033$), three MP conditions had significant effect. The Pair wise comparison analysis revealed that when the corresponding condition made the amplitude of ERP higher (Corresponding>close>standby).

Discussion

The design of our current experiment obeys all the four criterions proposed by Valentini (we had provided a blind, random task design and exposure information details. unbiased statistical analyses could be seen in the Result Section) [Valentini et al., 2007]

We have investigated the influence of EMF given by MP on working memory system especially for colors. The behavior result in our experiment indicates that MP-EMF has no influential effect on the behavior of our memory which means that our memory will not be promoted or weakened because of our mobile phone usages.

However, the ERP analysis supports an interesting result that MP-EMF does affect our working memory ERP components. In the early period (50-80 ms), PERIOD also has an obviously interaction with CONDITION which may indicate that these two procedures (storage and recollection) could be separated depend on MP conditions. Storage and recollection could be observed significantly different during 200-300 ms. During the same period, PERIOD factor also has significant interaction effects with CONDITION and ELETRODES factors respectively. Based the analysis above, we could reasonable assumed that during 200-300 ms, the procedure of our color-related working memory could be separated into two parts: storage and recollection.

After we separately analyzed these two procedures, we could find that MP-EMF may have more effect on the recollection procedure than storage. The main effect of CONDITION factor is significant during 200-300 ms ($p=0.023$) and 50-100 ms ($p=0.087$, marginally significant) which means that MP-EMF does influence the recollection procedure in these two periods. Different brain regions will also be affected by MP-EMF differently. For the recollection period, ELECTRODE has

main effect during 50-100 ms (p=0.044) and 210-280 ms (p=0.008). Both in 100-150 ms period and 200-300 ms period, the interaction effect between CONDITION and ELECTRODE are obvious. During 200-300 ms, compare to parietal and occipital lobes, frontal lobes will be influenced by different MP conditions. During the same period, affection given by corresponding condition on different brain regions will be more significant than the other conditions (Corresponding>Close>Standby). It may make us believe that, during 200-300 ms in recollection period, MP-EMF will influence our cerebral function in a great extent. On the other side, for the storage period, we could not find any evidence to prove that MP-EMF has influence on this procedure.

Similar to the previous experiments, MP-EMF did not affect color memory behavior both in accuracy and respond time. However, as we have used color as our visual stimulating materials, the ERP result of our current study could not be in consistent with previous studies. [Hamblin et al., 2004; Kleinlogel et al., 2008; Stefanics et al., 2008] Most importantly, compare to the previous studies, we have found in Fig.4 and Table 5 that the amplitude of ERP signal is obviously larger under the corresponding condition during the recollection period than the other two conditions. We may rational believe that the corresponding condition will lead our brain to spend more resource while we are trying to recollect some visual information. However, our experiment cannot give a definite explanation about whether this influence is positive or not for human beings. More detailed explanations need further physiology studies. At the same time, the values quoted in Table 1 are not as accurate as those obtained by using standardized testing methods or precisely controlled. [Preece et al., 2005] However, these values could give us a relative measure of exposure and make this experiment more convinced.

There are also several detail issues that should be mentioned. As Jarrold and Towse pointed out that gender difference could not be ignored. [Jarrold and Towse, 2006] However, in our experiment, there are just five female subjects which could not balance the gender influence. More importantly, as the common knowledge has shown, pictures could bring different emotions to different subjects. For example, Dark blue and grey might make people sad or unpleasant, and light green or red will make people pleased. For this reason, the experiment in our current study is affected by emotion factors inevitably. In our experiment, we try to focus on the visual working memory procedure and avoid the interference arouse by auditory system. However, the process of storage and recollection could be more complex, for the colors we have chosen in the experiment could be easily named via verbal method. Composite colors (made up by several basic colors) may be better for our experiment. During the data-analysis procedure, we could observe several discrepancies among three MP conditions in grand average figure. However, due to the size of subject-group, no significant evidence could show that they are different. This problem might be improved by choosing a larger group in further studies. A GSM mobile phone (Nokia 5200) was used in our experiment though 3G based mobile phones are more prevalent in recent society. Similar studies could be done based on our current experiment to investigate the EMF influence on color-related working memory.

WM is a system that is too complex to uncover all the details of its mechanism. Thus, the following issues should be considered if we want to make an improvement for the study of effect of MP-EMF on working memory in future studies. Firstly, it is necessary to consider the effect of color, because different colors cause different kinds of psychological processing. Secondly, emotion or other cognitive functions may influence the WM system to some extent. In further step, we should add some specific tasks to find out how these cognitive functions associate with WM system under different MP-EMF levels. Thirdly, different experiment conductors used different kinds of

MP in their studies respectively and that might lead to various results because of the EMF-details. It is better for us to make a special instrument to simulate the MP-EMF. The results of these researches should be the best reference to the manufactories of MP. At last, what is the long-term effect given by MP? Arai's research [Arai et al., 2003] has proved that a group of long-term MP users had a higher degree of hearing loss. Based on these long-term MP users, we could study long-term MP-EMF effect on working memory. As we have discussed above, the frontal and hippocampus are related to the LTM.[Izquierdo et al., 1999, 2007; Cammarota et al., 2005; Countryman et al., 2005] Therefore, it is possible to study the MP-EMF influence on LTM based on this physiology theory.

Conclusion

In our current study, we selected focal colors as our experimental materials to investigate the influence of MP-EMF on human's non-spatial visual information working memory. The result indicates that though our WM behavior is not affected by MP-EMF, some ERP components are influenced under three MP conditions (close, standby and corresponding). Under the corresponding condition, people will cost more cerebral resource when they try to recollect the color materials from memory. This study could not support the long-term (exposure last for months, even for years) effect aroused by MP-EMF. Our research will contribute to further studies concerning MP-EMF effect on human beings, in spite of some existing limitations. More meticulous study designs and larger subject groups may lead to a more persuasion result in the future.

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