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Effects of electromagnetic fields emitted by GSM phones on working memory: A meta-analysis.

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ABSTRACT

Background and Objective: Current treatments for Alzheimer's Disease (AD) do not affect the course of the illness and brain stimulation techniques are increasingly promoted as potential therapeutic interventions for AD. This study reviews the effects of electromagnetic field (EMF) exposure vs. sham exposure on working memory (WM) performance of healthy human participants.

Method: Online literature databases and previous systematic reviews were searched for studies of EMF and WM in participants without reported memory problems. Two thousand eight hundred and fifty seven studies were identified and ten studies met the inclusion criteria. An assessment of study quality was completed and separate, random effects meta-analyses were conducted for each of the three WM tasks included: n-back, substitution and digit span forward.

Results: No differences were found between participants exposed to active EMF vs sham conditions in any of the three working memory tasks examined.

Conclusion: Results indicate that EMF does not affect WM during the n-back, substitution and digit-span tasks. Future studies should focus on the possible effects of chronic exposure to EMF in older adults with AD using a battery of comparable WM and attention tasks, before EMF can be seriously considered as a potential modulator of WM in AD.

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INTRODUCTION

AD is a neurodegenerative disorder characterised by an insidious onset and progressive disturbance in cognitive function with memory being particularly affected. Symptomatic treatments including cholinesterase inhibitors provide modest relief but do not delay disease progression (AD2000, 2004). Other AD treatments are sought to reduce cognitive decline associated with AD and delay the course of disease progression.

Brain stimulation techniques are now being advocated as potential treatments for several neurodegenerative disorders. Deep Brain Stimulation (DBS) has been widely used to treat tremor, dyskinesia and motor fluctuation in Parkinson's disease (see Honey and Ranjan, 2012 for a review) and the first clinical trial for the use of DBS on cognitive function in patients with Dementia with Lewy Bodies is now underway (NCT02263937). Transcranial direct current stimulation (tDCS) and transcranial magnetic stimulation (TMS) have both shown promise in improving cognitive function of patients suffering neurodegenerative dementias including AD (see Elder and Taylor, 2014 for a review). Recently, exposure to EMF, such as those emitted by mobile phones, has emerged as a potential modifier of cognition (see Barth et al., 2008 for a review). This idea is supported by animal studies which report improvements in WM following exposure to EMF (Arendash *et al.*, 2012; 2010). Phones from the Global System for Mobile communication (GSM) emit high frequency EMF in the range from 850 to 2000MHz which is partly absorbed by brain tissue (Schonborn *et al.*, 1998).. There are reports that GSM-induced EMF can increase cerebral metabolism and excitability in brain regions directly exposed to signal (for review see Valentini *et al.,* 2007). A treatment based on exposure to EMF could therefore provide an inexpensive, non-

invasive, non-pharmacological therapeutic intervention for cognitive decline associated with AD.

Use of mobile phones has increased exponentially in recent years and although their impact on health and normal brain function in humans has come under intense investigation over the last decade, findings are nevertheless conflicting. In 2012, Ng *et al.* reported that in a group of older participants with age-related cognitive decline, more frequent mobile phone users showed better performance on the Mini Mental State Exam (MMSE) and neuropsychological tests including measures of memory and attention. This epidemiological study could not distinguish between causal and consequence association, but the idea that EMF can benefit cognition is supported by several empirical studies. Koivisto *et al.* (2000) reported faster reaction times during WM tasks and improved response times during simple reaction and vigilance tasks and reduced cognitive time for mental arithmetic tasks. In 2003, Smythe and Costall provided further evidence to support improvements in memory under EMF exposure but only in male participants. Keetley *et al.* (2006) observed faster performance on a trail making task, but that accuracy during simple and choice response times decreased. Small improvements in attention have also been reported (Lee *et al.*, 2003).

Other studies, however have reported no effects on cognition including memory, attention and executive function (Haarala *et al.,* 2007; Krause *et al.,* 2000; Krause *et al.,* 2007; Haarala *et al.,* 2004; Haarala *et al.,* 2005; Haarala *et al.,* 2003; Besset *et al.,* 2005; Eltiti *et al.,* 2009; Delhez *et al.,* 2004). Despite the growing body of literature, differences in methodologies, exposure protocols and outcome measures have led to inconclusive results. Three recent meta-analyses report conflicting conclusions. In 2008, Barth *et al.* suggested that human

attention and WM were facilitated by exposure to EMF on the subtraction and 0-back tasks, whilst Valentini *et al.* 2010 and Barth *et al.,* 2012 reported no effects of exposure. These meta-analyses have several limitations in the context of assessing the effects of EMF on WM. Barth *et al.,* 2011 and 2007 included only the n-back task as a measure of WM in their analyses, and may therefore reflect task-specific conclusions that do not generalise to WM as a whole. In addition, Barth *et al's,* 2007 review was limited to studies completed by 2007, and is now nearly 10 years out of date. Whilst Valentini *et al.,* 2011 included the subtraction task in addition to the n-back, they compared data from two distinct versions of the task: *subtraction* vs. the more challenging *descending subtraction* task, which, in addition to WM, draws on components of attention and executive function, similar to the distinctions made between digit-forward and digit-backward tasks (Hale *et al.,* 2002) and is therefore not directly comparable to the subtraction task.

Before EMF can be seriously considered as a novel treatment for AD, consensus must be reached on its potential to modulate cognition. Although episodic memory deficits are prominent in early AD, few EMF studies measure this construct and recent reports from animal studies point explicitly to improvements in WM. To our knowledge there are currently no studies of direct EMF exposure on WM performance in patients with AD, MCI, age-related cognitive decline or even subjective cognitive complaints. Focusing on the most up-to-date literature, beyond the scope of existing meta-analyses, the current study examined whether acute exposure to EMF emitted by GSM mobile phones affects WM performance in human participants without reported memory difficulties.

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METHODS

Literature search and selection

Online databases (PubMed, Cochrane, Web of Science, Embase, PsychARTICLES, PsychINFO (1806-present) were searched on 21 August 2013. The following search terms were used: *'RCT, randomised, randomized, emf, electromagnetic field, mobile phone, cell phone, cellular phone, GSM phone, cordless phone, portable phone, rf, radiofrequency, cognition, cognitive, executive, motor, memory, behavioural, psychomotor, performance, attention, response time, reaction times, accuracy'*. All fields were searched and references of published articles were also inspected for relevant studies manually. The studies were selected on the basis of the following inclusion criteria:

1. Treatment (EMF on) and control group (EMF off/sham)

2. Within-subject and between-subject designs

3. Means and standard deviations/standard errors of dependent variables were available from article or author for both groups

4. Cognition was assessed using WM tasks defined as N-back task, Subtraction task and Digit-forward span task

5. Exposure to GSM or Universal Mobile Telecommunications System (UMTS)-like electromagnetic fields (pulsed or continuous wave)

6. Double or single blinding of study participants

7. Human participants

8. Studies published in peer reviewed scientific journals

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Assessment of study quality

The quality of included studies was assessed using the Cochrane Collaborations Risk of Bias Tool (Cochrane Collaboration) by four independent raters (OZ, HG, HC, MC). All discrepancies were resolved by discussion.

Data extraction and calculation of effect sizes

Means and standard deviations were extracted by four independent authors (OZ, HG, HC, MC) and discrepancies were resolved through discussion. Several studies reported data separately for parameters including side of exposure and type of EMF. As there is no consensus on the precise stimulation parameters and no a-priori predictions were made for these characteristics, weighted scores were computed by averaging the responses across those trials. To work out the combined means and standard deviations, the following formulae were used:

Combined mean = $((n1 * \bar{X}1) + (n2 * \bar{X}2))/combined\ n$

Combined SD = $\sqrt{(a+b)/(combined\ n - 1)}$, with $a = ((n1-1)*(SD1*SD1)) + ((n2-1)*(SD2*SD2))$ and $b = ((n1*n2)/combined\ n)*((SUMSQ(\bar{X}1, \bar{X}2) - 2*(\bar{X}1*\bar{X}2))$

Where n = number of participants, 1= active condition, 2 = sham condition

Averaged parameters included:

1. Left and right hemisphere exposure

2. Continuous vs pulsed wave

3. Target vs non-target: since 2/5 studies (Krause et al. 2007; Haarala et al. 2007) did not report data for target and non-target trials separately, data from these trials were averaged to compose a weighted score.

4. Finland vs Sweden

5. 20µT vs 400 µT

6. Sensitive vs control (self-reported sensitivity to EME vs no self-reported sensitivity to EME)

7. EP 'on' and RP 'on' and EP 'off' and RP 'off' conditions were averaged to analyse data from Besset et al. 2005.

Some studies reported 'number of false answers', '% error', or 'number of errors'. In these cases, % correct scores were calculated to allow comparison across all studies. The standardised mean difference (SMD) was used as a measure of effect size. Positive SMD values indicate faster or more accurate responses for active vs sham treatment whilst negative values indicate slower or less accurate responses for active vs sham treatment.

Meta-analyses

Statistical analyses were carried out using Review manager 5.3 (The Cochrane Collaboration, 2014). Only WM tasks that were present in three or more studies were included in the meta-analyses, and separate meta-analyses were conducted for each task. The meta-analyses were carried out as a comparison between EMF active and EMF sham conditions. The random effects model was used to estimate the overall SMD. The Z statistic was used to

test whether the overall pooled SMD was significantly different from 0. The I^2 statistic was used as an indicator of variability in SMDs between included studies with I^2 values ranging between 25%-49% signifying low heterogeneity, 50%-74% as moderate and 75% or greater as high heterogeneity. Publication bias was assessed using funnel plots.

RESULTS

Study characteristics

Initial non-refined searches produced 2857 results which were then subjected to evaluation of title and abstract content. This selection produced 123 results. Once duplicates were removed, 76 papers were identified for full evaluation and 10 studies, published between 1999 and 2009, met the inclusion criteria (see Figure 1 for more detail).

< insert figure 1 here>

In total, 553 participants were tested: 524 under active GSM exposure and 525 under sham conditions (one between-subjects study was included with 28 participants in the active condition and 29 in sham and 9 between-subjects design studies). Research characteristics of eligible studies are summarized in Table 1. All studies examined effects of EMF on WM using the n-back, subtraction or digit-span tasks. Participants in the Haarala *et al.,* 2007 study completed both the n-back and the subtraction tasks but since separate analyses were performed for each task, no double-counting of participants occurred. 9 of 10 studies were of a within-subjects crossover design with participants performing both the active and sham exposures in a counterbalanced order. Besset *et al.,* 2005 used a between-subjects design

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with one group performing the active and another group performing the sham exposure. Participants were exposed to EMF via a GSM phone or a signal generator connected to a GSM phone in 9 of 10 studies. Eltiti *et al.,* 2009 combined GSM and UMTS signal. Exposure duration for each session lasted between 30-120mins. In 9 studies, participants were exposed for 1-2 sessions completed within a fortnight and one study (Besset *et al.,* 2005) exposed participants for 2 hrs daily for 4 weeks. 7 studies reported EMF exposure to the right side of the head, one reported exposure to both sides (Haarala *et al.,* 2007) and two provided no details on side of exposure (Besset *et al.,* 2005 and Eltiti *et al.,* 2009). All except two studies (Koivisto *et al.,* 2000; 1999) used a double blind design.

< insert table 1 here>

Quality of studies

Table 2 provides a summary of potential sources of bias for included studies. No studies were excluded on the basis of inadequate ratings and only 1 of 10 studies was rated inadequate on 3 of 6 parameters. The remaining studies were all rated as adequate on 4 or more parameters. The randomisation of sequence generation and allocation concealment were least adequately addressed whilst blinding of participants and outcome measures, dealing with incomplete outcome data and selective outcome reporting were most adequate.

< insert table 2 here>

Meta-analyses

Three WM tasks were identified as being present in three or more studies: the N-back task, subtraction and digit span. Six studies were initially identified for the n-back task but one

study reported log-transformed data so had to be excluded from the analyses (Krause *et al.,* 2000), leaving 5 suitable studies (see Table 1). Separate meta-analyses were performed for each level of the n-back task and for the reaction time (RT) and accuracy (ACC) measures. Three studies were identified for the subtraction task (see Table 1). RT was used as the dependent variable as accuracy data was not available for Koivisto *et al.,* 1999. Three studies with digit span forward task were identified (see Table 1). In Besset *et al.,* 2005, only data from the exposure period (EP) and recovery period (RP) stages were used and data from the baseline period (BLP) were excluded as there was no exposure to EMF/sham during this period. Similarly, in Keetley *et al.,* 2006 only data in 'real field' exposure and 'sham field' exposure were used and 'pre exposure' data were excluded as performance in this condition was not subject to EMF/sham exposure.

Table 3 summarises the results of the meta-analyses. All WM measures examined in this review were homogenous, with the exception of the digit span task which showed heterogeneity. No significant differences between active EMF and EMF off/sham conditions were found for any of the three working memory tasks investigated.

<insert table 3 here>

No evidence of publication bias was found as indicated by the funnel plots for each task (see Figure 2).

 <insert figure 2 here>

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DISCUSSION

Our analysis does not support the hypothesis that exposure to EMF has any impact on WM of healthy human participants. This result is consistent with earlier meta-analyses (Barth *et al.,* 2011; Valentini *et al.,* 2011). In contrast to previous reports, we examined whether EMF affects performance during three separate WM tasks and compared only identical task conditions. Despite these methodological refinements, and examination of a larger pool of potentially eligible studies, no significant effects of EMF on WM were observed. It is possible that the WM tasks chosen were not sensitive to the effects of EMF and that other tasks measuring memory capacity and attention, which are most compromised in AD, might have indicated significant effects.

Closer inspection of the data suggests that heterogeneity observed in the digit span analysis is driven entirely by the Eltiti *et al.,* 2009 study, which combined signal from the 900 and 1800MHz frequency bands and counterbalanced participants to an additional UMTS signal exposure with a frequency of 2020MHz. This combination of frequencies is much higher than that used in the other three studies and may account for the drop in accuracy in the exposure condition. Removing this study achieves 100% homogeneity between tasks and does not produce any significant effects: -0.04 [-0.25, 0.17]; P=0.69, X²=0.16, Z=0.36.

Precise parameters of EMF exposure for most potential benefit are not understood and it is possible that characteristics including 'side of exposure' and 'type of wave' (pulsed vs. continuous) may interact with task performance. There is some, limited evidence that 'left-sided' exposure to EMF slowed response times during a spatial memory task (Eliyahu *et al.,* 2006 and Luria *et al.,* 2009). It is therefore possible that averaging across trials with left and right sided exposure has masked underlying effects on WM. Two studies included in the

analysis of the n-back tasks reported data separately for 'left vs. right' and 'continuous vs. pulsed' stimulation. In a separate, post-hoc analysis we therefore compared whether 'left-sided' exposure under pulsed stimulation (as GSM devises typically emit a pulsed wave) revealed any differences that may have been masked during combined analyses. No significant differences were found and all n-back tasks remained homogenous (see Table 4).

<insert table 4 here>

Current literature is limited to examiningshort-term EMF effects, where participants are exposed for brief durations, across few sessions, typically no more than a few days apart. Benefits from such exposure protocols may therefore be transient, an idea supported by findings that EMF-induced physiological changes, including cerebral metabolism and brain electrical activity, return to baseline levels as quickly as one hour following cessation of exposure (Valentini *et al.,* 2007; Hamlin and Wood, 2002). Other types of brain stimulation techniques rely on repeated application to induce longer lasting effects (Wilkinson *et al.,* 2014; Garin *et al.,* 2011) and allow for long-term plastic change following repeated stimulus exposure (Hoffman and Cavus, 2002). Effects of EMF may therefore be observed following longer exposure and follow-up protocols which allow potential treatment carry-over effects to emerge. A number of recent reports suggest that long-term exposure to EMF provides cognitive benefits in mice. Arendash *et al.,* 2010 found that daily EMF exposure during a 7-month period improved cognitive performance of AD transgenic (Tg) mice on a battery of cognitive tests compared to controls and reduced brain amyloid-β (Aβ) deposition. In 2012 these findings were extended to show that advanced Aβ deposition in the brains of very old AD Tg mice was reversed following daily EMF exposure over a 2-month period. These

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findings are encouraging and similar protocols now need to be applied to human participants.

By pooling results from different studies, this meta-analysis allowed us to provide a summary of current findings with more accurate estimation of effect size and without the difficulties of small sample size and low statistical power. This study is nevertheless limited by the number and the quality of studies included. One difficulty is that there is a shortage of studies which fulfil the minimum requirements for inclusion. Many studies were excluded due to unreported means and/or standard deviations required for analysis. Another shortcoming is the vastly different outcome measures across studies which could not be compared in the meta-analysis. In total, only 10 studies fulfilled our minimum inclusion criteria, so clearly these findings must be interpreted with caution. Given the large amount of conflicting data in the field, and the likelihood of future meta-analyses, establishing a minimum agreed standard for reporting methodological and statistical details, together with a standard battery of cognitive tests, would help advance this line of research. Given the wider context of AD-related cognitive decline that this study is set in, the average age of participants (28.5yrs) is also a noticeable limitation, particularly given that differential effects of EMF have been reported on physiological brain changes of old and young participants (Croft *et al.,* 2010; Veccio *et al.,* 2010). Similar studies now need to be conducted on cognitive effects of EMF in older populations with memory difficulties. The tolerability and incidence of adverse events will also be an important factor in determining suitability of using EMF amongst the older population who are more likely to suffer from ill health and a multitude of comorbidities.

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In conclusion, the current analysis provides no evidence that short-term exposure to EMF has an effect on WM and its potential for relieving cognitive decline associated with AD remains unconfirmed. Given the lack of current treatments for AD, there is an urgent need to explore other possible interventions such as EMF. Future studies should focus on long-term exposure to EMF and assess potential treatment carry-over effects on WM and attention, particularly in older participants with memory problems. More detailed reporting of methodological details and study results will enable a larger pool of comparable studies to be generated for future analyses. Finally, study designs which focus on specific stimulation parameters including side of exposure and type of wave with a focus on tolerability will greatly inform this field of research.

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Figure 1: PRISMA flow diagram detailing the number of records identified, included and excluded with reasons for exclusions. Adapted from Moher et al. (2009).
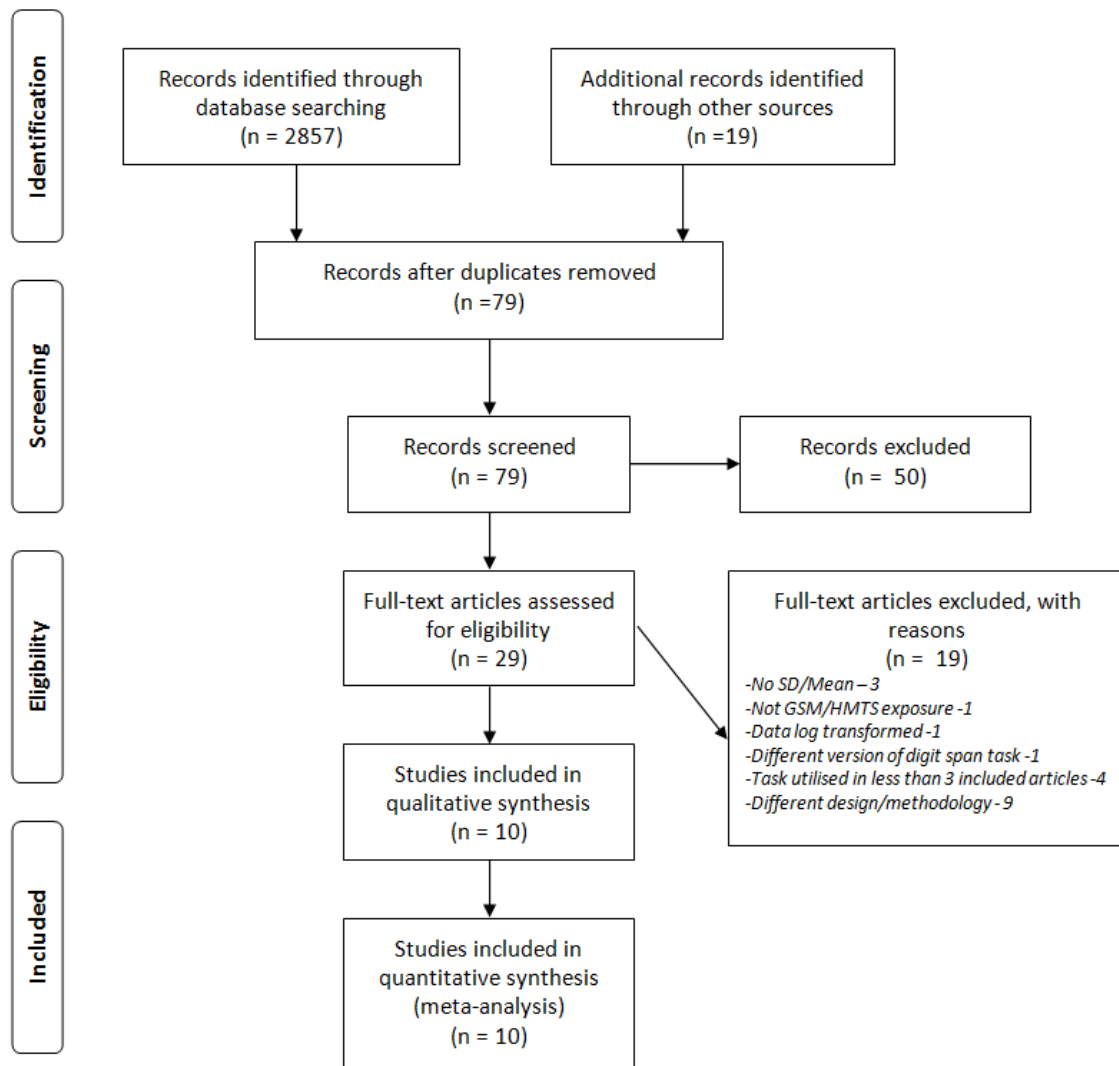
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Table 1: Characteristics of included studies for all three memory tasks

Study reference	Working memory task	Outcome Measure	Design	Exposure: gsm, frequency, continuous etc	Exposure duration	Blinding	Randomisation	Active sample	Control sample	Participant age
Haarala et al 2004	0-back, 1-back, 2-back, 3back	RT, ACC	Within-subject	Gsm phone mounted to left side of head with antenna, 902MHz, mean power 0.25W, pulsed	65mins	Double	Order of exposure counterbalanced	32	32	24.2yrs
Koivisto et al 2000	0-back, 1-back, 2-back, 3back	RT, ACC	Within-subject	Gsm phone mounted on head with antenna over left temporal lobe, 902MHz, mean power 0.25W, pulsed	30mins	Single	Order of task counterbalanced	48	48	23.2yrs
Krause et al 2007	0-back, 1-back, 2-back, 3back	RT, ACC	Within-subject	Signal generator connected to Nokia 6110 MP antenna, 902MHz, 0.25W, exposure to left and right under continuous and pulsed wave	40 mins for each exposure side	Double	Order of task counterbalanced	36	36	23.6yrs
Haarala et al 2007	0-back, 1-back, 2-back, 3back	RT, ACC	Within-subject	EMF generator connected to GSM Nokia 6110 MP antenna over left posterior temporal lobe, and over right posterior temporal lobe , 902MHz, 0.25W, continuous and pulsed wave	90mins	Double	Order of hemisphere, EMF and task were counterbalanced	36	36	23.8yrs
Haarala et al 2005	0-back, 1-back, 2-back, 3back	RT, ACC	Within-subject	GSM phone mounted on left side of head with antenna over left posterior temporal lobe, 902MHz, mean power 0.25W, pulsed	50mins on each of two successive days	Double	Order of task and exposure counterbalanced	32	32	12.1yrs
Koivisto et al 1999	Subtraction	RT	Within-subject	GSM phone mounted on left side of head with antenna over left posterior temporal lobe, 902MHz, mean power 0.25W, pulsed	1hr on each of two successive days	Single	Order of exposure counterbalanced	48	48	26.0yrs
Haarala 2007	Subtraction	RT, ACC	Within-subject	Signal generator connected to Nokia 6110 MP antenna, 902MHz, 0.25W, exposure to left and right under continuous and pulsed wave	3 sessions 90mins each separated by 1 week	Double	Order of exposure, task and hemisphere counterbalanced	36	36	23.8yrs
Haarala et al 2003	Subtraction	RT, ACC	Within-subject	GSM phone mounted to left side of head with antenna, 902MHz, mean power 0.25W, pulsed	2 session of 65mins 24hrs apart	Double	Order of task and exposure counterbalanced	64	64	24.2yrs
Besset et al 2005	Digit span forward	ACC	Between-subject	GSM phone held against preferred ear with preferred hand, 900MHz, mean power 0.54W, pulsed	2hrs/day for 4 weeks (EP stage)	Double	Unknown	28	29	24.3yrs
Keetley et al 2006	Digit Span forward	ACC	Within-subject	GSM (Nokia 6110) headset with antenna clipped onto head against left ear, mean power 0.25W, pulsed	2 x 30min sessions 1 week apart	Double	Order of testing session and exposure counterbalanced	120	120	33yrs
Eltiti et al 2009	Digit Span forward	ACC	Within-subject	GSM signal combined 900 and 1800MHz; UMTS – 2020MHz	50mins	Double	Order of task and exposure counterbalanced	44	44	46.1yrs

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Table 2: Potential source of bias for included studies based on the Cochrane Collaboration Risk of Bias Tool

Study reference	Type of study	Randomisation: Sequence generation	Randomisation: allocation concealment	Blinding of participants	Blinding of outcome assessors	Incomplete outcome data	Selective outcome reporting	No. of adequate ratings	Further details
Haarala et al. 2004	Within subjects CO design	Inadequate	Inadequate	Adequate	Adequate	Adequate	Adequate	4/6	No information about sequence generation or allocation concealment
Koivisto et al. 2000	Within subjects CO design	Inadequate	Inadequate	Adequate	Adequate	Adequate	Adequate	4/6	No information about sequence generation or allocation concealment
Krause et al. 2007	Within subjects CO design	Inadequate	Inadequate	Adequate	Adequate	Adequate	Adequate	4/6	No information about sequence generation or allocation concealment
Haarala et al. 2007	Within subjects CO design	Inadequate	Adequate	Adequate	Adequate	Adequate	Adequate	5/6	No information about sequence generation provided
Haarala et al. 2005	Within subjects CO design	Inadequate	Inadequate	Adequate	Adequate	Adequate	Adequate	4/6	No information about sequence generation or allocation concealment
Koivisto et al. 1999	Within subjects CO design	Inadequate	Adequate	Adequate	Adequate	Adequate	Adequate	5/6	No information about sequence generation provided
Haarala et al. 2003	Within subjects CO design	Inadequate	Inadequate	Adequate	Adequate	Adequate	Adequate	4/6	No information about sequence generation or allocation concealment
Besset et al. 2005	Between subjects design	Inadequate	Inadequate	Inadequate	Inadequate	Adequate	Adequate	4/6	No mention of randomisation, sequence generation, allocation of concealment, blinding of participants or outcome assessors
Keetley et al. 2006	Within subjects CO design	Inadequate	Adequate	Adequate	Adequate	Adequate	Adequate	5/6	No information about sequence generation provided
Eltiti et al. 2009	Within subjects CO design	Adequate	Inadequate	Inadequate	Inadequate	Adequate	Adequate	3/6	No information about allocation of concealment or blinding of participants or outcome assessors

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Table 3: Homogeneity Measures, P-Values, SMD and 95% Confidence Intervals for Working Memory Tasks under the pulse/continuous and left/right conditions averaged

Task	No. of studies/participants	RE pooled estimate (SMD)	95% CI	X²	Heterogeneity (p-value)	Overall effect: Z	Overall effect: P	I²
0-back RT [a]	5/216	0.01	-0.18, 0.20	1.25	0.87	0.11	0.91	0%
1-back RT [a]	5/216	0.09	-0.10, 0.28	1.63	0.80	0.96	0.34	0%
2-back RT [a]	5/216	0.05	-0.14, 0.24	0.69	0.95	0.87	0.39	0%
N-back 3 RT [a]	5/216	-0.12	-0.31, 0.07	1.67	0.80	1.22	0.22	0%
0-back ACC [a]	5/216	0.05	-0.13, 0.24	0.40	0.98	0.56	0.58	0%
1-back ACC [a]	5/216	0.03	-0.16, 0.22	0.97	0.92	0.31	0.76	0%
2-back ACC [a]	5/216	-0.03	-0.22, 0.16	0.72	0.95	0.34	0.73	0%
3-back ACC [a]	5/216	-0.02	-1.30, 1.26	0.56	0.97	0.03	0.98	0%
Subtraction RT [b]	3/112	-0.06	-0.32, 0.21	0.04	0.98	0.41	0.68	0%
Digit span ACC [c]	3/219	-0.13	-0.32, 0.06	4.05	0.17	1.37	0.72	51%

[a]*Haarala et al. (2007); Krause et al. (2007); Haarala et al. (2005); Haarala et al. (2004); Koivisto et al. (2000).*
[b]*Haarala et al. (2007); Haarala et al. (2003); Koivisto et al. (2000).*
[c]*Eltiti et al. (2009); Keetley et al. (2006); Besset et al. (2005).*

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Table 4: Homogeneity Measures, P-Values, SMD and 95% Confidence Intervals for Working Memory Tasks under the pulsed, left exposure condition

| Task	No. of studies /participants	RE pooled estimate (SMD)	95% CI	X²	Heterogeneity (p-value)	Overall effect: Z	Overall effect: P	I²
0-back RT [a]	5/216	0.00	-0.19, 0.19	1.40	0.84	0.01	0.9999	0%
1-back RT [a]	5/216	0.03	-0.16, 0.23	0.52	0.97	0.35	0.72	0%
2-back RT [a]	5/216	0.06	-0.13, 0.25	0.74	0.95	0.44	0.66	0%
N-back 3 RT [a]	5/216	-0.15	-0.34, 0.04	1.08	0.90	1.55	0.12	0%
0-back ACC [a]	5/216	0.10	-0.09, 0.29	0.57	0.97	1.07	0.28	0%
1-back ACC [a]	5/216	0.04	-0.15, 0.23	1.23	0.87	0.38	0.71	0%
2-back ACC [a]	5/216	-0.02	-0.21, 0.17	0.77	0.94	0.21	0.84	0%
3-back ACC [a]	5/216	0.03	-0.17, 0.22	0.64	0.96	0.25	0.80	0%
Subtraction RT [b]	3/112	-0.06	-0.32, 0.21	0.04	0.98	0.41	0.68	0%
Digit span ACC [c]	3/219	-0.13	-0.32, 0.06	4.05	0.13	1.37	0.17	51%

[a]*Haarala et al. (2007); Krause et al. (2007); Haarala et al. (2005); Haarala et al. (2004); Koivisto et al. (2000).*

[b]*Haarala et al. (2007); Haarala et al. (2003); Koivisto et al. (2000).*

[c]*Eltiti et al. (2009); Keetley et al. (2006); Besset et al. (2005).*

Figure 2: Funnel plots for all three tasks included, under each task condition.
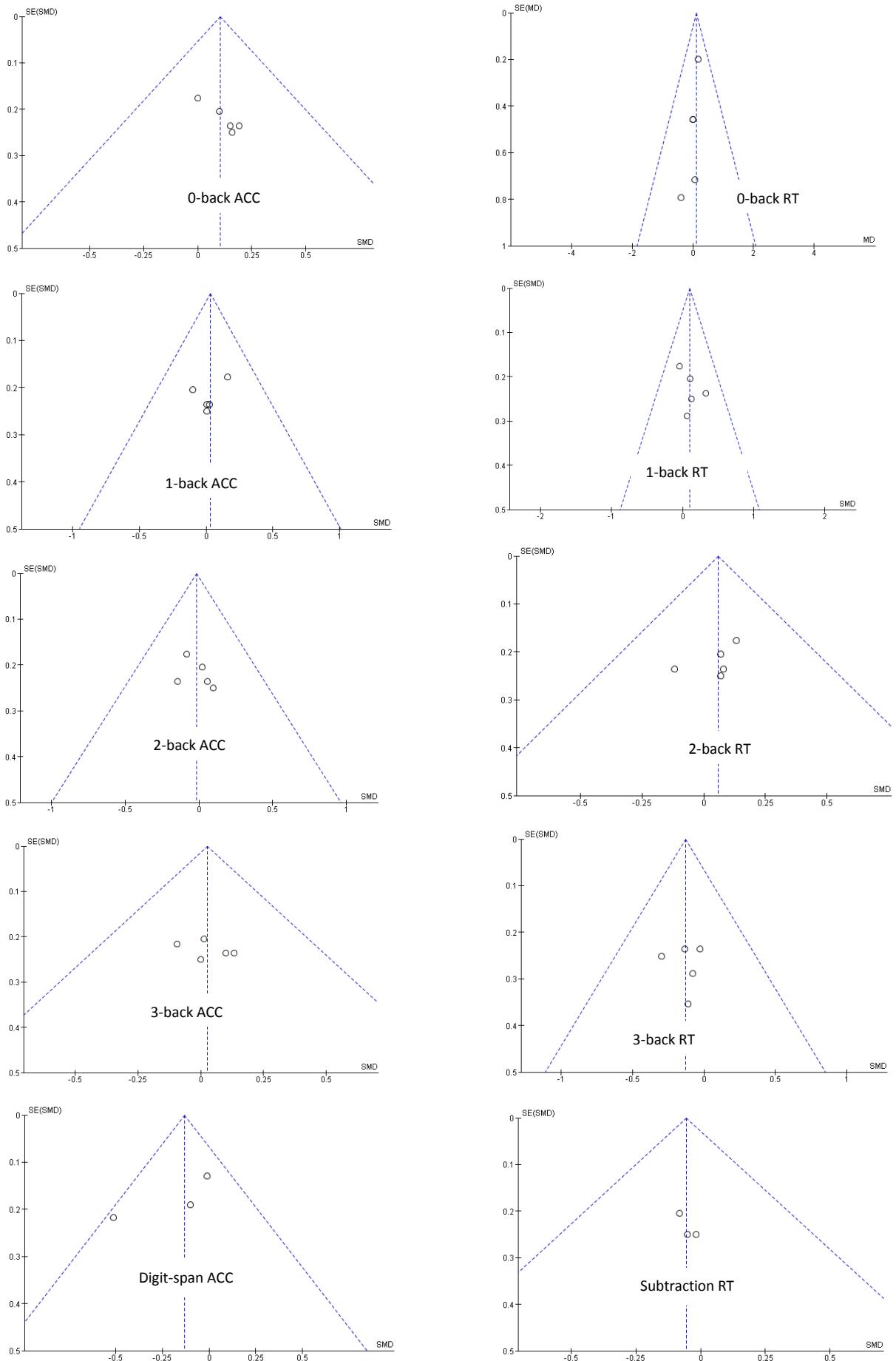
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