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Reducing false memories by magnetic pulse stimulation

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ABSTRACT

False memories are ubiquitous and often to our detriment. Yet, certain pathologies, including anterior temporal lobe dementia and autism, can lead to literal recall and thus greater resistance to false memories. This inspired us to reduce false memories by temporarily inhibiting the left anterior temporal lobe, using low frequency magnetic pulse stimulation. This site has been implicated in semantic memory and conceptual labelling. After active stimulation, participants in the sham/TMS group had 36% fewer false memories than they had with sham stimulation, and intact veridical memory. This is comparable to the improvement that people with autism and semantic dementia show over "normal" individuals. This finding suggests a potential method for reducing certain types of false memories.

Our memories can be misleading. Bartlett [1], some 76 years ago, noted that memories are not literal representations of the past. Instead, "facts" are unconsciously constructed to fit our schemata [17,31]. Possibly, this strategy confers an advantage in storing and manipulating schemata for future planning [31] or is a by-product of computational economy [34]. However, any advantage comes at a cost, such as in wrongful convictions based on inaccurate testimonies [17]. There would be obvious benefits if false memories could be reduced.

False memories have been the subject of interdisciplinary study and have been examined from various theoretical perspectives. They have also been the subject of applied and practical research that has endeavoured to reveal causal mechanisms and also whether these processes can be reversed. Although there exist methods for reducing false memories at the encoding stage (e.g. item specific processing; see Ref. [18]), these are ineffective in a forensic context, where the need for accurate memory is only realised after the event. Post-encoding, it is difficult to reduce false recognition rates, even when people are warned about false memories and intentionally apply strategies to reduce them [8].

A clue for achieving our goal of reducing false memories *post-encoding* comes from patients with left anterior temporal lobe dementia who have autistic-like qualities [19,21,29]. Individuals with autism and temporal lobe dementia are known for being literal [6,13,19,21,33,34] and less susceptible to false memories [3,32]. On the other hand, the more concept orientated we are, the more we tend to categorize and the more prone we are to false memories [5,12,34].

Indeed, the left anterior temporal lobe (LATL) is vital for semantic processing, being implicated as the region responsible for conceptual knowledge, labels and categories [7,21,22,24,37]. When the LATL is damaged, patients lose their semantic memory and their ability to name or label objects, while retaining the ability to recall literal details [7,21,37].

For these reasons, we hypothesized that inhibition of the LATL by repetitive transcranial magnetic stimulation (rTMS) would reduce false memories involved mainly with semantic processing by diminishing our tendency to reconstruct facts to fit our preconceptions. Low frequency rTMS is known to temporarily inhibit neural activity in a localized area of the cerebral cortex [25,39].

To investigate this possibility, we adapted the paradigm of Roediger and McDermott [28]. Their experiment showed that people who have heard semantically related words such as "physician", "nurse", "hospital", and so on, falsely remember that they have heard words form the same semantic category, for example "doctor". Our experimental paradigm capitalized on this well-known demonstration of false memory.

Twenty-eight participants were recruited from the University of Sydney community (19 female; mean age = 29, S.D. = 9). All participants were fluent English speakers and right handed, yielding a laterality quotient of at least +50 on the Edinburgh Handedness Inventory. They had no history of neurological disease or mental illness and were screened via the TMS Adult Safety Screen Protocol [15].

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Participants, naïve to the hypothesis of the experiment, were assigned to one of two conditions: sham–TMS or Baseline–Baseline. Gender ratio and mean age were the same for both groups.

The data for eight other participants were excluded from our analysis because we discovered in post-experiment interviews that they were psychology students who were highly familiar with our false memory paradigm and as a result had employed mnemonic strategies. Exclusion criteria were established a priori and were applied based on post-experiment interview, prior to any analysis.

The experiment was conducted in accordance with the Declaration of Helsinki and was approved by the University of Sydney Human Research Ethics Committee.

In selecting categories of stimuli for the false memory task, two criteria were balanced against each other. We chose categories that had reasonably high false recognition rates [36] and contained words that were closely related enough to allow us to select three critical lures (instead of one) whilst leaving nine study words that would establish the category concept. Traditionally, the Roediger and McDermott paradigm ensures sufficient power by including a larger number of categories, each with a single critical lure. However, due to the transitory effects of rTMS, we needed to shorten the test to three categories. We included three critical lures per category to maintain sufficient power in the test. Piloting confirmed the efficacy of our modified DRM test in revealing false memories.

Low frequency repetitive magnetic stimulation (rTMS) was administered with a Medtronic MagPro magnetic stimulator with a 70-mm Butterfly coil (MCF-B65). The resting motor threshold was determined by placing the coil over the left primary motor area and establishing the minimum amount of stimulator output required to produce motor-evoked potential with a peak to peak amplitude of 50uV in the right first dorsal interosseous muscle.

The left anterior temporal cortical stimulation site was determined by measuring laterally and anteriorly from the vertex (laterally 40% of the intra-auricular distance; anteriorly 5% of the distance from inion to nasion). This location is approximately half way between T7 and FT7 on the International 10-20 System for electrode placement. We acknowledge that using rTMS in a non-motor area without a neuronavigation system may have resulted in some loss of precision. However, our positioning method has been shown to correlate highly with MRI-based stereotactic approaches, and is regarded as adequate, even "advantageous", in studies which (like ours) require a "medium grain of precision" [10]. The location of stimulation was kept constant by using a chin rest and a fixed magnetic coil. Of relevance to a recent fMRI investigation [16], it is extremely unlikely that the frontoparietal region was stimulated in our study.

In the rTMS stimulation condition, the intensity of stimulation was 90% of the motor threshold at 1 Hz for 10 min. The average intensity of stimulation was 44.1% ± 5.9% (mean ± S.D.). In the sham stimulation condition, the magnet was inverted and placed over the same site for 10 min. The magnetic stimulation was negligible in the sham sessions, but the rTMS apparatus was active and produced audible clicks identical to those produced during the real rTMS sessions.

Participants completed the memory task twice. Participants in the sham–TMS group were tested first with sham stimulation between the study and test phase of the DRM task and then secondly with active rTMS between the study and test phase of the task. To ensure an initial placebo effect, participants were told that they would be receiving (active) rTMS, and were unaware that their initial stimulation was sham. The Baseline–Baseline group completed the task twice without any stimulation but with an equivalent break between the study and test phases.

We decided not to counterbalance the order of sham versus active rTMS for several reasons. We administered sham stimulation before active rTMS because rTMS produces a tapping sensation and often muscle contractions. Because of this, had people already experienced active rTMS they would have been very likely to notice phenomenological differences between active and sham stimulation and realize that the second session was sham, ruling out any placebo effect. Furthermore, administering sham before active rTMS allowed testing to be conducted in a single brief session, minimizing the potentially confounding effects such as time of day or psychological state on participants' performance [20]. Had rTMS been administered first, there would have needed to have been a lengthy delay, to prevent any lingering effects of rTMS from affecting performance in the sham condition.

We asked our participants to memorize a series of 27 words, each presented for three seconds on a computer screen. The words were selected from three different semantic categories (e.g. bread, music and doctor) [28]. Participants in the sham–TMS group then received 10 min of sham stimulation (those in the Baseline–Baseline group had an equivalent distracting break, total 15 min), after which they were tested for their memory of the words. They were presented with 27 words in succession and were asked to click 'yes' if they had seen the word earlier or 'no' if not. Specifically, participants were shown nine "true" words (words that they had seen before), nine "false" words (words that they had not seen before but which belonged to one of the semantic categories), and nine distractor words (words that did not belong to any of the three categories and which had not been seen before).

The process was repeated with a parallel form of the memory task (the order of the two word lists was counterbalanced). Participants in the sham–TMS group received low frequency rTMS between the study and test phases of the memory task, those in the Baseline–Baseline group had a distracting break of equivalent length.

We hypothesized that low frequency rTMS would result in reduced susceptibility to the "false" words, relative to sham stimulation or baseline performance. Comparison of false memories under rTMS with performance under sham stimulation enabled us to examine any possible placebo effect. A reduction in false memories for the Baseline–Baseline group would also indicate a practice effect.

We compared participants' error rates using a mixed design two-way ANOVA: Group (sham–TMS versus Baseline–Baseline; between-subject) × Time (first versus second test; within-subject). We incorporated a repeated measures approach, since there is significant variability in people's response to magnetic stimulation [27].

We hypothesized that rTMS would result in fewer false memories, relative to sham stimulation or baseline performance. In the sham–TMS group, false memories were reduced immediately after rTMS (relative to sham stimulation performance) in 9 out of 14 participants; four participants showed no change and one participant had slightly more false memories. In contrast, the Baseline–Baseline group showed no systematic improvement when retested: the mean for this group on their second trial was slightly higher.

There were no significant main effect results for either variable. There was no significant difference between the sham–TMS and Baseline–Baseline groups overall (F (1,26) = 1.069, p = 0.31 (>0.05); sham–TMS mean = 2.46, S.D. = 2.06; Baseline–Baseline mean = 3.25, S.D. = 2.14). There was also no significant overall difference between the first and second test, negating the possibility that the result was due to a practice effect (F (1,26) = 2.43, p = 0.13 (>0.05); first test mean = 3.04, S.D. = 2.20; second test mean = 2.68, S.D. = 2.06).

There was, however, a significant interaction effect (F (1,26) = 9.74, p = 0.004 (<0.01). As shown in Fig. 1, participants had (on average) three false memories under sham stimulation

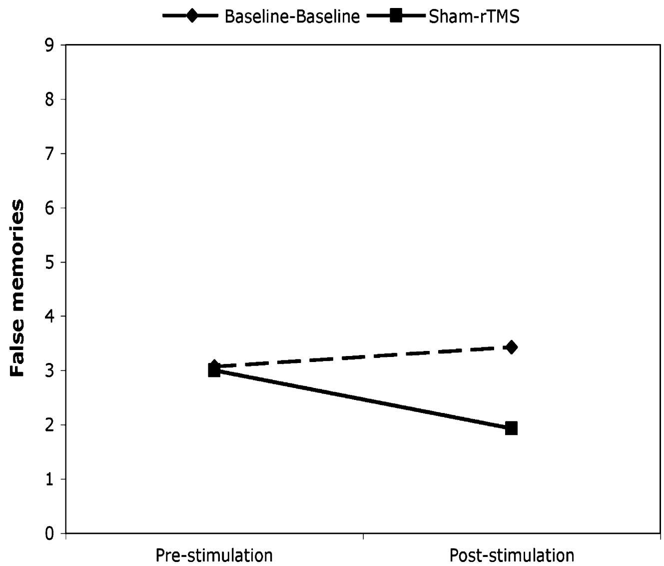

Fig. 1. Reduction in false memories. A comparison of the average number of false memories for sham–TMS vs. Baseline–Baseline. There was a 36% reduction in false memories after rTMS, relative to performance under sham stimulation. False memories remained constant for the Baseline–Baseline group.

and reported 36% fewer false memories after rTMS, constituting a medium effect size (0.52). False memories remained constant across the two tests in the Baseline–Baseline group, indicating that the results were not influenced by practice effects. This is consistent with previous studies (without stimulation), which have shown non-significant improvement (the effect size is typically around 0.1 or less) when participants performed the test a second time if, as in our experiment, different word lists were used [2,4]. Even when the word lists were the same [40], the improvement was much smaller than we found after rTMS.

Importantly, we found that veridical memory for "true" words was intact in the majority (10 out of 14) of participants after rTMS. This is despite the fact that most participants in our study had excellent veridical memory for "true" words before rTMS (8 out of 14 participants had perfect scores) and thus their performance for "true" words could only stay the same or decline after stimulation. Neither of the main effects, nor the interaction, was significant for veridical memory. There was no significant difference between the sham–TMS and Baseline–Baseline groups overall ($F(1,26) = 0.82$, $p = 0.38$; sham–TMS mean = 7.96, S.D. = 1.40; Baseline–Baseline mean = 8.36, S.D. = 1.03). Neither was there a significant overall difference between the first and second test ($F(1,26) = 0.36$, $p = 0.55$; first test mean = 8.21, S.D. = 1.10; second test mean = 8.11, S.D. = 1.37).

False memories are ubiquitous [1,17,31]. They are only one of many examples that reflect the highly conceptual nature of our cognitive processes. We do not normally have conscious access to the literal details that comprise labels or schemata [1,33,34]. In fact, the more mature our mind, the more solidified our concepts become [5,12] and the more susceptible we are to false memories.

We found a 36% reduction in false memories by temporarily inhibiting the LATL with rTMS. The fact that we were able to eliminate one out of three false memories is significant. Previous studies [26] involving stimulation of the LATL have found that rTMS has a subtle effect on participants. However, for the first time, we demonstrated a potential method for reducing false memories while keeping veridical memory intact.

The LATL is implicated in semantic representation [26], conceptual labelling [7,21,22,24,37] and left fronto-temporal lobe dementia [13,19]. The 36% reduction in false memories after rTMS in false memories is comparable to the advantage people with semantic dementia [32] and autism [3] have over "normals". Our finding is consistent with earlier reports of increased literal awareness following rTMS [35,41] and Miller's account that "loss of function in the LATL may lead to paradoxical functional facilitation" ([38], see also Refs. [13,14]).

Recent fMRI studies have found activation in the frontoparietal cortex while processing false memories [16]. Our finding challenges the view that the frontoparietal region is solely responsible for false memories. It is possible that the decision-making frontal lobes [9] are reliant on input from the repository of schema associated with the LATL. This accords with theories of multi-region processing for complex cognitive tasks and is consistent with a recent review by Pobric et al. [26], who argued that technical limitations of fMRI are biased against signal detection in the anterior temporal lobes unless the fMRI is paired with PET. Importantly, the study demonstrated that inhibition of LATL in normal participants can temporarily lead to semantic impairment in picture and word comprehension tasks, mimicking symptoms of semantic dementia. It concluded that "with impairment to the anterior temporal lobe, core semantic representations become degraded and patients are unable to activate all of the information associated with a concept".

It remains unclear if the reduction in false memories we induced with rTMS is due solely to inhibition of semantic ("concept") centres in the left temporal lobe. It could also be contributed to by a "flow on" disinhibition of analogous (contralateral) areas in the right temporal lobe. These contralateral areas may be associated with literal detail, but are normally inhibited by the cortical areas responsible for "concepts". This possibility is consistent with evidence about hemispheric competition [9,11], as is also the possibility of reversing the inhibition by suppressing the dominant cortical area with rTMS [23,30]. This explanation is consistent with our finding that people's veridical memories remained intact despite inhibition of the semantic centre by rTMS.

Although the neurophysiological mechanisms that contributed to the reduction in false memory after rTMS cannot be specified precisely, it is the behavioural evidence that false memories can be reduced by rTMS that is crucial. A method of reducing false memories while preserving veridical memories has wide-ranging potential applications. Further studies employing different experimental paradigms (e.g. Loftus's misinformation test) and stimulation protocols are underway to expand the generalisability and practical applications of this finding.

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