Use of mobile phones and changes in cognitive function in adolescents

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ABSTRACT

Background Several studies have investigated the impact of mobile phone exposure on cognitive function in adults. However, children and adolescents are of special interest due to their developing nervous systems.

Methods Data were derived from the Australian Mobile Radiofrequency Phone Exposed Users' Study (MoRPhEUS) which comprised a baseline examination of year 7 students during 2005/2006 and a 1-year follow-up. Sociodemographic and exposure data were collected with a questionnaire. Cognitive functions were assessed with a computerised test battery and the Stroop Color-Word test.

Results 236 students participated in both examinations. The proportion of mobile phone owners and the number of voice calls and short message services (SMS) per week increased from baseline to follow-up. Participants with more voice calls and SMS at baseline showed less reductions in response times over the 1-year period in various computerised tasks. Furthermore, those with increased voice calls and SMS exposure over the 1-year period showed changes in response time in a simple reaction and a working memory task. No associations were seen between mobile phone exposure and the Stroop test.

Conclusions We have observed that some changes in cognitive function, particularly in response time rather than accuracy, occurred with a latency period of 1 year and that some changes were associated with increased exposure. However, the increased exposure was mainly applied to those who had fewer voice calls and SMS at baseline, suggesting that these changes over time may relate to statistical regression to the mean, and not be the effect of mobile phone exposure.

What this paper adds

- Existing studies on exposure to radiofrequency (RF) electromagnetic fields (EMF) and cognitive function provide inconsistent results.
- While some studies suggested that RF EMF exposure could have an effect on cognitive function, other studies found no effects.
- There is special scientific interest in young people due to their still developing nervous systems.
- This study shows changes in response times over a 1-year period in some of the computerised tasks but no change in accuracy.
- Changes over time may relate to statistical regression to the mean and not be the effect of mobile phone exposure.

INTRODUCTION

The use of mobile (cellular) phones has increased worldwide during the last decade especially in children and adolescents.[1–3] This has coincided with concerns that exposure to radio frequency (RF) electromagnetic fields (EMF) might have negative impacts on health. In particular, children and adolescents are of special interest. Young people might be more vulnerable due to their still developing nervous systems and the potential for higher cumulative RF exposure during their lifetimes.[4–7]

As mobile phones are used close to the head, part of the EMF energy from the handset is absorbed into the head and the brain.[7 8] It has been suggested that these fields may have effects on neuronal activity and cognitive function in humans. Recently, studies undertaken primarily in adults have investigated a possible influence of exposure to mobile phone frequencies on cognitive function. However, the results of these mostly experimental studies have been inconsistent. While the findings of some studies suggested exposure to mobile phones could have an effect on cognitive function,[9–15] other studies found no effect.[16–23] A meta-analysis that included 19 studies investigating the effects of mobile phones on cognitive function concluded that exposure might have a slight effect on attention and working memory. However, the direction of the effect (eg, decrease or increase in reaction time) was inconsistent and the association was only seen in some studies.[24]

To date only two experimental studies have focused on cognitive function in children and adolescents, with inconsistent results. Preece *et al* reported that exposure to a GSM 900 handset was associated with shorter reaction times in children, although these results were not statistically significant.[25] In the second study, no association could be seen between the experimental exposure and cognitive function in children.[26] One major limitation of these studies was the small sample size. To date the Mobile Radiofrequency Phone Exposed Users' Study (MoRPhEUS) is the only community-based epidemiological study that has investigated possible associations between exposure to mobile phones and cognitive function in children and adolescents. The cross-sectional results showed an association between mobile phone use and faster but less accurate responses on some higher level cognitive tasks.[27]

In this longitudinal analysis of data from MoRPhEUS, we extended our previous baseline cross-sectional analysis to investigate if the observed results were still consistent over a period of 1 year in a cohort of Australian adolescents. We aimed to investigate if an effect in cognitive outcome occurred after a 1-year period and/or whether an increase in exposure over the period was followed by changes in cognitive outcomes.

MATERIALS AND METHODS

Study design and participants

The data were derived from the MoRPhEUS study, an epidemiological study examining possible associations between exposure to mobile phones and cognitive function in Australian secondary school students.[27] The participants were recruited from a representative sample of 20 secondary schools across Melbourne, Victoria. The study comprised two examinations: a baseline examination of year 7 students (typical age 12—13 years) during 2005/2006 and a 1-year follow-up in 2006/2007. At both time points (baseline and follow-up), participants completed an exposure questionnaire, a computerised cognitive test battery and the Stroop Color-Word test. To be included in the longitudinal analysis, students had to take part in examinations at both time points. Furthermore, adolescents with a known cognitive disorder and/or receiving psychotropic medication were excluded.

All participants and their parents gave written informed consent. The study was approved by the Monash University Standing Committee on Ethics in Research Involving Humans.

Questionnaire

Use of mobile phones was assessed with a modified version of the questionnaire used in the INTERPHONE study, a large case—control study investigating an association between exposure to mobile phones and brain tumours in adults.[28] The questionnaire included items on the number of voice calls made and received per week and the number of text messages (SMS) made and received per week. It also sought information on sociodemographic data, including age, sex and ethnicity (languages other than English spoken at home). Socioeconomic status (SES) for each subject was estimated from Australian Bureau of Statistics data using the Socio Economic Index For Areas (SEIFA) of advantage/disadvantage for the postcode of residence.[29]

Cognitive tests

Cognitive function was assessed with a computerised psychometric test battery (CogHealth; CogState, Melbourne, 2005) and the Stroop Color-Word test.[30]

The Stroop test was comprised of four tasks that measure susceptibility to interference effects in various mental functions, especially learning and memory. In the first task, students were asked to read 50 names of four different colours (blue, green, red, yellow) which appeared in black print (Form A). In the second task (Form B), subjects had to read the written colour names of the words independently of the colour of the print (eg, they would have to read ‘green’ no matter what the colour of the print was). Form C required the students to name the colour (blue, green, red, yellow) of 50 meaningless symbols. The last test, Form D, required subjects to name the colours of the letters independently of the written word, for example, if the word ‘red’ was printed in yellow they would have to say ‘yellow’. For each of the four tasks response times and errors were recorded.[30 31]

CogHealth is a validated computerised test of memory and thinking utilising the familiar visual stimuli of playing cards.[32—34] The test battery comprised seven tasks that assessed a range of cognitive functions such as psychomotor, visual attention, executive function and memory (table 1).

Statistical analysis

We used two exposure metrics: total number of self-reported voice calls (made and received) per week and total number of SMS (made and received) per week. To exclude extreme outliers, phone calls and short messages were restricted to a maximum of 70 calls/SMS per week. Both variables were log transformed to normalise data distributions.

The response times and error rates of Stroop Form B were compared with Form A and those of Form D with Form C.[27] To normalise the distributions, mean response times for each of the seven CogHealth tests were log transformed and arcsine transformed hit rates were used to express the accuracy for each test.

Two main analyses were performed to investigate possible associations between mobile phone use and changes in cognitive function between baseline and follow-up:

a. Changes in outcomes (follow-up—baseline) versus exposure at baseline in 2006. This was performed to test whether there was an effect after a latent period of 10 months.
b. The second model investigated whether an increase in exposure was followed by a change in cognitive function. Therefore, changes in outcomes (follow-up—baseline) were compared with changes in exposure (follow-up—baseline). Exposure variables for voice calls and SMS were dichotomised: 0=decrease or same number of voice calls and SMS in 2007; 1=increase in voice calls/SMS in 2007.

We used linear regression models estimated using generalised estimating equations[35] to allow for the clustering of students within schools assuming an independent working correlation.[36] The models included additive terms for age at baseline, sex, ethnicity, growth (difference in height between baseline and follow-up), time period between examination at baseline and

Table 1 Description of the CogHealth test battery

Test	Description	Measured domains	Outcomes
Simple reaction time	A button had to be pressed whenever a card appeared on a screen	Signal detection	Response time for true positives and negatives in ms Hit rate in per cent
Choice reaction time	A button had to be pressed to indicate whether a card was red or black	Signal detection	Response time for true positives and negatives in ms Hit rate in per cent
One-back task	A ‘Yes/No’ button had to be pressed to state if a new played card was the same or different to the last one presented	Working memory	Response time for true positives and negatives in ms Hit rate in per cent
Two-back task	A ‘Yes/No’ button had to be pressed to state if a card was the same or different to an earlier one, following an intervening card	Working memory	Response time for true positives and negatives in ms Hit rate in per cent
One card learning task	A ‘Yes/No’ button had to be pressed to state if the played card had been previously seen	Learning	Response time for true positives and negatives in ms Hit rate in per cent

follow-up, and SES (divided into quintiles). Statistical analyses were carried out using SAS v 9.1.

RESULTS

Descriptive data

Overall, 479 students were invited to take part in the MoRPhEUS study. Of those, 317 participated in the baseline study and 238 in both the baseline and follow-up studies (response: 75%). Two students had to be excluded due to a known cognitive disorder (attention deficit hyperactivity disorder). Complete Stroop test data were available for analysis for 236 students, but four participants were excluded due to missing CogHealth data (leaving n=232). The follow-up examination was on average 10 months (range: 8–18 months) after baseline.

The median age of the participants at baseline was 12.9 years, and at follow-up the median age had increased to 13.8 years (table 2). The proportion of mobile phone owners increased from 75% at baseline to 86% at follow-up. The total number of self-reported voice calls (made and received) per week as well as the total number of SMS made and received also increased from baseline to follow-up. At baseline, students reported a median of eight voice calls and eight SMS per week. At follow-up, the median numbers of voice calls and SMS had increased to 10 per week. Overall, there was a strong correlation between baseline and follow-up number of calls (Spearman r=0.7).

Performance in the Stroop Color-Word test improved with an overall decrease in response times between baseline and follow-up (table 3). Numbers of errors were unchanged, but with all medians being 0, the numbers of errors were too low to be informative (data not shown).

Performance on CogHealth tasks showed similar trends to the Stroop results (table 4). Response times decreased for all seven CogHealth tasks from baseline to follow-up, but accuracy remained essentially the same.

Comparing those who were followed up with those who dropped out, no differences in sociodemographic, exposure or cognitive data were observed (data not shown).

Association between use of mobile phones and cognitive function

Table 5 shows the results of linear regression models for changes in outcomes (outcome at follow-up—outcome at baseline) against exposure (voice calls and SMS) at baseline. There was a positive association between a higher number of voice calls in 2006 and an increase in response time to some tasks during the study period. There were no consistent associations between changes in accuracy and number of calls at baseline.

An association was observed between the number of calls at baseline and changes from baseline in working memory (two-back task and one-card learning task). Students who reported a larger number of calls at baseline had an increase in response times in these two tasks. No associations were seen between the number of calls in 2006 and changes in response time ratios in the Stroop task.

One of the working memory tests (two-back task) showed an increase in response times from baseline to follow-up with higher number of SMS in 2006. This finding was consistent with that for voice calls. No significant associations were observed between number of SMS and the other CogHealth or Stroop tasks.

Table 6 gives the results of analyses to determine whether changes in exposure over the 1-year period were associated with changes in cognitive outcomes. Dividing the participants into two groups revealed that an increase in exposure over the study period mainly occurred among those with lower numbers of calls at baseline and a decrease in exposure for those who already had high numbers of voice calls and SMS in 2006 (data not shown).

An association between difference in numbers of voice calls and working memory (two-back task) response time was observed (table 6). Those with an increase in exposure over the 1-year period had a greater reduction in response time than those

Table 2 Sociodemographic and exposure data for baseline and follow-up

Variable	Baseline	Follow-up
	Median (IQR)	**Median (IQR)**
Age, years	12.9 (11.7–14.3)	13.8 (12.7–15.1)
	Prevalence (%)	**Prevalence (%)**
Male sex, n (%)	106 (45.0)	
Mobile phone ownership	178 (75.4)	203 (86.0)
Ever used a mobile phone	223 (94.1)	232 (98.3)
	Median (IQR)	**Median (IQR)**
Total number of voice calls per week	8 (4–16)	10 (5–21)
Total number of SMS per week	8 (2–20)	10 (4–20)

Table 3 Descriptive statistics for the Stroop Color-Word test (medians and IQRs)

	Baseline	Follow-up	p Value*
Form A			
Response time (seconds)	20.6 (18.5–22.8)	19.1 (17.1–20.9)	<0.001
Form B			
Response time (seconds)	22.6 (20.1–25.6)	21.3 (18.9–24.3)	<0.001
Form C			
Response time (seconds)	28 (25.4–31.0)	25.3 (22.3–28.3)	<0.001
Form D			
Response time (seconds)	46.1 (40.5–53.0)	39.9 (35.2–46.6)	<0.001
Form (B–A)/A (time ratio)	0.10 (0.03–0.19)	0.12 (0.04–0.21)	
Form (D–C)/C (time ratio)	0.64 (0.49–0.81)	0.57 (0.43–0.71)	

*p Values relate to the Wilcoxon signed-rank test.

Table 4 Descriptive statistics for the CogHealth tasks (medians and IQRs)

Variable	Baseline	Follow-up	p Value*
Simple reaction time			
Response time (ms)	313 (275–380)	308 (272–367)	0.33
Accuracy (%)	97.2 (92.1–100.0)	97.2 (92.2–97.2)	0.79
Choice reaction time			
Response time (ms)	564 (493–677)	546 (477–646)	0.001
Accuracy (%)	92.3 (85.7–96.8)	93.7 (85.7–96.8)	0.28
One-back memory task			
Response time (ms)	749 (643–867)	669 (583–796)	<0.001
Accuracy (%)	88.2 (78.9–93.7)	90.0 (81.1–93.7)	0.10
Two-back memory task			
Response time (ms)	836 (705–988)	766 (642–895)	<0.001
Accuracy (%)	78.9 (58.8–89.3)	81.1 (62.8–90.9)	0.03
One card learning task			
Response time (ms)	909 (733–1102)	852 (708–991)	0.001
Accuracy (%)	55.8 (45.7–66.7)	59.5 (50.0–69.0)	0.11
Movement monitoring			
Response time (ms)	472 (408–552)	432 (375–496)	<0.001
Accuracy (%)	83.3 (76.9–90.9)	83.3 (76.9–90.9)	0.96
Associative learning			
Response time (ms)	1273 (1087–1492)	1152 (979–1356)	<0.001
Accuracy (%)	72.0 (61.9–80.0)	72.0 (62.0–80.4)	0.93

*p Values relate to the Wilcoxon signed-rank test.

Table 5 Results of the linear regressions of number of voice calls and SMS at baseline in 2006 and changes in cognitive outcomes

		Difference in outcome between 2006 and 2007			
		Voice calls 2006		SMS 2006	
		Estimate	95% CI	Estimate	95% CI
Stroop Form A/B	Response time*	−0.001	−0.018 to 0.017	0.006	−0.010 to 0.022
Stroop Form C/D	Response time*	0.008	−0.024 to 0.041	0.007	−0.029 to 0.043
Simple reaction time	Response time*	0.009	−0.003 to 0.021	0.008	−0.004 to 0.019
	Accuracy†	0.123	−1.160 to 0.407	−0.154	−0.534 to 0.225
Choice reaction time	Response time*	0.005	−0.002 to 0.012	0.007	−0.003 to 0.016
	Accuracy†	0.011	−0.018 to 0.041	0.010	−0.022 to 0.042
One-back task	Response time*	−0.024	−0.059 to 0.011	−0.019	−0.045 to 0.007
	Accuracy†	0.016	−0.030 to 0.062	0.008	−0.036 to 0.053
Two-back task	Response time*	0.042	0.004 to 0.079	0.041	0.001 to 0.082
	Accuracy†	−0.001	−0.041 to 0.040	−0.035	−0.076 to 0.007
One card learning task	Response time*	0.045	0.009 to 0.081	0.029	−0.380 to 0.062
	Accuracy†	−0.003	−0.019 to 0.014	−0.009	−0.032 to 0.014
Movement monitoring	Response time*	−0.001	−0.015 to 0.014	0.010	−0.009 to 0.029
	Accuracy†	−0.016	−0.040 to 0.007	0.009	−0.018 to 0.035
Associative learning	Response time*	0.007	−0.004 to 0.018	0.006	−0.007 to 0.019
	Accuracy†	0.015	−0.010 to 0.042	0.007	−0.010 to 0.024

Adjusted for age at baseline, sex, ethnicity, growth (height difference between baseline and follow-up), time period between examination at baseline and follow-up, and socioeconomic status.
*$\log_{10}$ (response time in ms).
†Arcsine transformed hit rate.

with a decrease or no change in exposure. However, students who had more voice calls in 2007 than in 2006 showed lesser reductions in response time to the simple reaction time task. No associations between differences in number of voice calls and differences in the Stroop task were observed. Furthermore, differences in number of text messages were not related to changes in any of the Cog Health or Stroop tasks.

DISCUSSION

This study is the first to investigate changes in mobile phone use and cognitive function over a period of 1 year in a cohort of adolescents. We found associations between reported use of mobile phones and changes in some of the cognitive outcomes, especially changes in response times rather than changes in accuracy. Participants with more voice calls and SMS at baseline, but no increase in exposure over the 1-year period, demonstrated lesser reductions in response times over the 1-year period in some of the CogHealth tasks. However, no associations were seen between mobile phone use and the Stroop Color-Word test.

Further, there was a difference in some of the results of the cognitive tests between baseline and follow-up. Subjects were quicker in the follow-up than at baseline, which has been observed previously in a study where cognitive tests were repeated in children.[32] Repeated measurements of cognitive function can be affected by practice (or training) effects. Some studies have shown practice effects with repeated measurements using CogHealth over short time intervals but only on a few tasks and not consistently across studies and tasks.[32–34] We attempted to minimise practice effects by requiring all participants to first undertake a trial run through the entire CogHealth battery before recording response times and accuracy. As the

Table 6 Results of the linear regressions of differences in voice calls and SMS and changes in cognitive outcomes

		Difference in outcome between 2006 and 2007			
		Voice calls		SMS	
		Estimate	95% CI	Estimate	95% CI
Stroop Form A/B	Response time†	−0.017	−0.053 to 0.019	−0.010	−0.053 to 0.033
Stroop Form C/D	Response time*	0.042	−0.039 to 0.122	−0.022	−0.089 to 0.046
Simple reaction time	Response time*	0.024	0.007 to 0.042	0.006	−0.017 to 0.029
	Accuracy†	0.922	−1.006 to 2.850	1.254	−1.122 to 3.629
Choice reaction time	Response time*	0.009	−0.007 to 0.025	0.008	−0.005 to 0.021
	Accuracy†	−0.007	−0.078 to 0.064	−0.060	−0.130 to 0.009
One-back task	Response time*	−0.003	−0.084 to 0.078	−0.041	−0.119 to 0.038
	Accuracy†	−0.066	−0.133 to 0.001	−0.039	−0.108 to 0.029
Two-back task	Response time*	−0.079	−0.156 to −0.003	0.006	−0.092 to 0.104
	Accuracy†	−0.002	−0.070 to 0.065	−0.016	−0.114 to 0.082
One card learning task	Response time*	−0.068	−0.151 to 0.016	−0.042	−0.140 to 0.055
	Accuracy†	−0.018	−0.056 to 0.019	−0.045	−0.105 to 0.016
Movement monitoring	Response time*	−0.017	−0.049 to 0.015	−0.030	−0.063 to 0.003
	Accuracy†	−0.008	−0.057 to 0.041	−0.039	−0.086 to 0.008
Associative learning	Response time*	0.015	−0.036 to 0.065	0.021	−0.044 to 0.085
	Accuracy†	−0.028	−0.078 to 0.022	−0.037	−0.082 to 0.008

Reference category: same number of calls and SMS or decrease in calls and SMS in 2007.
Adjusted for age at baseline, sex, ethnicity, growth (height difference between baseline and follow-up), time period between examination at baseline and follow-up, and socioeconomic status.
*$\log_{10}$ (response time in ms).
†Arcsine transformed hit rate.

follow-up examination in our study was on average 10 months after baseline, a sustained practice effect seems unlikely.

We observed that changes in some of the cognitive tests occurred after a 1-year period. Participants with a higher number of calls at baseline in 2006 demonstrated less of an improvement in response times for the working memory tasks at follow-up, and those with a higher number of text messages in 2006 also demonstrated less improvement in response times for the two-back task.

Those participants who had more voice calls in 2007 than in 2006 became faster in the two-back task, but relatively slower in the simple reaction task in comparison to those participants who had the same number of calls or less calls in 2007 than in 2006. It has to be kept in mind that the increase in exposure mainly occurred among those with lower numbers of calls at baseline in 2006 and thus they reached a similar exposure status as those who already had higher numbers of voice calls and SMS in 2006. We consider that the change in outcome might be the effect of regression to the mean, which happens when unusually large or small measurements tend to be followed by measurements that are closer to the mean.[37 38] Therefore, it could be that true changes in exposure had corresponding causal changes in outcomes. Since the students were compared on multiple tests we also cannot exclude the possibility that some of the observed significant results were due to chance.

Furthermore, we observed significant results for the two-back task for voice calls and text messages. This result indicates that the observed results are unlikely to be due to EMF as the handset is close to the head during voice calls but not when sending or receiving text messages. As opposed to the voice calls, very little EMF is emitted during text messaging.

To investigate if the observed associations might be confounded by some other factors like media consumption, we included these variables to the models. No difference in the results was seen (data not shown). Furthermore, we restricted the analysis to those who owned a mobile phone to observe if the lifestyle of students with mobile phones differs from that of students without a mobile phone. The results also show no difference (data not shown).

The period of follow-up was relatively brief for a longitudinal investigation of dose-related changes in cognitive function in adolescents. The small effects that were observed and the few positive findings might also be due to short follow-up.

In the cross-sectional analysis of the baseline data in our study, students who reported a higher usage of mobile phones per week demonstrated shorter response times for some of the tasks.[27] Up to now, only two other studies have investigated a possible association between exposure to mobile phones and cognitive function in children and adolescents.[25 26] These experimental studies were only 24—48 h in duration and so were not able to investigate effects over a longer period of time. As there are no published studies that have investigated longitudinal associations between use of mobile phones and cognitive function in this age group, a comparison with other results is not yet possible.

A strength of our study was the collection of data at two time points (baseline and 1-year follow-up). So far, all of the studies that have investigated possible effects of mobile phone exposure on health outcomes (other than neurocognitive effects) in children and adolescents were cross-sectional and therefore changes over time could not be assessed.[2 3 27 39 40]

Further strengths of this study were the community-based sampling and its larger sample size (n=236) in comparison to previous experimental studies. Previous studies that investigated possible associations between mobile phone exposure and cognitive function in the relevant age group had experimental designs and included only a limited number (n=18, 32) of participants.[25 26] Furthermore, the response from students who participated in both examinations (baseline and follow-up) was good (75%) with an acceptable attrition rate. All of the cognitive tests used in the study have been well validated and previously used to measure cognitive function in children and adolescents.[32 41—43] We think it unlikely that attrition of the cohort has substantially influenced the findings as baseline sociodemographic, exposure and cognitive data were very similar between those who were followed up and those who dropped out (data not shown).

One limitation of the study was that the assessment of mobile phone use had to rely on self-reports of the participants. Using self-reports can be prone to a possible awareness bias, which can lead to a misclassification of exposure and thus spurious findings.[44 45] However, the questionnaire that was used was based on a validated instrument. We used number of voice calls as exposure metric instead of duration of voice calls per week, because these have been found to be more accurate than the duration of calls. While studies on adolescents showed that adolescent recall of number of calls was moderate, self-report of duration of calls was poor in this age group.[46 47] It would have been interesting to access more objective phone use data in calling records from providers to supplement the self-report calling data, however, it was not possible to access this information, mostly because adolescents in Australia chiefly use prepaid phones.

We have observed some changes in cognitive function that occurred with a latency period of 1 year as well as some changes that occurred due to an increase in exposure. However, the increase in exposure mainly occurred among those who had smaller numbers of voice calls and SMS in 2006. Therefore, we suggest that the observed changes over time may relate to statistical regression to the mean and not be the effects of mobile phone exposure.

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Competing interests Michael Abramson holds small parcels of shares in Telstra and SingTel which both operate mobile telephone networks in Australia. Christina Dimitriadis holds a small parcel of Telstra shares. Geza Benke, Imo Inyang and Silke Thomas have no conflicts of interest to declare. Rodney Croft has received funds to conduct research from both the government and the mobile telecommunications industry.

Patient consent Obtained.

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