Encoding Mechanisms in Directed Forgetting

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Date: 2021-02-28T00:00:00+00:00

Abstract

Does directed forgetting (intentional forgetting) require cognitive effort? Some studies have found that directed forgetting may be the result of passive decay, wherein F items (items to be forgotten) fail to receive effective rehearsal because selective rehearsal is allocated to R items (items to be remembered), a processing mechanism that does not require cognitive effort. However, other research has demonstrated that the directed forgetting process may involve active inhibition of memory processing triggered by forgetting cues, which consumes cognitive effort, with frontal ERP components observed in cognitive neuroscience studies providing evidence for this mechanism. An alternative perspective suggests that the directed forgetting encoding process may simultaneously encompass both active inhibition and passive decay, though the manner in which these two processing mechanisms interact remains unclear. To further elucidate the cognitive mechanisms underlying the directed forgetting encoding stage, future research should incorporate non-cognitive factors into investigation and examine directed forgetting characteristics across different populations, thereby attempting to resolve theoretical controversies.

Full Text

Encoding Mechanism in Directed Forgetting

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Abstract

Does intentional forgetting require cognitive effort? Some studies suggest that directed forgetting results from passive decay—specifically, that F items (to-be-forgotten items) fail to receive effective rehearsal because R items (to-be-remembered items) are selectively rehearsed, a process that does not require cognitive effort. However, other research indicates that directed forgetting involves active inhibition of memory processing induced by forgetting cues, which apparently consumes cognitive effort. Evidence for this mechanism comes from frontal lobe ERP components observed in brain cognition research. An alternative view posits that the encoding process in directed forgetting may involve both active inhibition and passive decay, though how these two mechanisms interact remains unclear. To further clarify the cognitive mechanisms underlying the encoding stage of directed forgetting, future research needs to incorporate non-cognitive factors and examine directed forgetting characteristics across different populations, thereby attempting to resolve theoretical controversies.

Keywords: directed forgetting, encoding stage, active inhibition, passive decay

Memory is one of humanity’ s crucial cognitive functions, yet effective memory necessarily entails effective forgetting. As an integral part of memory function, forgetting plays a vital role in daily life. Forgetting helps us update memory systems, eliminate unnecessary memory traces, reduce the impact of negative information, and enhance memory efficiency. Consequently, the cognitive mechanisms of forgetting have long been a central focus for psychologists.

The cognitive mechanisms underlying forgetting are complex. Some forgetting occurs passively, while others require active engagement from the individual. Forgetting can be intentional and under active control (Lee & Lee, 2011). Because this forgetting process is purposefully accomplished by participants, it is also termed intentional forgetting. As Anderson and Hanslmayr (2014) noted, forgetting theories that ignore consciousness’ s control over forgetting would overlook a substantial force shaping our memory outcomes—precisely why an increasing number of psychologists are focusing on intentional forgetting. Generally, intentional forgetting in psychological research refers to the process where individuals perform corresponding cognitive processing tasks under the instruction of a forgetting cue (typically including memory instructions, with memory effects compared between the two to demonstrate forgetting). This research process is commonly called directed forgetting.

Directed forgetting was first proposed by Bjork et al. (1968). To date, two primary research paradigms have developed: the item-method directed forgetting paradigm (Fawcett & Taylor, 2008; Gallant et al., 2017; van Hooff & Ford, 2011) and the list-method directed forgetting paradigm (Pastötter et al., 2015; Sahakyan et al., 2020). Both paradigms consist of two phases: an encoding stage and a retrieval stage. The main difference between them lies in how forgetting or memory materials are presented during encoding. In the item-method paradigm, study items are presented one by one, followed randomly by “remember” or “forget” instructions (called R-cues and F-cues respectively). Participants are asked to remember or forget the study items according to these cues. The corresponding study items are labeled TBR (To-be-remembered, abbreviated as R items) and TBF (To-be-forgotten, abbreviated as F items). The list-method paradigm typically divides study items into two lists. After studying the first list, an instruction is presented to forget or remember the previously shown list, after which participants study and remember the second list. Both methods examine participants' memory performance for presented items during the test phase. If R items are recognized or remembered better than F items, a directed forgetting effect is demonstrated (Fawcett & Taylor, 2008). Given that most research on the encoding mechanisms of directed forgetting employs the item-method paradigm (particularly in cognitive neuroscience experiments), this paradigm will be the focus of the present paper.

Most psychological experiments using the item-method to study directed forgetting have found significant directed forgetting effects. During this process, selective rehearsal of memory items (R items) leads participants to perform better on subsequent tests for R items than for F items. However, two opposing views exist regarding the forgetting of F items. Passive decay theory posits that F items do not receive the same elaborative processing as R items and therefore gradually fade from memory—a passive process (Lee, 2012; Lee, 2017) that does not consume cognitive effort. Active inhibition theory, conversely, argues that forgetting of F items involves active participation from the individual, resulting from F-cue-induced active inhibition of F items (Fawcett & Taylor, 2008; Fawcett & Taylor, 2010; Fawcett & Taylor, 2012). Numerous behavioral and cognitive neuroscience experiments have provided evidence for this theory (Gao et al., 2018; Jing et al., 2019; Ludowig et al., 2010; Rizio & Dennis, 2013). Currently, controversy between these two theories persists. This paper will review research on the processing mechanisms during the encoding stage of directed forgetting from the perspective of this controversy and propose future research directions.

2 Cognitive Processing Mechanisms of Directed Forgetting: Passive Decay or Active Inhibition?

Most research on directed forgetting attributes forgetting to either passive decay or active inhibition. Both theories have supporting evidence from behavioral experiments.

2.1 Passive Decay in Directed Forgetting: Theory and Evidence

A representative of passive decay theory is Popov et al. (2019). Using the item-method, this study examined how previously learned items affected subsequent item learning. They found that R items appearing after F items were remembered better than R items appearing after other R items, and this effect was cumulative—the more preceding F items, the better the memory performance for subsequent R items. This result supports passive decay theory because passive decay does not consume cognitive resources. Consequently, R items following F items have more cognitive resources available for processing than R items following other R items, and the more preceding F items, the more cognitive resources accumulate, leading to better memory performance for subsequent R items. This contradicts active inhibition theory, which posits that active inhibition consumes more cognitive resources than memory (Fawcett & Taylor, 2008). Under this view, R items following F items would have insufficient resources for processing, resulting in poorer memory performance.

Tan et al. (2020) employed a novel item-method paradigm to study directed forgetting. They modified the single F and R learning items into paired items. Each pair was either in a uniform condition (both words to be remembered or both forgotten, i.e., R-R/F-F) or a mixed condition (remember one and forget the other, i.e., R-F/F-R). The study found that R items were remembered better in mixed conditions than in uniform conditions. This result supports passive decay theory (in R-F/F-R conditions, only the R item needs to be remembered; the F item does not require selective rehearsal and will gradually decay without occupying cognitive resources, so R-F/F-R items are remembered better than R-R items) and contradicts predictions from active inhibition theory (in R-F/F-R conditions, the F item would consume more cognitive resources to inhibit, leaving fewer resources for the R item, thus weakening R item memory performance). Additionally, some studies, while not explicitly mentioning passive decay, are based on its principles. For example, Lee (2012) proposed the processing load hypothesis of directed forgetting through three experiments using the item-method paradigm, suggesting that the fewer cognitive resources allocated to F items during encoding, the fewer opportunities for selective rehearsal they receive, making them easier to forget and gradually decay from memory. Collectively, these studies suggest that forgetting of F items can be explained from a passive perspective: when cognitive resources are expended on R items, few resources remain for processing F items, which fade from memory without rehearsal, naturally requiring no cognitive effort.

2.2 Active Inhibition in Directed Forgetting: Theory and Evidence

Early evidence for active inhibition theory came from Zacks et al. (1996), who compared directed forgetting mechanisms between younger and older adults. However, Fawcett and Taylor (2008) argued that the interpretation of Zacks et al.' s (1996) results was not unique and lacked direct evidence. They therefore designed a new experiment that inserted a probe stimulus after R-cues and F-cues. The experiment found that when the probe stimulus appeared 1400ms or 1800ms after the cue, response times for the probe task were longer following F items than following R items, indicating that F items involved a more cognitively resource-consuming processing. However, this effect disappeared when the probe stimulus appeared 2600ms after the cue. This research demonstrates that forgetting during directed forgetting encoding does consume cognitive resources, possibly reflecting active inhibitory attention control, though this inhibitory process may be completed within a relatively short time frame. The study did not discuss the specific time course of inhibition. While these results have been interpreted as supporting active inhibition theory, some researchers argue that the prolonged response times shortly after forgetting may not be caused by forgetting itself but rather by attentional shifting—specifically, that shifting attention from F-cues to other stimuli consumes cognitive resources, resulting in longer probe response times following F-cues (Tan et al., 2020). This challenge has yet to be verified.

In addition to examining the active versus passive nature of forgetting through cognitive resource utilization, researchers can also investigate subjective effort levels, which are closely linked to motivation. Foster and Sahakyan (2012) introduced motivational components by dividing to-be-forgotten materials into two categories assigned -5 points and 0 points. Participants were told that if they remembered a -5 point item, 5 points would be deducted from their total score, but no points would be deducted if they forgot it. For 0-point items, neither remembering nor forgetting affected the score. This arrangement gave participants stronger motivation to forget the high-cost items. During the test phase, to prevent participants from falsely complying with experimenters' expectations to gain more points, the experimenter announced before testing that the point deduction would be canceled and changed the instructions to "10 points will be added for each word recalled from previously presented items." Results showed that -5 point items were forgotten better than 0-point items. Because failing to forget -5 point items during encoding would incur substantial costs, the superior forgetting effect demonstrates that forgetting is an active cognitive processing mechanism. In contrast, 0-point items, being a relatively passive process without cost consequences, were not forgotten as effectively.

Some studies, while not directly using active inhibition to explain directed forgetting, have produced results consistent with active inhibition theory. Bancroft et al. (2013) discovered a surprising phenomenon: when presentation durations for both R-cues and F-cues were extended, memory performance for both R and F items improved, and by similar magnitudes. This result clearly cannot be explained by passive decay resulting from selective rehearsal (because according to selective rehearsal, longer processing time should weaken F item memory) but better fits an active inhibition mechanism for F items (as cue duration extends, continuously applying cognitive effort to inhibit F items becomes more difficult, allowing more F items to enter memory). This study suggests that time parameters must be considered in directed forgetting research because active inhibition effects disappear after exceeding certain durations.

Active inhibition theory is supported not only by behavioral experiments but also by most EEG studies. ERP research has found that during the encoding stage of directed forgetting, F-cues elicit larger N2 components in the frontal lobe, reflecting active inhibition of memory (Gallant & Dyson, 2016; Paz-Caballero et al., 2004), while R-cues elicit larger P3 components in the parietal lobe, reflecting selective rehearsal of memory items (Ye et al., 2019). This combination of active inhibition of F items and selective rehearsal of R items produces the significant directed forgetting effect. To more precisely localize the brain regions involved in active inhibition, Ludowig et al. (2010) used intracranial event-related potentials and found that F-cues elicited reduced negative ERP components in the hippocampus, reflecting the hippocampus' s inhibitory function on F items. Gao et al. (2018) found that F items elicited stronger frontal N2 components and parietal P3 and LPC components than R items, indicating that F-cues could trigger stronger cognitive control, leaving fewer cognitive resources available for subsequent reprocessing of F items. However, Gao et al. (2019) opposed interpreting frontal ERP components as markers of active inhibition, suggesting they might reflect not enhanced memory inhibition but rather broad attentional control.

Beyond EEG evidence, brain imaging results also support directed forgetting as a complex active inhibition process. Rizio and Dennis (2013) found that encoding-related processes in the left inferior PFC and medial temporal lobe (MTL) contributed to subsequent memory success, while inhibitory processes in the right superior frontal lobe and right inferior parietal lobe contributed to subsequent forgetting success. Furthermore, connectivity analysis revealed that during successful intentional forgetting, activity in the right superior frontal cortex was negatively correlated with activity in the left MTL, a pattern not observed during incidental forgetting or encoding. This indicates that inhibition and encoding activities interact, and that successful forgetting of F items in directed forgetting relates to suppressed brain regions, whereas incidental forgetting or encoding involves no inhibitory processes and only connects with encoding regions. Rizio and Dennis (2013) confirmed that F items successfully recalled during the retrieval phase elicited stronger activity in the right inferior prefrontal and parietal regions compared to successfully remembered R items, with stronger activation in these regions potentially representing active inhibitory effects from the encoding phase. Rizio and Dennis (2017) further examined retrieval-phase brain mechanisms, finding that recalling F items elicited stronger activity in the prefrontal cortex, right superior frontal gyrus, and inferior frontal gyrus than recalling R items. Combined with their 2013 results, they speculated that inhibition of F items during encoding made retrieving F items during the retrieval phase more cognitively demanding. However, this study did not directly confirm encoding-phase inhibitory mechanisms, as the difficulty recalling F items could also result from passive decay during encoding that substantially reduced F item memory traces, requiring more effort during retrieval.

Other brain mechanism studies supporting active inhibition theory include Xie et al.' s (2020) transcranial magnetic stimulation experiment, which found that the right dorsolateral prefrontal cortex plays an important role in inhibiting and controlling memory. The EEG, brain imaging, and TMS experiments described above all indicate that memory inhibition activities have extensive neural underpinnings, though precise brain region localization and working mechanisms require further exploration.

Researchers have offered explanations for these results supporting active inhibition mechanisms in directed forgetting. Hourihan and Taylor (2006) emphasized the active nature of inhibition, proposing that processing of F-cues is a cognitive stopping process that competes with the active encoding process for R-cues.

When F-cues win this competition, they prevent attention from returning to F items. Hourihan and Taylor (2006) and Barnier et al. (2007), when studying directed forgetting characteristics in autobiographical memory, suggested that forgetting may relate to different memory requirements that create competitive relationships similar to retrieval-induced forgetting mechanisms but with differences. While this research can partially explain active inhibition in directed forgetting, its use of episodic memory-like stimulus materials—materials that are more distinct and less competitive than traditional word stimuli—means the hypothesis' s applicability to word materials requires further verification. Additionally, van Hooff and Ford (2011) proposed that active inhibition in directed forgetting may include two mechanisms: inhibition of F item processing and inhibition of F item memory representations, which may occur at different stages. While these various explanations are reasonable, they remain speculative based on research evidence and lack direct empirical support, requiring supplementation in future studies.

The behavioral and cognitive neuroscience results described above all indicate to some extent that active inhibition mechanisms exist in directed forgetting, preventing attention from focusing on F items and thereby preventing memory traces from forming in corresponding brain regions. This is a cognitively effortful process that may consume more cognitive resources than memory itself. However, it is worth noting that while some cognitive neuroscience studies interpret frontal lobe activity as inhibitory, the frontal lobe is also involved in many other cognitive activities, so causal relationships cannot be definitively established. Moreover, neural activities underlying memory and forgetting are not limited to frontal regions; other brain areas may also participate in attention and working memory processes (Gamboa et al., 2018). Therefore, the active inhibition mechanism of directed forgetting requires further behavioral and neuroscientific research for thorough verification and refinement.

2.3 Comparison of the Two Theories

In summary, two mainstream perspectives currently exist regarding directed forgetting: passive decay and active inhibition. Passive decay theory posits that participants, following directed forgetting instructions, remember R items and forget F items. Typically, participants' memory strategy is rehearsal—selectively rehearsing R items while F items, lacking rehearsal opportunities, gradually decay from memory representations. Consequently, F items show poorer memory performance than R items in subsequent tests, demonstrating the typical directed forgetting phenomenon. The primary cause of forgetting is passive decay of to-be-forgotten items (Basden et al., 1993). In contrast, active inhibition theory emphasizes active suppression of cognitive resources, proposing that F-cues initiate inhibitory mechanisms that actively reduce further processing of F items, thereby suppressing F item memory representations below baseline levels. This results in significantly lower memory performance for F items than R items in subsequent tests, manifesting the directed forgetting effect.

Active inhibition and passive decay during the encoding stage represent two different forms of forgetting but are not entirely opposing. First, both explain the same outcome—the characteristic directed forgetting pattern where R items are remembered better than F items (Fawcett & Taylor, 2008). Second, both occur during the encoding stage: passive decay results from selective rehearsal of R items during encoding, while active inhibition involves active control of attentional resources during encoding. Furthermore, research has found that active inhibition and passive decay may coexist in directed forgetting processes (Fellner et al., 2020), suggesting both contribute to forgetting—an F item' s forgetting may begin with active attentional inhibition followed by passive decay, with the two processes operating at different time points. Of course, the theories also have clear distinctions. In passive decay theory, F item forgetting is a passive process caused by selective rehearsal of R items, with attention itself not operating on F items. Active inhibition theory emphasizes attention' s direct inhibition of F items, representing a more active process.

Regarding the relationship between the two theories, some studies have found that certain directed forgetting features seem explainable by both active inhibition and passive decay modes. For example, Montagliani and Hockley (2019) studied directed forgetting effects for different categories of words, confirming the existence of directed forgetting effects and finding that false alarm rates for new words were lower for F items than R items. This result stems from reduced activation of F items' category words during the test phase, which can be explained from both passive decay and active inhibition perspectives.

3 Other Possible Mechanisms in Directed Forgetting

Beyond passive decay caused by reduced selective rehearsal and active inhibition of F items, do other processing mechanisms exist in directed forgetting? Answering this question requires modifying traditional directed forgetting paradigms, such as studying passive forgetting and intentional forgetting together. Zwissler et al. (2015) added uncued items (U items) to traditional F and R items—memory items requiring no cognitive processing. Comparing memory performance across three item types, they found F items were remembered worse than R items, showing the directed forgetting effect, but F items were remembered better than U items. Similarly, Gao et al. (2016) introduced a non-cue condition (NC condition) in the classic directed forgetting paradigm. Both behavioral and ERP results showed F items were remembered better than NC items. These two studies indicate that directed forgetting effects are weaker than passive forgetting, suggesting that active forgetting instructions do not facilitate forgetting and may even lead to better memory for some F items. This phenomenon directly contradicts active inhibition theory, and passive decay theory cannot explain why memory performance differs between F items and U items (or NC items) when both involve passive decay.

If active inhibition theory is invalid, then frontal lobe activity observed in previous directed forgetting studies (Anne et al., 2011; Rizio & Dennis, 2013; van

Hooff & Ford, 2011) may not result from active inhibition but rather from non-inhibitory processes in the frontal lobe, such as cognitive conflict monitoring (Silvetti et al., 2014), or may reflect unsuccessful inhibition (Lee & Lee, 2011; Zwissler et al., 2015). Notably, Schindler and Kissler (2018) used picture stimuli to compare ERP waveforms evoked by F-cues, R-cues, and no-cues, finding that R-cues elicited larger frontal P2, frontal late negativity, and parietal late positivity than F-cues and no-cues, indicating that R items received more attentional resources. Meanwhile, F-cues and no-cues elicited larger frontal N2 than R-cues, and crucially, F-cues elicited larger right prefrontal late positivity than both R-cues and no-cues, and larger late parietal positivity than no-cues. Given that behavioral results showed F items were remembered better than U items, we can speculate that right prefrontal and parietal activation may not reflect inhibition but rather some selective processing mechanism that makes actively processed F items better remembered than passively processed U items.

We therefore face a dilemma: If F items involve passive decay mechanisms, how do we explain F items' better memory performance compared to U items (or NC items) that also involve passive decay? Conversely, if F items involve active processing mechanisms that cannot be active inhibition, what active processing mechanism participates in directed forgetting? Why does this mechanism make directed forgetting less effective than passive forgetting? What factors influence this processing mechanism? Moreover, beyond the frontal lobe, what other brain regions participate in directed forgetting? These questions require further exploration.

4 Summary and Outlook

Controversy persists regarding whether the cognitive processing during the encoding stage of directed forgetting involves passive decay or active inhibition, primarily manifested in three aspects. First, although numerous studies have provided evidence for active inhibition and passive decay, there is a lack of effective integration between experimental research and theory. Second, purely cognitive mechanisms rarely occur in isolation; memory is linked with many non-cognitive factors, yet previous research has seldom considered non-cognitive influences. Third, current directed forgetting research has rarely examined similarities and differences in cognitive mechanisms across different populations (e.g., different age groups, health statuses). Given these issues, future research should proceed in the following directions:

First, explore integration pathways between theory and empirical evidence. Since mainstream empirical research and theories support either active inhibition or passive decay resulting from reduced selective rehearsal, can we attempt to integrate both? Bancroft et al. (2013) provide some insight, finding that in the absence of secondary tasks, extending cue duration enhances F item memory. This enhancement is not a result of passive decay but rather reflects individuals' inability to maintain prolonged inhibitory engagement. This suggests that memory mechanisms are highly flexible: when secondary tasks are present, cognitive resources are prioritized for them, leaving insufficient resources for either active inhibition or passive decay of F items, thereby causing forgetting. When secondary tasks are absent, sufficient cognitive resources exist to process F items, though whether this involves active inhibition, passive decay, or both remains uninvestigated. More direct integration evidence comes from Fellner et al. (2020), whose EEG research indicates that both active inhibition and passive decay exist in directed forgetting. The former occurs in earlier time windows after forgetting cue presentation, while the latter occurs in later windows. These are independent processes that both function in memory' s autonomous control mechanisms, consistent with previous behavioral results (e.g., Fawcett & Taylor (2008) found inhibition may cease functioning after 1800ms). Although the time courses from these studies are not identical, both suggest that active inhibition and passive decay may coexist. Marevic and Rummel (2020) share this view, proposing that most item forgetting effects result from passive decay due to reduced selective rehearsal, while a small portion results from active attentional inhibition. Reviewing these studies reveals that active inhibition and passive decay in item-method directed forgetting are not simply mutually exclusive but likely both present during the encoding stage as two independent processing phases occurring at different time points. Active inhibition may occur in earlier stages after forgetting instructions, followed by passive decay of F items resulting from selective rehearsal of R items. These two processes jointly contribute to F item forgetting. While theoretical integration has received some support from behavioral and neurocognitive data, existing research is insufficient to provide complete answers regarding specific time nodes for both processes and whether different processing mechanisms imply different brain activation patterns. Current conclusions are mostly speculative based on correlations, lacking strong causal arguments. Future research requires more behavioral and neurocognitive experiments for in-depth investigation.

Second, examine the influence of non-cognitive factors. Current research on directed forgetting mechanisms primarily considers pure cognitive factors, rarely addressing non-cognitive influences. One undeniable fact is that participants' cognitive activities during directed forgetting encoding and retrieval are influenced not only by cognitive factors like attention and memory but also by non-cognitive factors. Some studies have already found that personality characteristics (Delaney et al., 2015), emotional states (Gallant & Dyson, 2016), confidence levels (Woodruff et al., 2006), and motivational intensity (Foster & Sahakyan, 2012; Ren et al., 2018) affect directed forgetting processing. Human cognitive activities cannot be separated from non-cognitive factors, especially in active cognitive processes that are more susceptible to such influences. Therefore, non-cognitive factors can better help control individuals' cognitive processes. Future research should incorporate non-cognitive factors as moderating variables to more comprehensively examine directed forgetting mechanisms, thereby helping resolve theoretical controversies.

Finally, examine directed forgetting characteristics across different populations. Some studies have compared directed forgetting mechanisms across different ages and health statuses, such as Zacks et al. (1996) and Rizio and Dennis (2014) comparing older and younger adults, and Kuehl et al. (2017) comparing depressed and healthy populations, and Catarino et al. (2015) studying PTSD patients. More comparative research in the future will help comprehensively reveal the developmental status of directed forgetting encoding mechanisms across different populations, thereby helping us better resolve theoretical controversies.

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Note: Figure translations are in progress. See original paper for figures.