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Recollection after inhibition: The effects of intentional forgetting on the neural correlates of retrieval

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ABSTRACT

Intentional forgetting is posited to utilize both encoding and inhibition to control what information enters long-term memory. Within the context of the directed forgetting paradigm, evidence for the role of inhibition to support forgetting has been examined primarily during encoding. Specifically, past studies have shown that when encoding processes are intentionally inhibited, information is less likely to be remembered. Despite the recruitment of such inhibitory processes, not all items are successfully forgotten. The current study examined whether items that should have been forgotten (F items), but were ultimately recollected, showed neural evidence at retrieval of having previously undergone attempted inhibition, particularly when compared to items that received “remember” instructions (R items). Results indicate that recollection of F items engaged additional activity in the prefrontal cortex, including the right inferior frontal gyrus and right superior frontal gyrus, suggesting that retrieval of these items required greater effort, most likely due to inhibitory processes that were engaged at encoding. These results suggest that inhibitory processing during attempted but unsuccessful forgetting can result in a more difficult retrieval period.

KEYWORDS

Intentional forgetting;
Inhibition; Retrieval.

Intentional forgetting has been posited to rely on the recruitment of inhibitory mechanisms that prevent the deep encoding or retrieval of irrelevant or outdated information. Neuroimaging research supports this theory, finding that intentional forgetting is associated with activity in the right prefrontal cortex, a region that has been widely implicated in inhibitory control processes (Anderson et al., 2004; Nowicka, Marchewka, Jednorog, Tacikowski, & Brechmann, 2011; Rizio & Dennis, 2013; Wylie, Foxe, & Taylor, 2008). Specifically, within the context of memory paradigms, the right superior/middle frontal gyrus is differentially activated when information is cued to be forgotten compared to when it is cued to be remembered. Moreover, connectivity analyses have provided correlational evidence in support of the inhibitory control theory, demonstrating that activity in the right superior prefrontal cortex (PFC) is negatively correlated with encoding-related activity in the medial temporal lobe (MTL) during successful intentional forgetting, but not during incidental forgetting (Rizio & Dennis, 2013). Likewise, the hippocampus has been shown to be less active during

the suppression of memories as compared to during memory retrieval (Anderson et al., 2004).

Despite the increasing body of research that has focused on better understanding cognitive processes that support intentional forgetting, it is important to consider the fact that not all attempts at forgetting are successful. For example, in the context of the Think/No-Think paradigm (TNT), which elicits inhibitory processes at the time of memory retrieval, only a small portion of to-be-forgotten items, approximately 18%, are actually successfully forgotten (Anderson & Huddleston, 2012). Like the TNT paradigm, successful forgetting is also not achieved for all items in the Directed Forgetting (DF) paradigm, which cues individuals during the initial item presentation to forget certain stimuli (F items), but instructs them to remember others (R items). While a comparison across studies similar to that of Anderson and Huddleston (2012) has not been published, behavioral data presented in seven relatively recent neuroimaging DF studies indicate that approximately 45% of F items were successfully forgotten (statistic calculated from behavioral data published in: Bastin & Van der Linden, 2003; Nowicka

et al., 2011; Paz-Caballero & Menor, 1999; Paz-Caballero, Menor, & Jimenez, 2004; Rizio & Dennis, 2013; Ullsperger, Mecklinger, & Müller, 2000; Wylie et al., 2008). Given that more than half of all F items are not successfully forgotten during directed forgetting, there is an increased need to understand the cognitive processes that are associated with the ultimate retrieval of these items.

It should not be surprising that participants may experience failures in the attempt to forget information, just as they experience failures in attempts to intentionally remember. Neuroimaging research indicates, however, that across both the TNT and DF paradigms, inhibitory activity in the right superior and middle PFC is observed during trials in which participants are instructed to forget information, regardless of whether or not forgetting is successful (e.g., Anderson et al., 2004; Rizio & Dennis, 2013; Wylie et al., 2008). These findings are interpreted as reflecting an individual's attempt to inhibit the memory of the F items, even when that attempt is ultimately unsuccessful (i.e., the F item is subsequently remembered). However, it is unclear whether subsequent retrieval of F items is any more difficult, or is reliant on added cognitive resources, compared to retrieval of R items. To investigate the theory that such memories are influenced to some degree by inhibition attempt, we must examine neural activation at the final retrieval stage.

The current study sought to investigate whether the neural correlates of retrieval success differed depending on the encoding history of the items, within the context of a DF paradigm. Specifically, we explored whether attempted inhibition of encoding affects the neural processes that are recruited at the time of retrieval. With respect to the DF paradigm, most studies have only focused on encoding-related activity (but see Bastin et al., 2012), and none have looked for differences between the neural signatures of retrieval for F and R items. In this way, the current analysis represents a novel attempt at understanding the effect of encoding-related inhibitory processes on retrieval mechanisms. Additionally, most DF studies have used yes/no recognition tests, thereby limiting their ability to examine recollection-based memory responses. By using a Remember/Know/New retrieval task, the current study also allowed for an examination of recollection differences. Observable

differences between the recollection of R and F items may be subtle, but would be a particularly effective way of testing for residual effects of inhibitory processes.

We posited that if an item undergoes attempted inhibitory processing during encoding, the memory trace for this item should be weakened, and as a consequence, its recollection should require more effort than those items that were intentionally encoded. This increased effort during the retrieval of F items should require additional recruitment of activity in the right PFC, including both the inferior and superior frontal gyri, which are consistently associated with retrieval-related effort and task difficulty, particularly after differential encoding instructions have been provided (e.g., Buckner, Koutstaal, Schacter, Wagner, & Rosen, 1998; Schacter, Savage, Alpert, Rauch, & Albert, 1996; Skinner, Fernandes, & Grady, 2009). If attempted inhibition does not affect the storage of F items, however, then retrieval activity should not differ for F and R items.

Methods

Participants

Twenty-seven adults between the ages of 18 and 24 participated for monetary compensation. The data from three participants were excluded because of scanner issues (two participants) and failure to follow instructions (one participant). Thus, 24 participants (mean age = 20.88 years, $SD = 1.62$) were included in the final analysis. All participants were healthy, right-handed, native English speakers, with no history of neurological or psychiatric episodes. Before scanning, all participants completed a battery of neuropsychological tests to measure cognitive processes related to speed, memory, and language function. All participants scored above 27 on the Mini Mental State Examination (MMSE) (Folstein, Folstein, & McHugh, 1975) and no participant scored below two standard deviations of the age-matched normative score on any of the other neuropsychological tests. All participants provided written informed consent, and the Pennsylvania State University Institutional Review Board approved all procedures.

Materials

Three hundred sixty nouns were chosen. Words had an average Kucera-Francis written frequency of 110 (range: 50–275), and an average concreteness of 433 (range: 254–600). One hundred words were randomly marked as to-be-remembered (R items), another 100 were marked as to-be-forgotten (F items) during encoding, and the remaining 160 were used as “new” items during the recognition test.

Procedure

The experiment employed a traditional item method Directed Forgetting paradigm. During encoding, which took place in the scanner, each of the 200 R and F items appeared individually on the screen for 1000 ms, and were followed by a fixation cross that remained on the screen for 2000 ms. Following the delay, a set of five colored pound signs was presented for 3000 ms (see Rizio & Dennis, 2013 for figures depicting the task). Participants were instructed that words followed by green pound signs should be remembered (R items), as they would appear on an upcoming memory test, and words followed by red pound signs should be forgotten (F items), as they would not be on the memory test. The encoding trials were broken into five blocks of 40 words, with R items and F items appearing in a pseudorandom order, such that no more than three of the same trial type appeared sequentially.

Following encoding, participants completed a 10-minute interference task (the Matrix Reasoning subtest of the WAIS). Next, participants performed the retrieval task in the scanner, which included the presentation of 360 words: The 100 R items and 100 F items from encoding, and 160 new words. Each word appeared individually on the screen for 2500 ms, and participants made a Remember/Know/New memory decision during that time (Yonelinas & Jacoby, 1995). Each trial was followed by a jittered fixation that lasted between 1500 and 3000 ms, and averaged 2000 ms. It was stressed to the participants that their memory response should *not* depend on whether the word had been marked as R or F during the study phase, but should instead depend only on whether the word was old or new.

Image acquisition

Imaging data were acquired using a 3T Siemens Magnetom Trio MRI scanner. Functional retrieval data were obtained in five, 5.60-minute runs, each consisting of a total of 168 volumes. Images were collected using an echo-planar imaging (EPI) sequence with a 2-second repetition time (TR), 30 ms echo time (TE), 240 mm field of view (FOV), and a 70-degree flip angle. Thirty-four slices were acquired per TR, with a slice thickness of 3.8 mm, resulting in 3.8 mm³ isotropic voxels. Structural images were acquired during the interference task, using a T1 weighted gradient echo sequence MPRAGE, with a TR of 2300 ms, a TE of 3.41 ms, a 230 mm FOV, and a voxel size of 0.9 mm³.

Image processing

Preprocessing and statistical analyses were performed using Statistical Parameter Mapping software in MATLAB (R2010.A; SPM8, 2008). Data were slice-timing corrected, realigned, normalized to the Montreal Neurological Institute (MNI) template, and smoothed with an 8 mm Gaussian smoothing kernel. No individual moved more than 3 mm in any direction in any run. Clusters of significant activation were converted to Talairach coordinates (Talairach & Tournoux, 1988) and are reported as such in all tables.

Data analysis

Encoding-related activity has been reported previously (Rizio & Dennis, 2013, 2014), and the current work focuses only on activity during retrieval. Trial-related activity was modeled with a general linear model (GLM) for each participant with a stick function corresponding to stimulus onsets, convolved with a hemodynamic response function (HRF). Confounding factors, including head motion and magnetic field drift, were also included in the model. Statistical Parametric Maps were identified for each participant by applying linear contrasts with the parameter estimates (beta weights) for the events of interest, resulting in a *t*-statistic for every voxel.

Given that our goal was to examine neural activity associated with successful retrieval, we focused our analyses on R and F items that were “remembered.”

All other trial types (familiarity hits, misses, correct rejections, and false alarms) were treated as regressors of no interest. The choice to focus on recollection was based on our interest in assessing the role of cognitive control and inhibitory processes as they pertain to the most item-specific form of recognition memory. Additionally, because recollection and familiarity have been shown to rely on distinct regions, focusing entirely on recollection ensures that the memory signal is not weakened by the inclusion of two separate, independent memory responses (Henson, Rugg, Shallice, Josephs, & Dolan, 1999; Ranganath et al., 2004).

To obtain results that were corrected for multiple comparisons, we used Monte Carlo simulations (<https://www2.bc.edu/sd-slotnick/scripts.htm>) to define individual voxel and cluster extent thresholds (e.g., Slotnick, Moo, Segal, & Hart, 2003). In this study, an individual voxel threshold of $p < .005$ was used in combination with a cluster extent threshold of 19 voxels (1043 mm³), which yielded results corrected for multiple comparisons at $p < .05$.

In order to confirm that our paradigm produced a typical pattern of retrieval success activation, we first compared recollection activity to forgetting activity, collapsing across R and F items. To investigate the role of encoding instruction on successful retrieval, a direct comparison between recollection of F items and recollection of R items was conducted (F item-Recollect > R item-Recollect). This contrast was exclusively masked with the contrast F item-Forget > R item-Forget in order to ensure that any observed differences were unique to successful recollection, and not driven entirely by study history (i.e., general differences between all F and R items). While results for the contrast of interest were corrected for multiple comparisons using the method described above, the exclusive mask was created at the more liberal threshold of $p < .05$ (uncorrected) and 10 voxels.

Results

Behavioral results

Intentional forgetting is frequently measured by comparing the rates of successful memory between R and F items. Participants exhibited significant intentional forgetting ($t(23) = 6.05$,

Table 1. Rate of response and reaction time as a function of trial type.

Word type	Rate of response	Reaction time (ms)
	Mean (SE)	Mean (SE)
R Items		
Recollection	0.43 (0.09)	1231.52 (30.90)
Familiarity	0.30 (0.06)	1560.87 (49.80)
Forget	0.27 (0.05)	1497.84 (52.70)
F Items		
Recollection	0.26 (0.05)	1316.18 (41.33)
Familiarity	0.35 (0.07)	1484.36 (41.59)
Forget	0.39 (0.08)	1473.06 (54.25)
Foil		
Recollection	0.09 (0.02)	1412.93 (44.31)
Familiarity	0.30 (0.06)	1552.73 (45.33)
Correct Rejection	0.61 (0.12)	1434.09 (51.03)

Notes: R Items = Words that participants were instructed to remember; F Items = Words that participants were instructed to forget

$p < .001$), such that rates of successful retrieval for R items ($M = 0.73$, $SE = 0.15$) were greater than that for F items ($M = 0.60$, $SE = 0.12$) when collapsing across recollection and familiarity. Participants also exhibited intentional forgetting when considering only recollection ($t(23) = 5.57$, $p < .001$), such that they produced greater rates of recollection for R items ($M = 0.43$, $SE = 0.09$) than for F items ($M = 0.26$, $SE = 0.05$). A comparison of reaction times between the two trial types of interest revealed significant differences ($t(23) = 4.13$, $p < .001$), such that recollection responses to F items ($M = 1316.18$ ms, $SE = 41.33$) took significantly more time than recollection responses to R items ($M = 1231.52$ ms, $SE = 30.90$) (see Table 1 for all means and standard errors).

Neuroimaging results

Retrieval success activity was found throughout the typical retrieval network, including bilateral prefrontal, parietal, and temporal cortices, as well as the right parahippocampal gyrus during successful recollection as compared to forgetting (see Table 2). These results indicate that even in the context of an intentional forgetting paradigm, participants activated the typical retrieval network.

Focusing on differences in recollection-related activation, F items recruited greater activity in the right inferior frontal gyrus and right superior frontal gyrus as compared to R items (see Figure 1 and Table 3).

Table 2. Successful recollection (recollection > forgetting).

	BA	H	Coordinates (T&T)			t	mm ³	voxels
			X	Y	Z			
Middle Frontal Gyrus	9	L	-49	24	30	9.43	213178	3885
Inferior Frontal Gyrus	47	L	-33	23	-5			*
Superior Frontal Gyrus	11	L	-30	56	-10			*
Medial Frontal Gyrus	8	M	-8	26	46			*
Middle Frontal Gyrus	8	R	41	18	43			*
Superior Frontal Gyrus	8	R	33	26	53			*
Inferior Frontal Gyrus	47	R	26	23	-11			*
Precuneus	7	M	-4	-66	41			*
Anterior Cingulate	32	M	-2	32	25			*
Posterior Cingulate	31	M	-2	-33	30			*
Cuneus	17	L	-14	-84	6			*
Middle Frontal Gyrus	10	R	41	53	7	3.84		40
Parahippocampal Gyrus	35	L	-19	-28	-9	3.88		19
Middle Temporal Gyrus	20	L	-60	-32	-12	5.60		137
Middle Temporal Gyrus	21	R	67	-42	1	4.20		31
Inferior Parietal	40	R	49	-40	56	3.05		200
Inferior Parietal	40	L	-41	-62	47	8.88		424
Superior Parietal	7	R	38	-66	52	6.96		200
Middle Occipital Gyrus	19	R	41	-82	7	4.73		66
Cerebellum	—	R	11	-81	-31	5.07		64
Cerebellum	—	R	4	-55	33	4.53		85
Cerebellum	—	L	-8	-80	-25	4.11		85
Cerebellum	—	L	-11	-58	-23	3.21		85
Cerebellum	—	M	0	-47	-17	3.60		19

Notes: BA = Brodmann's Area; H = Hemisphere; t = statistical t value; T&T = Talairach and Tournoux coordinates; R = Right; L = Left; M = Midline; * = Representative peaks from large cluster.

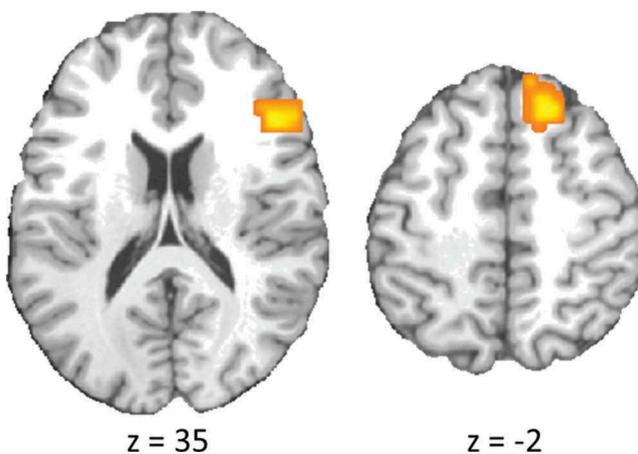


Figure 1. Recollection-related activity following an instruction to forget. Participants recruited significantly greater activity in right inferior and superior frontal gyri during the recollection of F items compared to the recollection of R items (see Table 3 for cluster extent information).

Discussion

The purpose of the current investigation was to explore whether or not items that should have been forgotten, but were ultimately recollected, showed evidence of attempted inhibition at retrieval.

Table 3. Recollection after an instruction to forget (recollection of F items > recollection of R items).

	BA	H	Coordinates (T&T)			t	mm ³	voxels
			X	Y	Z			
Inferior Frontal Gyrus	45	R	49	28	14	4.05	1975	36
Superior Frontal Gyrus	8	R	19	32	52	3.96	2359	43

Notes: BA = Brodmann's Area; H = Hemisphere; t = statistical t value; T&T = Talairach and Tournoux coordinates; R = Right; L = Left; M = Midline

When comparing the neural processes that support the recollection of F items with those that support the recollection of R items, we found that participants recruited more activity in the right inferior and superior frontal gyri. As our results were exclusively masked with the contrast F item-Forget > R item-Forget, the observed increase in activation was not a general characteristic of retrieval-related activity for all F items, but was instead unique to only those F items that were recollected.

While the DF paradigm is based on the premise that memories are inhibited at encoding, our results indicate that the cognitive control mechanisms that underlie intentional forgetting can also be observed at the level of retrieval. Specifically, participants recruited more PFC activation during the recollection of items they had been instructed to forget at encoding as compared to items they had been instructed to remember. While some research indicates that regions of the PFC specifically support retrieval success (e.g., McDermott, Jones, Petersen, Lageman, & Roediger, 2000), both sides of our contrasts of interest were composed of recollected items (i.e., successful retrieval), with the only difference being the instructions that were associated with the items at encoding. As such, the observed increase in PFC activation for recollection of F items as compared to that of R items requires an alternative explanation. The dorsolateral PFC and inferior frontal gyrus (including BAs 45 and 46) have been associated with retrieval effort (Buckner et al., 1998; Maril, Wagner, & Schacter, 2001; Schacter, Alpert, Savage, Rauch, & Albert, 1996), while the right superior frontal cortex (BAs 8/9) has been shown to distinguish retrieval effort from retrieval success (Skinner et al., 2009). The specific BA regions identified in past studies of retrieval effort are quite similar to those reported in the current study. Thus, in line with our predictions, our results suggest that recollection of F items requires more effort during retrieval than those that were intentionally encoded.

We posit that the greater effort utilized during retrieval of F items is a result of inhibitory processes employed during encoding that limited the strength of the encoding episode and weakened the memory trace. Previous neuroimaging research has provided evidence that active inhibitory processes support intentional forgetting during encoding stages (Rizio & Dennis, 2013; Wylie et al., 2008). Our work, combined with these past results, strongly indicates that even those F items that are ultimately recollected undergo some degree of inhibition at encoding, and that this inhibition has a lasting effect on memory processing.

Two additional pieces of evidence support the theory that the observed PFC activation reflects the greater effort needed to recollect F items, as compared to R items. First, making a recollection decision for F items took significantly more time than the same decision for R items. This pattern is consistent with past literature suggesting that longer latencies are associated with weaker memory traces, thus making it more difficult to respond (e.g., Doshier, 1982; Nelson & Narens, 1980). The difference in response latency was rather small (85 ms), and it is unlikely that the observed PFC activation is due to differences in time on task, because such differences should also be associated with differences in activation in low-level perceptual processing regions, such as the visual cortex. Because the only observed differences occur in the PFC, the pattern of response latencies confirms the theory that recollection of F items is more difficult than R items.

Second, we wish to make the claim that recollection of F items is more difficult and requires greater effort, specifically because these items had undergone attempted, albeit unsuccessful, inhibition during encoding. For this to be true, inhibitory-related activity at encoding should be observed for these items. An additional analysis of previously published data (from Rizio & Dennis, 2013) confirms this, as F items that were subsequently recollected were associated with greater activation of the right superior frontal gyrus and inferior parietal lobe *at encoding*, compared to R items that were subsequently recollected. Activity in these regions has previously been associated with both inhibitory attempt and success during the encoding period of the Directed Forgetting paradigm (Rizio & Dennis, 2013; Wylie et al., 2008), and their activation supports the notion

that recollection of F items is more difficult precisely because inhibitory processes were engaged at the time of their initial presentation. An alternative explanation for this pattern could be offered, such that it is possible the increased PFC activation reflects residual inhibitory processing, or a combination of residual inhibition and increased effort. Additional research will be needed to further explore this possibility, and in particular, examine whether or not inhibitory control and intentional forgetting, which are typically observed as a transient process that cannot be maintained over a long delay, could be observed several minutes after the initial item presentation (MacLeod & Macrae, 2001).

The current results are supported by electrophysiological studies, which have illustrated that neural activation at retrieval differs as a function of encoding instructions (Paz-Caballero & Menor, 1999; Ullsperger et al., 2000; Van Hooff, Whitaker, & Ford, 2009). Like the current study, these studies suggest that F items are more difficult to retrieve than R items, potentially because they underwent inhibition at encoding (Paz-Caballero & Menor, 1999; Ullsperger et al., 2000). Specifically, the retrieval of F items, compared to R items, elicited enhanced positivity within the 200–300 ms range, which has been interpreted as reflecting difficulty accessing the semantic representations of the words, a sign that they were not encoded to the same degree as R items (Paz-Caballero & Menor, 1999). Additional electrophysiological work has found larger parietal old/new effects for R items compared to F items, suggesting that an instruction to remember results in retrieval that is based on recollection, whereas an instruction to forget results in a reliance on familiarity at retrieval (Van Hooff et al., 2009). Similarly, the only other fMRI study that has explored the neural correlates of retrieval following intentional forgetting revealed that the successful retrieval of F items recruited more activation in regions associated with familiarity processing than did the failed retrieval of F items (i.e., F items that were forgotten; Bastin et al., 2012). Our results, combined with past studies, provide evidence that even those F items that are successfully recollected do not undergo the same extent of encoding as similarly recollected R items. Rather, inhibitory processes, even those that ultimately fail, appear to degrade the memory trace for F items in a way that makes them more difficult to retrieve at

test. Moreover, our results provide additional nuance to this theory, as our analyses separated different types of memory responses and the contrast of interest focused entirely on recollection. For this reason, we can conclude that recollection-based decisions are made more difficult by providing an instruction to forget at encoding, but can reject the notion that participants rely on familiarity-based processing to make retrieval decisions following inhibition, since familiarity responses were not included in the analysis.

Conclusion

Our results indicate that encoding processes within the DF paradigm have a significant impact on retrieval mechanisms. Specifically, the recollection of information associated with an instruction to forget was found to exhibit greater activity in PFC regions than the recollection of information that was intentionally encoded. This suggests that most F items, even if they are ultimately remembered, likely undergo inhibitory processing at encoding, which leads to a weaker and less accessible memory trace during retrieval. The effects of such inhibition appear to require the recruitment of greater retrieval effort to recollect these F items, as compared to items that were intentionally encoded and recollected. Together, these data provide insight into the way in which irrelevant information is both inhibited and recollected.

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Disclosure statement

The authors declare that no competing interests exist, financial or otherwise.

References

- Anderson, M. C., & Huddleston, E. (2012). Towards a cognitive and neurobiological model of motivated forgetting. *True and False Recovered Memories: Toward a Reconciliation of the Debate*, 58, 53–120. doi:10.1007/978-1-4614-1195-6_3
- Anderson, M. C., Ochsner, K. N., Kuhl, B., Cooper, J., Robertson, E., Gabrieli, S. W., ... Gabrieli, J. D. (2004). Neural systems underlying the suppression of unwanted memories. *Science*, 303(5655), 232–235. doi:10.1126/science.1089504
- Bastin, C., Feyers, D., Majerus, S., Balteau, E., Degueldre, C., Luxen, A., ... Rustichini, A. (2012). The neural substrates of memory suppression: A fMRI exploration of directed forgetting. *PLoS ONE*, 7(1), e29905. doi:10.1371/journal.pone.0029905
- Bastin, C., & Van der Linden, M. (2003). The contribution of recollection and familiarity to recognition memory: A study of the effects of test format and aging. *Neuropsychology*, 17(1), 14–24. doi:10.1037/0894-4105.17.1.14
- Buckner, R. L., Koutstaal, W., Schacter, D. L., Wagner, A. D., & Rosen, B. R. (1998). Functional-anatomic study of episodic retrieval using fMRI. I. Retrieval effort versus retrieval success. *Neuroimage*, 7(3), 151–162. doi:10.1006/nimg.1998.0327
- Dosher, B. A. (1982). Effect of sentence size and network distance on retrieval speed. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 8(3), 173–207. doi:10.1037/0278-7393.8.3.173
- Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Minimal state". A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research*, 12(3), 189–198. doi:10.1016/0022-3956(75)90026-6
- Henson, R. N., Rugg, M. D., Shallice, T., Josephs, O., & Dolan, R. J. (1999). Recollection and familiarity in recognition memory: An event-related functional magnetic resonance imaging study. *Journal of Neuroscience*, 19(10), 3962–3972.
- MacLeod, M. D., & Macrae, C. N. (2001). Gone but not forgotten: The transient nature of retrieval-induced forgetting. *Psychological Science*, 12(2), 148–152. doi:10.1111/1467-9280.00325
- Maril, A., Wagner, A. D., & Schacter, D. L. (2001). On the tip of the tongue. An event-related fMRI study of semantic retrieval failure and cognitive conflict. *Neuron*, 31(4), 653–660. doi:10.1016/S0896-6273(01)00396-8
- MATLAB (2010) [Computer software]. http://uk.mathworks.com/products/new_products/release2007b.html
- McDermott, K. B., Jones, T. C., Petersen, S. E., Lageman, S. K., & Roediger, H. L. (2000). Retrieval success is accompanied by enhanced activation in anterior prefrontal cortex during recognition memory: An event-related fMRI study. *Journal of Cognitive Neuroscience*, 12(6), 965–976. doi:10.1162/08989290051137503
- Nelson, T. O., & Narens, L. (1980). Norms of 300 general-information questions: Accuracy of recall, latency of recall, and feeling-of-knowing ratings. *Journal of Verbal Learning and Verbal Behavior*, 19(3), 338–368. doi:10.1016/S0022-5371(80)90266-2
- Nowicka, A., Marchewka, A., Jednorog, K., Tacikowski, P., & Brechmann, A. (2011). Forgetting of emotional information is hard: An fMRI study of directed forgetting. *Cerebral Cortex*, 21(3), 539–549. doi:10.1093/cercor/bhq117
- Paz-Caballero, M. D., & Menor, J. (1999). ERP correlates of directed forgetting effects in direct and indirect memory

- tests. *European Journal of Cognitive Psychology*, 11(2), 239–260. doi:10.1080/713752308
- Paz-Caballero, M. D., Menor, J., & Jimenez, J. M. (2004). Predictive validity of event-related potentials (ERPs) in relation to the directed forgetting effects. *Clinical Neurophysiology*, 115(2), 369–377. doi:10.1016/j.clinph.2003.09.011
- Ranganath, C., Yonelinas, A. P., Cohen, M. X., Dy, C. J., Tom, S. M., & D'Esposito, M. (2004). Dissociable correlates of recollection and familiarity within the medial temporal lobes. *Neuropsychologia*, 42(1), 2–13. doi:10.1016/j.neuropsychologia.2003.07.006
- Rizio, A. A., & Dennis, N. A. (2013). The neural correlates of cognitive control: Successful remembering and intentional forgetting. *Journal of Cognitive Neuroscience*, 25(2), 297–312. doi:10.1162/jocn_a_00310
- Rizio, A. A., & Dennis, N. A. (2014). The cognitive control of memory: Age differences in the neural correlates of successful remembering and intentional forgetting. *PLoS ONE*, 9(1), e87010. doi:10.1371/journal.pone.0087010
- Schacter, D. L., Alpert, N. M., Savage, C. R., Rauch, S. L., & Albert, M. S. (1996). Conscious recollection and the human hippocampal formation: Evidence from positron emission tomography. *Proceedings of the National Academy of Sciences of the United States of America*, 93(1), 321–325. doi:10.1073/pnas.93.1.321
- Schacter, D. L., Savage, C. R., Alpert, N. M., Rauch, S. L., & Albert, M. S. (1996). The role of hippocampus and frontal cortex in age-related memory changes: A PET study. *Neuroreport*, 7, 1165–1169. doi:10.1097/00001756-199604260-00014
- Skinner, E. I., Fernandes, M. A., & Grady, C. L. (2009). Memory networks supporting retrieval effort and retrieval success under conditions of full and divided attention. *Experimental Psychology*, 56(6), 386–396. doi:10.1027/1618-3169.56.6.386
- Slotnick, S. D., Moo, L. R., Segal, J. B., & Hart, J. (2003). Distinct prefrontal cortex activity associated with item memory and source memory for visual shapes. *Cognitive Brain Research*, 17(1), 75–82. doi:10.1016/S0926-6410(03)00082-X
- SPM8 (2008) [Computer software]. <http://www.fil.ion.ucl.ac.uk/spm/software/spm8/>
- Talairach, J., & Tournoux, P. (1988). *Co-planar stereotaxic atlas of the human brain*. Stuttgart, Germany: Thieme.
- Ullsperger, M., Mecklinger, A., & Müller, U. (2000). An electrophysiological test of directed forgetting: The role of retrieval inhibition. *Journal of Cognitive Neuroscience*, 12(6), 924–940. doi:10.1162/08989290051137477
- Van Hooff, J. C., Whitaker, T. A., & Ford, R. M. (2009). Directed forgetting in direct and indirect tests of memory: Seeking evidence of retrieval inhibition using electrophysiological measures. *Brain and Cognition*, 71(2), 153–164. doi:10.1016/j.bandc.2009.05.001
- Wylie, G. R., Foxe, J. J., & Taylor, T. L. (2008). Forgetting as an active process: An fMRI investigation of item-method-directed forgetting. *Cerebral Cortex*, 18(3), 670–682. doi:10.1093/cercor/bhm101
- Yonelinas, A. P., & Jacoby, L. L. (1995). The relation between remembering and knowing as bases for recognition - Effects of size congruency. *Journal of Memory and Language*, 34(5), 622–643. doi:10.1006/jmla.1995.1028