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ALTERING THE EFFECTIVENESS OF REMINDERS: POSITIVE AND NEGATIVE MNEMONIC EFFECTS OF ASSOCIATIVE RETRIEVAL PROCESSES IN HUMAN EPISODIC MEMORY

PhD thesis

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Introduction

Reminders guide our memories, and their effectiveness to find memories change dynamically. In this dissertation, I present studies on how these changes occur due to three processes: stopping retrieval, competitive retrieval, and repeated retrieval.

The process of retrieving consciously accessible memories has been described as a dynamic interaction of cues and target memories (Norman & Bobrow, 1979; Raaijmakers & Shiffrin, 1988; Tulving, 1983).

Several theories have been laid down to explain how cue-target associations might be changed. These theories were mainly concerned about forgetting, but also postulated hypotheses about positive changes in cue-target associations. Inhibitory theories claim that inhibitory mechanisms play a role in these changes (Anderson, 2003), whereas interference theories claim that interference itself is sufficient to explain memory phenomena (Malmberg & Shiffrin, 2005). Here, the term 'inhibitory' stands for theories that involve an active inhibitory process.

Interference theories

A prototypical interference model is the Search of Associative Memory (SAM) model of Raaijmakers and Shiffrin (1981), further expanded by Mensink and Raaijmakers (1988) and then Shiffrin and Steyvers (1997), and Malmberg and Shiffrin (2005). This model assumes an active search process that is determined by association strengths between memory representations, and the retrieval process is fully cue-driven. For a target memory to be retrieved from long-term memory, cues are assembled in a short-term store. Then, potential targets are sampled based on the strength of their association to the cue relative to the strength of association of other targets to the same cue in the same set. If sampling is complete,

recovery of the target memory occurs based on the absolute strength of the cue-target association.

Inhibition theories

A prototypical inhibitory theory is the inhibitory control theory proposed in its first form by Anderson and Bjork (1994), and then further specified in Anderson (2003). This theory conceives retrieval to be an active, effortful search process guided by cognitive control. It not only takes into account the strength of associations between memories, but assumes that memory items per se have memory strength. Accordingly, retrieval success is a function of cue-target associations *and* target memory strengths.

The specific questions this dissertation covers are derived from the key discrepancies between the two lines of theories. The thesis is an attempt to furnish evidence to the theoretical debate between accounts of remembering and forgetting cue-target associations.

Main objectives

Key points of disagreement between the two major lines of theories (inhibitory and interference accounts) explaining the changes pertaining to retrieval of cue-target associations, concern the locus of the effect, the cue-dependence of the changes occurring to the accessibility of memories, the retrieval dynamics, and the role of cognitive control. Study 1-3 tried to shed light on this debate.

The inhibitory control theory of memory inhibition (Anderson, 2003, 2005; Levy & Anderson, 2008) posits that target memory representations can be weakened by intentionally stopping target retrieval (Anderson & Green, 2001). Our first objective was to test this prediction by testing both cued recall of targets and recall of cues cued by the targets using the think/no-think (TNT) manipulation in Study 1.

The same theory also posits that the representation of non target memories can also be weakened when these memories interfere with retrieval during cued recall of a target memory, and this interference needs to be resolved by inhibitory executive control, leading to retrieval-induced forgetting (RIF) (Anderson et al., 1994; Anderson & Spellman, 1995). Since competitive retrieval is a necessary condition for this type of memory inhibition to occur (Anderson, 2003), but the results of experiments factorially manipulating competition during retrieval are mixed (Anderson & Levy, 2011; Raaijmakers & Jakab, 2012b; Verde, 2013), our objective in Study 2 was to understand the exact function relating interference and RIF.

A further assumption of the above theory is that it is not strengthening of target memories but competitive retrieval that leads to RIF (i.e., the assumptions of strength independence and retrieval specificity). A general logic to test this prediction has been to strengthen memories to the same degree by either repeatedly exposing participants to target memories or have participants repeatedly retrieve them, and see whether it is only the competitive strengthening

(retrieval) that causes RIF. However, the entire testing effect research is about differences between memory strengthening induced by repeated retrieval versus repeated study events (Roediger & Butler, 2011; Roediger & Karpicke, 2006a). Hence, the objective of Study 3 was to test the auxiliary hypothesis inherent in tests of strength independence and retrieval specificity, namely that restudying material in tests of RIF leads to the same amount of memory strengthening as retesting material.

The fourth objective of the dissertation was to look at the neural correlates of the testing effect. To our knowledge, Study 4 was one of the first studies to assess the differential neural correlates of repeated retrieval versus repeated study.

New scientific results

Thesis I. Suppressing target memory retrieval leads to changes in cue-target associations, but not in target memory representations. (Study 1)

The finding that individuals can stop cued recall, and that this leads to forgetting of cue-target associations is well established (Anderson & Huddleston, 2012). It has been unclear whether such a forgetting is due to active inhibition of target memories or substitution of cue-target associations with novel cue-substitute associations. In the former case, forgetting of unwanted target memories would occur due to inhibition through cognitive control (Anderson & Green, 2001), whereas in the latter the cause would be interference caused by substitutes. To test these assumptions in one experiment, Study 1 used a modification of the standard TNT procedure. When presented with cues to unwanted memories, participants were either instructed to suppress or to find substitutes to the unwanted targets. A second manipulation was that for half of the participants, the final test consisted of a standard cued recall test, whereas for the other half, the test involved a reverse cued recall test. In this reverse test, targets were given as cues, and participants had to respond with the cue word.

Importantly, both suppression and substitution lead to forgetting of targets when participants were cued in the standard way. Crucially, when cued with targets, suppression led to facilitation of cues, contrary to substitution which did not have such a facilitatory effect. This Study is informative in two ways: First, it shows that both interference and inhibitory accounts can explain the forgetting in TNT. Second, it clearly shows that the forgetting effect is due to changes in cue-target associations, and not changes in memory items.

Thesis II. Retrieval-induced forgetting is a non-monotonic function of competitor interference during retrieval. (Study 2)

Retrieval of cue-target associations induces forgetting of related cue-competitor associations (Anderson et al., 1994). Interference theories assume that this is due to the fact that the cue-target association is strengthened (see Anderson, 2003). This change will lead to a decreased probability of competitor recall at later time points. In contrast, inhibitory theories suggest that when a competitor interferes with recall of a target related to the same cue, interference is resolved through cognitive control, inhibiting the competitor. A critical test to decide between the two accounts would be to show that retrieval-induced forgetting (RIF) is interference dependent.

Indeed, several experiments have used factorial manipulations of competitor interference (e.g., by manipulating taxonomic frequency of competitors) to test this assumption (Anderson & Levy, 2011), but the results have been inconclusive (Anderson et al., 1994; Williams & Zacks, 2001; Anderson & Levy, 2011). This led to the suggestion that some null results may occur despite the fact that RIF is interference dependent *if* the relationship between interference and RIF is not a linear one. Study 2 aimed at understanding the exact relationship between interference and RIF, and found that RIF is interference dependent. More importantly, it found that RIF is a non-monotonic function of interference caused by competitors.

Thesis III. Retrieval-induced forgetting depends on competitive retrieval, but manipulations of learning strategy cannot provide evidence for strength independence of RIF. (Study 2 and 3)

The same critical difference, as described by Thesis II, between inhibition and interference theories leads to another potential decisive test. Interference theories suggest that the way cue-target associations are strengthened is irrelevant for RIF. What matters here is the magnitude

of strengthening. Contrary to this suggestion, inhibitory theories assume that RIF can occur independently of the magnitude of cue-target strengthening (i.e. RIF is strength independent). What matters here, is the amount of competition competitors induce at the time of cue-target retrievals.

There is abundant evidence (see Anderson & Levy, 2011, Storm, 2011) that repeated study of cue-target associations and repeated retrieval of targets to cues have dissociable effects on cue-target and cue-competitor recall. They lead to the same amount of cue-target strengthening, but only repeated retrieval leads to cue-competitor forgetting. These results clearly favor the inhibitory account over the interference account. However, an auxiliary hypothesis in these tests, that repeated retrieval and repeated study lead to the same amount of strengthening is in sharp contrast with results on the testing effect (e.g. Karpicke & Roediger, 2008). Study 3 tested the auxiliary hypothesis (repeated retrieval and repeated study strengthen memories to the same extent). It found that indeed, in the retrieval practice paradigm as well, repeated retrieval leads to greater memory strength than repeated study. This advantage was only evident after a delay of five days, and was coupled with a RIF effect at short delays. This suggests that although RIF is dependent on competitive retrieval, as proposed by the inhibitory theories, it is also strength dependent, as suggested by the interference theories.

Thesis IV. Repeated retrieval enhances later retrieval by stabilizing activity patterns in a network of brain areas related to cognitive control. (Study 4)

Different manipulations on cue-target associations, e.g. repeated study (restudy) versus repeated retrieval (retest) have been shown to have differential effect not only on cue-competitor recall (Anderson et al., 1994) but also on cue-target recall (Roediger & Karpicke, 2006a). The positive effect on cue-target recall after retest compared to restudy (i.e., the testing effect) becomes evident only after delays of at least a few days.

Study 4 was one of the first attempts to investigate neural correlates of the testing effect. To address this issue, we measured brain activity using event related fMRI during a final cued recall test in brain areas related to cognitive control (localized with an n-back task). Previously to this final test of cue-target associations, participants had learnt cue-target associations in either retest or restudy trials. This pretest learning occurred either twenty minutes or a week before the final test. We found that cognitive control related brain activity was larger for restudied associations than retested ones on the short term. Importantly though, activity during cued recall of restudied associations decreased to a great extent on the longer run, whereas activity during cued recall of retested associations remained the same. We suggested that the testing effect, i.e., the long-term advantage of retest over restudy, is due to the stabilization of activity patterns in areas of the brain related to cognitive control.

Discussion

This dissertation aimed at understanding mechanisms modifying the effectiveness of cued recall processes. In particular, it investigated mechanisms behind the negative effect of stopping retrieval, and the negative and positive effects of cued recall processes on later recall of retrieved memories and of non-retrieved memories related to the retrieved ones.

The results of the dissertation favor the interference accounts over the inhibitory accounts. However, two results of the dissertation are not easily accommodated by interference theories. First, the results of Study 2, showing interference dependence, suggest that cognitive control might play a role in changing cue-target associations. Second, the results of Study 3 and 4 suggest that retrieval is a process more powerful in changing cue-target associations than other, less effortful, types of reencounters with memories, i.e. changes in cue-target association have retrieval-specific attributes.

There are two current theories that might accommodate retrieval specificity, without reference to any inhibitory mechanism that acts on item level representations. One is the latest upgrade of the SAM retrieval model (Raaijmakers & Shiffrin, 1981), the SAM-REM theory (Malmberg & Shiffrin, 2005). The SAM-REM model assumes that retrieval leads to a larger strengthening of context-target associations than restudy, and this can lead to no RIF in instances involving no retrieval prior to final test. A framework closely related to the SAM-REM model is the episodic inhibition proposed by Racsmány and Conway (2006). This framework assumes that cue-target associations form episodic representations independent of the memories' representational activation in the semantic network. The notion of retrieval specificity is inherent in this framework, because it clearly dissociates the effect of activations in the semantic network and pattern shaping during episodic retrieval.

A future question is what further specifications are needed for both the SAM-REM model (Malmberg & Shiffrin, 2005), and the episodic inhibition framework (Racsmány & Conway, 2006) to accommodate the present findings. Now, with a renewed interest partly stemming from advances in animal research on reconsolidation (Nader, 2009), the idea of memories being reconstructive (Bartlett, 1932; Schacter et al., 1998) has started again to generate novel research on the factors that might rewrite or modify memories by each act of retrieval, including such wide areas as the effect of sleep, arousal or cognitive control (Finn & Roediger III, 2011; Hardt, Einarsson, & Nader, 2010; Hupbach, Gomez, Hardt, & Nadel, 2007; Nader & Einarsson, 2010; Nader, 2009; Schiller & Phelps, 2011; St Jacques & Schacter, 2013). This dissertation is part of this research and I hope it will itself foster novel research in the field of memory.

List of publications related ot the thesis

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