Do 2G and 3G Mobile Phone Exposures Affect Working Memory in Children, Adults and Elderly?

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Introduction

With the substantial uptake of mobile telephony since the late 1980s, there has been considerable interest in the possibility that mobile phones (MP) may adversely affect human cognition. Behavioural studies have so far been inconclusive, with some reports of improvements, some reports of impairments, but on the whole no replication of these findings. A series of studies by the Krause group have produced interesting findings in terms of working memory, and in particular the n-back task. Koivisto et al (2000) originally reported improved reaction time on the most difficult version of the n-back (3-back), and suggested that this may be because the effect of the phone is only noticeable when the task is very difficult. However, these results were not replicated (Haarala et al 2003; Krause et al 2007). One conclusion that may be drawn from this is that the first results were merely due to chance. However, neurophysiological investigations (e.g. Krause et al. 2007) suggest that there may be subtle changes to brain function that are affected by a number of factors (such as difficulty) that make replication difficult. If this is the case, then we may see effects of MP exposure on working memory after controlling for such factors. To address this issue, the present study tested for the effect of MP exposure on working memory, whist controlling for difficulty level. It thus tested for effects on the n-back task, individually calibrated such that the task was difficult but could be performed appropriately. This provides a task that has greater opportunity of being modulated by a stressor.

Further to this, there is very little research assessing the effect of age on possible MP-related effects. This is because most research tests university students, which tend to be healthy young adults, and so it is also possible that the lack of consistency in the MP/working memory may be due to the different ages of the particular samples tested. The possibility of differential effects for different ages may be relevant in that the different anatomies of different age groups may result in differential absorption of MP emissions (de Salles et al 2006), and the different stages of neural development may also be differentially affected by stressors (see review by Romeo and McEwen, 2006). The present study thus tests for effects of MP-related exposure in three age groups (13-15, 19-40 and 55-70 year olds). It has also been suggested that there may be differential effects of 2G and 3G exposures on humans, particularly as 2G but not 3G exposures include ELF components. For example, performance has been reported to be affected by pulsed but not continuous RF (Regel et al, 2007). The present study thus performed the above tests of working memory in different age-groups, under 2G, 3G and sham conditions separately.

Materials and Methods

38 children (13-15 years, 21 male, 17 female), 42 young adults (19-40 years, 21 male, 21 female) and 20 elderly (55-70 years, 10 male, 10 female) volunteers took part in the study, which was a repeated-measures, double-blind counterbalanced design. Participants were tested on 3 separate days at least 4-days apart, with one of 3 exposures on each of the testing days (2G, 3G, Sham). On each, they performed each of the 1-back, 2-back and 3-back visual working memory task between approximately 10 and 25 minutes into the exposure. Order of exposure, side of exposure (left/right) and order of difficulty level were counterbalanced across subjects and randomly assigned. Participants were tested while sitting in an acoustically and electrically attenuated chamber, approximately 0.6 m from a computer monitor where the n-back stimuli were presented. A cradle containing a 2G handset on one side and a 3G on the other side of the head was placed on the participant's head, with one or neither of the phones transmitting.

For each of the 3 n-back tasks there were 90 stimuli (consisting of 21 consonants, each is approximately 2cm width and 4cm height on screen), which were each presented for 500 ms (SOA = 3 ms) on a computer monitor. Different versions were used for each difficulty level and exposure condition. Participants were asked to respond as quickly and accurately as possible to each 'letter' that was the same as the letter 1, 2 or 3-back (for the 1, 2 or 3-back task respectively). To reduce variability due to attentional lapses, a small monetary reward was offered that was based on performance. For each participant, individuals' mean accuracy rates from the Sham condition were used to determine the difficulty level to be used for that individual for the analysis (Optimum). This level was defined as the most difficult n-back condition that still resulted in at least 70% accuracy, and data was excluded if the participant could not achieve at least 50% accuracy in at least one of the n-back conditions.

A Nokia 6110 (pulse modulated at 217 Hz, 894.6 MHz output) test phone was used for the 2G exposure. This was set via manufacturer software to continuously transmit at a mean power output of 250 mW (peak power of 2 W). The speaker was removed and foam was placed over the speaker inside a phone case to ensure that there was no sound audible. Further to this, in all conditions, 50 dB background white noise was continuously generated to produce a consistent ambient noise level. 3G exposure was achieved by a standard (or 'dummy') model of a mobile phone handset, which consists of a metallic handset approximately the shape and size of a typical mobile phone in which there is incorporated a monopole antenna which is externally fed by an RF signal source. This setup produces no audible sound or temperature rise. The 3G model handset was driven with a 1900 MHz 3G modulated signal at 125 mW (average), the maximum average transmit power of 3G mobile phone handsets. Measurements and computational modelling of specific absorption rate (SAR) were conducted to determine induced SAR. For 2G, the resulting maximum peak spatial SAR averaged over 10 g was determined to be 0.674 W/kg, while for 3G the maximum peak spatial SAR (10 g)was determined to be 1.27 W/kg.

An exploratory analysis was performed to determine whether there were differences between groups and difficulty levels, for the Sham condition. This involved a three (Difficulty; 1-back, 2-back, 3-back) by three (Age; adolescents, young adults, elderly) repeated measures ANOVA, separately for the dependent variables accuracy and reaction time, where difficulty was assessed with linear contrasts. To test for effects of MP exposure, a three (Exposure; Sham, 2G, 3G) by three (Age; adolescents, young adults, elderly) repeated measures ANOVA was performed on accuracy and reaction time data separately, where the dependent variable was taken from the Optimum n-back condition. Post hoc t-tests tested for differences between Sham and 2G, and Sham and 3G, for each of the age groups (Bonferroni-corrected accounting for correlations; corrected p-values shown).

Results

Two of the young adult group were excluded because they were unable to achieve 50% accuracy on any of the n-back conditions. In the Sham condition, accuracy decreased and reaction time increased with difficulty level (accuracy, $F(1,95)=210.08$, $p<0.001$; reaction time, $F(1,95)=75.59$, $p<0.001$), but these patterns did not differ for the three age groups. There also no main effect of Group. There was no main effect of Exposure or Group on accuracy, but there was a significant Exposure by Group interaction ($F(4,190)=3.74$, $p=0.006$). Post hoc t-tests found that Sham was more accurate than 3G for the children ($F(1,37)=8.46$, $p=0.017$), but not for young adults or elderly, and that there was no difference between Sham and 2G for any age group. These results were confirmed with non-parametric analyses, and subsequent exploratory analyses found that these results were not affected by side of exposure (left/right), nor by order of exposure condition. No effects of exposure were found for reaction time.

Discussion

The present study supports previous research in that it did not observe changes in working memory performance as a function of 2G MP exposure in adults, and extends this to show that 3G exposure similarly did not have an effect in adults. Thus even though great effort was made to produce a challenging task that could still be performed appropriately, and provided financial incentive to reduce variance due to attentional deviance, no effect of MP exposure was observed in adults. However, reduced accuracy was found in children during the 3G exposure (with no effect in the 2G condition).

As this is the first test of the effect of 3G exposure on memory function in children, this positive finding clearly requires replication before it can be concluded that this is a real as opposed to chance finding. However, assuming that this does represent a real effect, this would provide the first evidence that children are more sensitive to MP exposure. This is particularly important, not only given the substantial increase in MP use amongst children, but also in that the brains of 12-15 year olds are undergoing substantial developmental changes, which may make minor perturbations of neural function more significant to children than adults. Similarly, it is worth noting that if this proves to be a real and not chance finding, then it would go some way to explaining the differing results in the literature, as it suggests that the different ages of the different samples may have acted as confounders.

The reduced accuracy in this group of children was restricted to the 3G exposure. Noting that 2G has a pulse content which is substantially absent in the 3G signal used here, this is unexpected in that where differential effects of pulse and continuous RF have been reported, it has tended to be in the opposite direction. For example Regel et al (2007) reported cognitive effects with pulse modulated but not continuous RF exposure. A possible explanation for this may be that whereas Regel (for example) kept RF frequency constant to make a more direct test of pulse modulation, the present study compared 2G and 3G exposures, with the 3G RF a much higher frequency than the 2G. Thus the RF frequency may have played a role in the reduction in the children's accuracy.

The present study has found that n-back performance is not affected by either 2G or 3G exposure when all age groups are considered together, but that this sample of children was less accurate in the 3G than Sham condition. This result needs to be replicated to ensure that it is not merely a chance finding, but if real it has important ramifications for our understanding of MP-related bioeffects.

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