On the Cognitive Processes Mediating Intentional Memory Updating

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Preface

In 1968, neuropsychologist Alexander R. Luria published his famous case study "In the Mind of a Mnemonist", in which he portrayed Solomon Shereshevsky, a Russian journalist, who took part in numerous of Luria's behavioral studies. Shereshevsky, who is simply called "S" in Lurias monograph, was able to recall entire speeches word for word, after hearing them once. He also could reproduce complex math formulas, passages in foreign languages and tables consisting of 50 numbers or nonsense syllables, all of which he was still able to recall after years. But S's extraordinary memory also put him under a massive strain because the weight of all the memories created paralyzing confusion: " *'No,' [S] would say. 'This is too much. Each word calls up images; they collide with one another, and the result is chaos. I can't make anything out of this'.*" In his despair, S even attempted to forget certain items by writing them down and burning the paper. His case is an impressive illustration that forgetting is a paramountly important feature of a well-functioning memory system. Indeed, successful retrieval of relevant information requires the ability to forget irrelevant information. For example, learning a new computer password or a friend's new address relies, at least partially, on our ability to forget the old password or address. This memory updating can be triggered intentionally by actively trying to suppress information.

A memory paradigm considered to be particularly well suited to capture these intentional updating processes is the list-method directed forgetting (LMDF) task (Bjork, LaBerge, & LeGrand, 1968, for a review, see MacLeod, 1998, or Bäuml, Pastötter, & Hanslymayr, 2010). Employing this paradigm, numerous studies since the late 1960s have consistently reported that cuing subjects to forget a previously studied list of items causes forgetting of that information in a later test (precue forgetting), while memory for a list of items studied subsequent to this forget cue is generally enhanced (postcue enhancement). Since the first LMDF experiments have been conducted, numerous accounts of the processes mediating the postcue enhancement and precue forgetting effects have been put forward.

A very recent explanation by Pastötter, Kliegl, and Bäuml (2012) reconciles several of the previous views. In particular, this account proposes that precue forgetting is caused by an inhibitory process that reduces access to the precue list context, thereby lowering the recall probability of that list in a later test. Because the to-be-forgotten list context is less accessible, it is also less interfering when the postcue list has to be recalled in a memory test, thus enabling the enhancement effect. But besides this process that acts during memory retrieval, an additional factor is thought to contribute to postcue enhancement that comes into play during the study phase. Providing a cue to forget the previously studied list is thought to boost the encoding of the first few items of the subsequently presented list.

The present thesis intended to test and, potentially, further bolster the framework of Pastötter et al. (2012). Indeed, there are several open questions regarding the "forces" behind the forgetting and enhancement effects in the LMDF task. For example, it is still unclear how exactly recall of the postcue material is facilitated during the testing period. The first part of this thesis thus aimed at shedding light on the very nature of this retrieval process. In particular, I tested the focused-search hypothesis which assumes that at test, the forget cue improves participants' ability to focus their memory search exclusively to the relevant postcue items. However, in order to thoroughly examine this hypothesis, calculating the percentage of correctly recalled words - the most common measure of memory performance - is not sufficient, because it does not yield a valid estimate of the breadth of memory search. Therefore, I analyzed so-called response latencies, a measure that does in fact vary systematically with the size of the mental search set (e.g., Rohrer, 1996). In addition to examining the adequacy of the focused-search hypothesis for the enhancement effect in the LMDF task, the first part of this thesis also sought to determine whether this account might be able to explain enhancement effects in two related memory tasks: Besides providing a forget cue, a context change between study of previous and subsequent information (Sahakyan & Kelley, 2002) as well as interpolated testing of previously studied information (Szpunar, McDermott, & Roediger, 2008) has also been shown to improve memory for subsequently studied information. If, indeed, breadth of memory search could be shown to be also crucially affected in these experimental situations, this would indicate that a focused-search process is not specific to LMDF, but may point to a general relevance of such a process for a well operating memory system.

The second part of this thesis examined the nature of the process mediating precue forgetting by testing whether this process is capable of discriminating between relevant and irrelevant precue items or whether this process treats all precue information similarly regardless of its relevance. To this end, I examined if people are able to forget only part of some previously studied material but to keep remembering the remaining material, when they are told to do so. Indeed, in certain contexts such selective goal-directed forgetting would seem useful, because in some situations only some information associated with an event may turn out to be relevant. For instance, when preparing for an exam, a student may receive information that some of the previously studied material is irrelevant for the upcoming test, whereas other parts of the material are likely to be tested. In such situations, LMDF would be adaptive only if the student was able to selectively forget the irrelevant precue information while keeping the relevant precue information in mind. If such selectivity actually arose, this might arguably speak in favor of Pastötter and colleagues' (2012) claim that precue forgetting is mediated by an inhibitory mechanism that reduces access to the precue context, because this mechanism has been suggested to be flexible (e.g., Anderson, 2005). However, a prominent non-inhibitory account of precue forgetting assumes that the forget cue induces an internal context change between lists, thereby impairing later access to the precue list (Sahakyan & Delaney, 2003; Sahakyan & Kelley, 2002). Such a change in context should generally result in forgetting of all precue items, even if only a part of the precue items had been forget-cued and the remaining part had been remember-cued. Thus, while a failure to find selectivity in LMDF would be in line with the non-inhibitory context-change account, evidence for selective LMDF could be interpreted in support of the inhibitory assumption of precue forgetting put forward by Pastötter et al. (2012).

To sum up, the present work intends to specify the nature of the processes mediating intentional memory updating, both regarding the enhancement of newer, relevant information and the forgetting of older, outdated information.

Contents

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Abstract

In list-method directed forgetting (LMDF), cuing people to forget previously studied information and to encode new material instead facilitates recall of the new material (postcue enhancement) but reduces recall of the previously studied information (precue forgetting). The first part of this thesis investigated the nature of postcue enhancement, with Experiments 1A-1C finding that postcue enhancement is accompanied with decreased response latencies. Because response latency is a sensitive index of participants' mental search set, this finding suggests that postcue enhancement arises due to a more focused memory search. In addition, response latency analysis suggested that such retrieval processes are not only crucial regarding postcue enhancement, but also improve memory of new material when previously studied material is tested prior to encoding of the new material (Experiment 2) or when a context change takes place prior to encoding of the new material (Experiment 3). The second part of this thesis examined the mechanisms underlying precue forgetting by testing whether people can selectively forget only part of the previously studied information while keeping in mind the remaining information. To this end, selectivity in LMDF was examined for two different study formats in Experiment 4: relevant and irrelevant precue items were either presented alternatingly or blocked. Selectivity arose for both study formats, which is consistent with an inhibitory account of precue forgetting. I finally argue that the present data affirm and substantiate a recent LMDF account that attributes precue forgetting to such an inhibitory mechanism and postcue enhancement to a combination of encoding and retrieval processes.

Chapter 1

Background

1.1 Interference Theory of Forgetting

For over a century, research into memory has tried to identify the processes mediating forgetting. During the so-called classical interference era (ca. 1900-1970), interference theory had been widely accepted as the dominant explanation of why we forget. The basic assumption of interference theory is that information in memory competes and the amount of interference is influenced by the similarity, strength, and number of competitors (for a review, see Anderson & Neely, 1996, Wixted, 2004). Empirically, interference refers to an impaired memory for target material when related material has been studied. Two of the most widely studied interference phenomena are retroactive interference (RI) and proactive interference (PI). RI had first been described by Müller and Pilzecker (1900) and refers to the finding that memory for a target list of items is impaired by the subsequent study of nontarget lists relative to a no-RI control condition in which only the target list is studied and no additional subsequent lists. PI refers to the finding that memory for a target list of items is impaired by the prior study of nontarget lists relative to a no-PI control condition in which only the target list is studied and no additional prior lists (e.g., Underwood, 1957).

By the early 20th century, an alternative explanation of forgetting, so-called decay theory, still played a major role. The central claim of decay theory is that a previously formed memory representation will fade as a function of time, if not accessed (Thorndike, 1914). However, findings of a classic sleep study conducted by Jenkins and Dallenbach (1924) raised doubts about the adequacy of that account, as subjects remembered more of a previously studied list when they slept before taking a memory test than when they remained awake. While interference should not play a crucial role during sleep, a decay process should be active regardless of whether people are asleep or awake and therefore, the results were interpreted in favor of interference theory. In addition, McGeoch (1932, 1942) brought forward theoretical arguments against decay theory, stating that the passage of time is not the cause of forgetting anymore than it is the case of physical deterioration associated with aging. McGeoch's argument that decay theory is therefore flawed from the outset was very influential in the 1930s and 1940s and helped interference theory to emerge as the predominant view of forgetting.

In particular, RI was considered the major alternative explanation of forgetting at that time. Several accounts of RI have been proposed. For example, the unlearning hypothesis assumes that learning of subsequent nontarget material weakens the traces left by the target material (Melton & Irwin, 1940). However, findings from Tulving and Psotka (1971) are not well in line with that account, because they indicate that the subsequent study of nontarget material only impairs accessibility of the target material, while the memory traces of the target material are still intact. McGeoch's (1942) response-competition theory is consistent with Tulving and Psotka's finding that the target information is still available and assumes that RI occurs because target and nontarget information is associated with a common cue, and as a result, the retrieval of the target information is blocked by nontarget information at test. However, the issue of which processes underlie RI has not yet been resolved once and for all.

In 1957, Underwood's seminal paper challenged RI as the dominant explanation of forgetting, arguing that forgetting in most situations may be attributed to PI rather than to RI. He considered the question of why across studies, the amount of forgetting over 24 hours in retention of a single list varied so widely, ranging from only 20% to about 80%. Underwood found that most of this variability could be seen as a function of the amount of previously studied information, because studies in which participants were presented with few prior lists showed much less forgetting than studies with a huge number of prior lists. He thus argued that the degree of forgetting is mostly determined by the degree of interference from previously learned material.

Underwood's (1957) perspective had a significant influence on the interference theory of forgetting and PI had been extensively studied over the following years (for reviews, see Anderson & Neely, 1996; Crowder, 1976). For example, PI has been shown to vary with similarity of the material (Wickens, Born, & Allen, 1963). Wickens (1970) found that there is almost complete release from PI for the target list when a shift from words to numbers occurs from the nontarget to the target list, whereas there is virtually no release from PI when a shift from verbs to adjectives takes place. Also, length of the retention interval between study of item lists and test affects the degree to which PI builds up, with long retention intervals causing substantially more PI than short retention intervals (e.g., Brown, 1958; Keppel & Underwood, 1962; Peterson & Peterson, 1959; Underwood, 1948; Watkins & Watkins, 1975).

However, the debate on the critical mechanisms underlying PI has not yet been resolved. Prominent accounts of PI can be divided into those that attribute PI to encoding factors and those that emphasize a crucial role for retrieval factors. Generally, encoding factors refer to processes by which information is translated into a memory representation, while retrieval factors encompass processes aimed at accessing stored information. Thus, not being able to correctly recall previously presented information could theoretically stem from a failure to encode that information during presentation, e.g. due to a lack of attention. Alternatively, while that specific information may have been adequately encoded, retrieval of that information may fail, e.g., due to a failure to generate adequate retrieval cues in a free recall test (Tulving, 1983).

Regarding PI, encoding-based accounts argue that in the PI condition, attentional resources deteriorate from the encoding of the earlier lists to the target list, thus causing decreased response totals for the target list (Bjork et al., 1968; Crowder, 1976; Kintsch, 1970). Recently, Pastötter, Schicker, Niedernhuber, and Bäuml (2011) found evidence in favor of this attentional view. The authors used EEG recordings during encoding and found an increase in alpha power, which is thought to reflect a decrease in attention (e.g., Sederberg et al., 2006), across encoding of multiple lists.

However, proponents of retrieval-based accounts of PI assume that in the PI condition, memory search for target list items is impaired at test. Temporal discrimination theory, a prominent retrieval account of PI, essentially implies that during recall of the target list, participants in the PI condition may not be able to focus their memory search to the target list but instead include items from prior lists into their mental search set, thus reducing the probability that a correct item is recalled (Baddeley, 1990; Bennett, 1975; Brown, Neath, & Chater, 2007; Crowder, 1976). Wixted and Rohrer (1993) provided empirical evidence in support of temporal discrimination theory. They exposed participants to a short item list, with or without prior study of further lists. Wixted and Rohrer not only analyzed response totals but also response latencies, an estimate for the mean duration with which an item is produced in free recall. The results showed that, with the study of prior lists, PI built up for the target list, as reflected in reduced response totals. Regarding response latencies, the authors additionally found an increase in latency for the target list when preceding lists were studied. As will be explained in more detail later, response latencies have been shown to provide a reliable index of search set size at test. Thus, the slowing of the retrieval process suggests that participants' search set size increases when PI builds up, which points to a central role for retrieval factors in PI.

Thus, both encoding and retrieval factors have been shown to play crucial roles for buildup of PI. Encoding factors may contribute because target list encoding may be less effective due to impaired attention, whereas retrieval factors also seem to have an impact because memory search for the target items has been found to be less focused when prior nontarget lists had been studied.

1.2 List-Method Directed Forgetting

While until the late 1960s, forgetting was mostly treated as a flaw of our memory, research in the last few decades increasingly focused on forgetting as a result of the need to update episodic memory in order to escape from PI (e.g., Levy & Anderson, 2002). Some work has since dealt with the positive effects of this updating processes. The list-method directed forgetting (LMDF) paradigm (Bjork et al., 1968, for reviews, see Bäuml et al., 2010, Johnson, 1994, or MacLeod, 1998) is generally considered a suitable operationalization of such updating processes (e.g., Bjork, 1978, 1989). In this task, participants typically study two lists of items. After presentation of List 1, they are either cued to keep remembering List-1 items (remember condition) or to forget List-1 items (forget condition). List 2 is always to be remembered. In a subsequent test, participants are always asked to recall both the precue items (List 1) and the postcue items (List 2) regardless of prior cuing.[1]

Studies have repeatedly shown that two effects mostly co-occur. While precue item recall is generally worse in the forget condition relative to the remember condition (precue forgetting), postcue item recall is improved in the forget condition relative to the remember condition (postcue enhancement) (e.g., Bjork, Bjork, & Anderson, 1998; MacLeod, 1998, 1999; Racsmány & Conway, 2006, Sahakyan & Kelley, 2002). While those studies have reported postcue enhancement and precue forgetting with verbal material, both effects have also been observed with visual (e.g., Basden & Basden, 1996) and autobiographical material (e.g., Barnier et al., 2007), as well as for subjects-performed tasks (Sahakyan & Foster, 2009). Furthermore, both effects have been found with young and older adults (e.g., Zellner & Bäuml, 2006), but are generally absent at very young age (e.g., Aslan, Staudigl, Samenieh, & Bäuml, 2010; Harnishfeger & Pope, 1996) and very old age (Aslan & Bäuml, in press). While it could be argued that precue forgetting might arise at least partially due to demand characteristics, offering participants money for each correctly recalled forget-cued item did *not* annihilate precue

[1]A variation of the LMDF task is sometimes used in the literature: item-method directed forgetting. In contrast to the LMDF task, in the item-method directed forgetting task, participants study a list of items and the exposure of each single item is followed closely by the cue to either remember it or forget it. On a later memory task, recall of remember-cued items is typically enhanced as compared with forget-cued items (for reviews, see Bäuml, 2008; MacLeod, 1998).

forgetting, thus rejecting that assumption (MacLeod, 1999). Overall, these results suggest that LMDF is a relatively general memory phenomenon.

One-Mechanism Accounts of List-Method Directed Forgetting

There is still an unresolved debate as to which mechanisms underlie postcue enhancement and precue forgetting in LMDF. Most of the earlier accounts proposed that both effects might be attributed to a single mechanism. For example, the selective-rehearsal hypothesis assumes that in the remember condition, participants silently rehearse precue as well as postcue items during postcue encoding. Yet, in the forget condition, participants devote all rehearsal activity to postcue items, because precue items are not expected to be tested later. Precue forgetting is thus explained as a result of less precue item rehearsal in the forget condition relative to the remember condition, whereas postcue enhancement arises due to increased postcue item rehearsal in the forget condition relative to the remember condition (Bjork, 1970).

However, numerous findings seem incompatible with a selective-rehearsal account of LMDF. For example, selective rehearsal attributes the forgetting and enhancement effects to differences in encoding and thus predicts that both effects should arise in free recall as well as in recognition tests. In fact, studies have mostly found that the forget cue does neither affect memory of the precue and postcue list in recognition tests (Basden & Basden, 1996; Basden, Basden, & Gargano, 1993; Geiselman et al., 1983; Gross, Barresi, & Smith, 1970; MacLeod, 1999; Schmitter-Edgecombe, Marks, Wright, & Ventura, 2004; Whetstone, Cross, & Whetstone, 1996, but see Benjamin, 2006). Furthermore, forgetting and enhancement effects are also generally absent in implicit tests (e.g., Basden et al., 1993, MacLeod, 1999). These findings suggest that precue items are still available in memory, but in order to be recovered, adequate cues are needed.

Geiselman et al. (1983) put forward an inhibitory explanation of postcue enhancement and precue forgetting, the retrieval-inhibition account. Precue forgetting is assumed to arise as a result of an active inhibitory process triggered by the forget cue that reduces access to the context of the precue material and postcue enhancement is thought to manifest itself due to the resulting decreased PI from the precue list (Geiselman et al., 1983; Melton & Irwin, 1940). The inhibitory account is consistent with the above-mentioned failures to detect typical LMDF effects in either recognition or implicit tests and is regarded one of the best supported accounts of LMDF (e.g., Anderson, 2005; Bäuml, 2008; Bjork, 1978, 1989; but see Sheard & MacLeod, 2005).

The most recent single-mechanism account of LMDF is the context-change account and, like the selective-rehearsal account, it attributes LMDF to a non-inhibitory mechanism. The context-change account essentially regards LMDF as just another example of a context-dependent memory phenomenon (e.g., Godden & Baddeley, 1975; Mensink & Raajimakers, 1988; Smith, 1979, 1982), assuming that the forget cue creates an internal context change, thus causing the postcue list to be encoded in a new context. When participants are told to retrieve the precue items, they have problems to go back to the original precue encoding context, which leads to the forgetting effect. Postcue enhancement is again assumed to appear due to reduced PI as a result of encoding precue and postcue items in separate contexts (Sahakyan & Kelley, 2002). Consistent with this hypothesis, a change in internal context has been demonstrated to simulate the two typical LMDF effects. In addition, it has been found that not only such context-dependent forgetting but also directed forgetting can be reduced if at test the original List-1 encoding context is reinstated (Delaney & Sahakyan, 2007; Sahakyan & Kelley, 2002). However, two electrophysiological studies that either gave a forget instruction (Bäuml, Hanslmayr, Pastötter, & Klimesch, 2008) or an instruction to change one's internal context (Pastötter, Bäuml, & Hanslmayr, 2008) between the study of two word lists, found distinct neural correlates of the forgetting effects, thus casting some doubt on the assumption that LMDF effects are mediated by a context change (Bäuml, Hanslmayr, Pastötter, & Klimesch, 2008, Pastötter, Bäuml, & Hanslmayr, 2008; see also section "Processes Mediating Precue

Forgetting" below).

Two-Mechanism Accounts of List-Method Directed Forgetting

However, more recent accounts have called into question the presumption that a single mechanism is responsible for both precue forgetting and benefits. If, indeed, both effects were caused by the same mechanism, precue forgetting and benefits should always co-occur. But, in fact, it has recently been shown that precue forgetting may arise without postcue enhancement (Bäuml & Kuhbandner, 2009; Conway, Harries, Noyes, Racsmány, & Frankish, 2000; Sahakyan & Delaney, 2003; Zellner & Bäuml, 2006) and postcue enhancement may occur without precue forgetting (Benjamin, 2006; Pastötter & Bäuml, 2010; Sahakyan & Delaney, 2005).

These findings have resulted in the emergence of several two-mechanism accounts of LMDF, attributing postcue enhancement and precue forgetting to different underlying mechanisms. For example, Sahakyan and Delaney's (2003) two-mechanism account argues that, while a context change provides the best explanation of precue forgetting, postcue enhancement may be attributed to the use of a more efficient encoding strategy after a forget cue has been provided. The authors proposed that a forget cue may cause participants to critically reflect on their prior (precue) encoding strategy, thus increasing the chance that they subsequently employ a deeper, more effective postcue encoding strategy. Indeed, Sahakyan and Delaney found that instructing participants to encode the postcue list with the same encoding strategy both in the forget and remember conditions abolished the enhancement effect. These findings suggest that that differences in people's encoding strategies may, in fact, modulate the degree to which postcue enhancement arises.

While Sahakyan and Delaney's (2003) account assumes that all postcue items should benefit from the improved postcue encoding strategy, Pastötter and Bäuml (2010) proposed another two-mechanism account, which argues that the forget cue only fosters encoding of early postcue items. Specifically, the forget cue is thought to induce a reset of encoding of early postcue items, and thus, to abolish memory load and again increase attention, which causes these items to be as effectively encoded as early precue items. While this encoding factor is suggested to account for postcue enhancement, precue forgetting is thought to be mediated by an inhibitory mechanism that reduces access of the precue context (Geiselman et al., 1983).

Evidence for this two-mechanism view comes from the analysis of items' serial position curves, which depict the recall probability of each individual item in a study list according to its position in the study list. Comparing serial position curves between the forget and remember conditions, Pastötter and Bäuml (2010) found that while precue forgetting arose for all precue items, postcue enhancement only showed up for the first four presented items. This pattern of results is generally in line with previous findings (Geiselman et al., 1983; Kimball & Bjork, 2002; Lehman & Malmberg, 2009; Sahakyan & Foster, 2009) and was interpreted as evidence for the involvement of the proposed reset process. Indeed, under the retrieval assumptions of both the retrieval-inhibition and the context-change accounts, a beneficial effect would have been expected for all postcue items, not only for early postcue items.

A second source of evidence stems from two electrophysiological studies that measured EEGs during encoding of the postcue list and found two effects that could be attributed to the forget cue and that were selectively related to postcue enhancement and precue forgetting (Bäuml et al., 2008; Hanslmayr et al., 2012). First, a reduction in phase coupling in the alpha frequency band (8-12 Hz) arose that was related to precue forgetting. Memories have been suggested to be represented in widespread cortical networks (Fuster, 1997), and thus, the decrease in phase coupling might reflect the downregulation of the irrelevant precue information, thus fitting an inhibitory view of the forgetting effect. Second, a decrease in alpha power was related to postcue enhancement. Because alpha power increases have been demonstrated to indicate a decreased encoding quality (e.g., Pastötter et al., 2008; Sederberg et al., 2006), the decrease in alpha power associated with postcue enhancement was suggested to reflect a reset of the encoding quality back to the level of the precue list.

Summing up, two-mechanism accounts of LMDF attribute precue forgetting and postcue enhancement to two distinct factors. While precue forgetting is assumed to arise due to reduced accessibility of the precue context which is either triggered via a context-dependent (Sahakyan & Delaney, 2003) or an inhibitory mechanism (Pastötter & Bäuml, 2010), postcue enhancement is thought to arise from an encoding-based mechanism, either a change in encoding strategy (Sahakyan & Delaney) or a reset of the encoding process (Pastötter & Bäuml).

Towards a More Comprehensive Theoretical Framework of List-Method Directed Forgetting Effects

Both Sahakyan and Delaney's (2003) and Pastötter and Bäuml's (2010) two-mechanism accounts suggest that retrieval factors do not play a crucial role for postcue enhancement. But recently, Pastötter et al. (2012) proposed a modified version of their earlier two-mechanism account (Pastötter & Bäuml, 2010) that again emphasized a critical role of such a retrieval factor. The authors supported this notion by several findings.

First, Pastötter et al. (2012) noted that, while almost all LMDF studies find reliable precue forgetting, postcue enhancement does not seem to appear as consistently. One factor in which LMDF studies differ is list output order at test. In some studies, subjects are asked to recall precue items first (e.g., Delaney & Sahakyan, 2007; Pastötter & Bäuml, 2010), while in other studies they are asked to recall postcue items first (e.g., Bjork & Bjork, 1996; Kimball & Bjork, 2002) or to recall precue and postcue items in any order they wish, thus inducing a tendency to recall the more recent postcue items first (e.g. Geiselman et al., 1983, Golding & Gottlob, 2005). Pastötter et al. (2012) conducted a meta-analysis of 20 LMDF studies in 15 articles comparing the magnitude of postcue enhancement as a function of test order, i.e., whether precue items were tested first and postcue items were tested second; or whether postcue items were tested first and precue items were tested second. Interestingly, when precue items were recalled first, on average, precue forgetting appeared but no postcue enhancement was present. When postcue items were recalled first, significant LMDF forgetting *and* enhancement arose.

Second, conducting two new experiments, Pastötter et al. (2012) manipulated list output order at test, with either the precue list tested first and the postcue list tested second, or vice versa. Consistent with their meta-analysis, precue forgetting emerged regardless of list output order at test, whereas reliable postcue enhancement arose only when the postcue list was tested first, but not when the precue list was tested first. Furthermore, an analysis of serial position curves showed that, when the precue list was tested first, reliable benefits in the forget condition arose only for early postcue items, which again implies the involvement of an (reset-of) encoding factor (Pastötter & Bäuml, 2010). However, when the postcue list was tested first, there was a reliable beneficial effect for *all* postcue items in the forget condition. The authors argued that this general enhancement effect for early, middle, and late postcue items was caused by a second - retrieval - factor. Specifically, reduced PI on the postcue list was suggested to be due to decreased accessibility of the precue list context, a mechanism that has previously been suggested to cause postcue enhancement in both the inhibitory and context-change accounts (Geiselman, 1983; Sahakyan & Kelley, 2002). However, testing the precue list first may reactivate PI on the postcue list and, consequently, the (reduced) postcue enhancement are caused only by one (reset-of-encoding) factor. Indeed, recent work has shown that, in a standard LMDF task, recall of some precue items improves recall of the remaining precue items (Bäuml & Samenieh, 2010, 2012) and thus, prior testing of the precue items may reduce their interference potential and, consequently, diminish subsequent enhancement of the postcue items.

In short, Pastötter et al. (2012) argue that precue forgetting is caused by retrieval inhibition, while two separate factors are suggested to contribute to postcue enhancement. The first factor is assumed to be a reset-of-encoding process, whose beneficial effect is restricted to early postcue items. The second factor is thought of as a product of the inhibitory process that, during memory retrieval, causes interference reduction for all postcue items due to the decreased accessibility of the precue material. While the first (encoding) factor is suggested to impact recall performance irrespective of output order at test, the retrieval factor should only come into play when the postcue material is tested first, thus preventing the precue material's interference potential from being reactivated by prior recall of that material.

1.3 Processes Mediating Postcue Enhancement

From the outset, the LMDF paradigm has been considered a model of intentional memory updating (e.g., Bjork, 1972) and thus, specifying the nature of the mechanisms underlying the enhancement effect has been of central interest. While some of the above presented accounts of LMDF attribute the enhancement effect to retrieval processes, arguing that the forget cue facilitates memory for the postcue list because PI from the precue list is reduced (e.g. Geiselman et al., 1983; Sahakyan & Kelley, 2002), other explanations favor the idea that the forget cue influences postcue encoding, thereby improving later postcue recall (Bjork, 1970; Pastötter & Bäuml, 2010; Sahakyan & Delaney, 2003).

As indicated in the previous section, there is indeed evidence that both retrieval and encoding factors play crucial roles. Regarding the involvement of encoding factors, several recent studies have shown that the forget cue causes a reset of the encoding process for early postcue items, thereby improving the recall of the postcue list (Bäuml et al., 2008; Hanslmayr et al., 2012, Pastötter et al, 2012). Regarding the involvement of retrieval factors, studies have repeatedly reported that a forget cue does not produce postcue enhancement effects in either recognition tests or implicit memory tests (Geiselman et al., 1983; Gross et al., 1970; MacLeod, 1999; Schmitter-Edgecombe et al., 2004; Whetstone et al., 1996; but see Benjamin, 2006, Sahakyan & Delaney, 2005), when in fact, reliable effects would be expected for these types of tests, if postcue enhancement purely arose due to improved encoding of the postcue list. Obviously, retrieval processes do play a role for postcue enhancement.

The Focused-Search Hypothesis

The Pastötter et al. (2012) framework takes into account the findings that both retrieval and encoding processes contribute to the postcue enhancement effect, thereby providing a more comprehensive perspective on the issue. However, there are still some open questions that this thesis intended to address. For example, while evidence for the nature of the encoding factor involved is relatively specific, suggesting that a reset process is responsible, there is no clear evidence what the nature of the retrieval process might be. This work comes up with a relatively specific hypothesis about how retrieval facilitates memory of the target list in the LMDF task, suggesting that a forget cue enhances segregation between nontarget and target lists and therefore enables participants to restrict their memory search to the target list, rather than searching the entire set of target and nontarget items that have previously been exposed.

This focused-search hypothesis is motivated by Wixted and Rohrer's (1993) study, which reported that response latencies increase for a target list when previous material had been encoded. Because response latencies have been shown to provide a reasonable index for the size of the mental search set at test (e.g., Rohrer, 1996), Wixted and Rohrer's results imply a less focused memory search for a target list when PI builds up. Consequently, a release from PI might again reduce response latencies reflecting a more focused memory search. Thus, breadth of search might be more focused on the target list when a forget cue has been provided relative to when a remember cue has been provided. The present thesis thus examined whether the focused-search hypothesis constitutes an adequate explanation of the postcue enhancement effect in LMDF. In addition, I wanted to determine the specificity of the hypothesis by investigating whether or not such a focused-search mechanism is involved in two related PI-release situations.

Specificity of the Focused-Search Hypothesis

There are some further effective "treatments" that, like a forget cue, cause a release from PI. Among these techniques are the context-change and interpolated-testing tasks. In the standard context-change task, participants are presented with two lists, like in the standard LMDF task. However, in the experimental condition, participants are instructed to change their internal context (context-change condition) instead of being provided with a forget cue. A typical example for inducing such an internal context change is by telling them to describe their childhood home or a travel to a foreign country. In the no-change condition, participants have to deal with an unrelated task that is not supposed to cause a context change, like e.g., an arithmetic task (e.g., Delaney, Sahakyan, Kelley, & Zimmerman, 2010; Sahakyan & Kelley, 2002). In a subsequent test of the two lists, typically a pattern of forgetting and enhancement arises, like in the LMDF paradigm: List-1 items are recalled significantly worse in the context-change condition as compared with the no-change condition, whereas recall of (the target) List 2 is improved in the context-change condition as compared with the no-change condition. Both the LMDF and context-change paradigms have been used to examine human memory updating, but while the LMDF task is generally considered as evidence that an intention to forget can cause memory updating, the context-change task is seen as evidence of contextual updating in episodic memory (e.g., Pastötter & Bäuml, 2007).

Studies on interpolated testing found that testing of previously studied information enhances memory for subsequently studied information (Nunes & Weinstein, 2012, Pastötter et al., 2011; Szpunar et al., 2008; Tulving

& Watkins, 1974; Weinstein, McDermott, & Szpunar, 2011; for further demonstrations of PI release, see Jacoby, Wahlheim, Rhodes, Daniels, & Rogers, 2010; Wixted & Rohrer, 1993). For example, Szpunar et al. had their participants study five lists in anticipation of a final cumulative test. This final test was announced to ensure continued retention of the item material during the whole study phase. The critical manipulation happened after the encoding of each Lists 1 through 4. Participants were either tested on each list or they were asked to solve an unrelated distractor task. An initial test of List 5 showed substantially increased recall with prior interpolated testing relative to the distractor condition that was still present in the later final cumulative test. Szpunar et al. also demonstrated that response totals were still drastically higher with interpolated testing relative to a restudy condition in which participants were again exposed to Lists 1 - 4 after initial presentation. Thus, the beneficial effect arose exclusively as a result of testing. Interestingly, this interpolated testing seems to yield a rather unique benefit, because not only does it enhance recall of subsequently studied target material (List 5), but also recall of the previously studied nontarget material. Thus, unlike in the LMDF and context-change tasks, no forgetting for the nontarget material arises.

Retrieval as well as encoding explanations have been proposed for the enhancement effects in both the context-change and interpolated-testing tasks. Regarding the involvement of encoding processes, it has been suggested that, like a forget cue, interpolated testing as well as a context change induce a reset of encoding that boosts the encoding of early target list items. Recent electrophysiological studies support such a view (Pastötter et al., 2008, Pastötter et al., 2011). The demonstration that, similar to a forget cue, interpolated testing and a context change also cause a reset of encoding seems to imply that for a variety of treatments, such reset processes may be a critical factor for PI reduction. Regarding the involvement of retrieval processes, both treatments have been suggested to improve target list recall due to reduced PI from the prior nontarget list(s) (Sahakyan & Kelley, 2002; Szpunar et al., 2008). There is some evidence that retrieval processes play at least a crucial role for the enhancement effect in the context-change task because the enhancement effect has been shown to be largely absent in recognition tasks (Sahakyan & Kelley, 2002). However, the very nature of these retrieval process remains obscure with respect to both tasks. Therefore, the current thesis analyzes whether for these two tasks, response latencies of the target lists are also affected. Such proceedings might help to gain some insight on whether or not the enhancement effects are mediated by a more focused memory search.

In sum, while previous work has generally found evidence for the involvement of retrieval processes in postcue enhancement in LMDF, the nature of this retrieval process has not yet been specified. The first part of the present thesis examined the focused-search hypothesis of postcue enhancement which assumes that in the forget condition, participants are better able to restrict their memory search to the postcue list, relative to the remember condition (Experiment 1). In addition, the present thesis investigated the specificity of the hypothesis by testing whether the focused-search hypothesis is also a suitable explanation for the enhancement effects in both the context-change (Experiment 2) and interpolated-testing tasks (Experiment 3).

1.4 Processes Mediating Precue Forgetting

The mechanisms that have been proposed to mediate the precue forgetting effect in the LMDF task can be broadly divided into inhibitory and non-inhibitory explanations. While the modified two-mechanism account of Pastötter et al. (2012) assumes that the context associated with the precue list is actively inhibited (see also Bjork, 1989; Geiselman et al., 1983), two prominent alternative accounts of precue forgetting, the context-change (Sahakyan & Delaney, 2003; Sahakyan & Kelley, 2002) and the selective-rehearsal explanations (Bjork, 1970), have argued for the involvement of non-inhibitory processes. The context-change account proposes that the forget cue induces a change in participants' internal context, which impairs recall of the precue list at test due to a mismatch between the precue list's encoding and retrieval contexts. In contrast, the selective-rehearsal hypothesis argues that precue forgetting arises because, during postcue encoding, participants in the remember condition rehearse precue as well as postcue items, whereas in the forget condition, they are assumed to solely rehearse postcue items, thus creating a disadvantage for precue items.

Because selective rehearsal attributes precue forgetting to differences in encoding, effects would not only be expected in recall tests, but also in recognition and in implicit tests. However, studies have repeatedly failed to detect precue forgetting in either recognition or implicit tests (Basden & Basden, 1996; Basden, Basden, & Gargano, 1993; Geiselman et al., 1983; Gross et al., 1970; MacLeod, 1999; Schmitter-Edgecombe et al., 2004; Whetstone et al., 1996). These findings, though, seem well in line with an inhibitory account, because it attributes precue forgetting to a reduced accessibility of the precue context and thus, forgetting should only arise in recall but not in recognition or in implicit tests.

Yet, the context-change explanation has also been shown to be capable of explaining a considerable number of LMDF findings. For instance, inducing a context change between the study of two lists in the absence of an instruction to forget mimicked the LMDF pattern of precue forgetting (and postcue enhancement) (Delaney & Sahakyan, 2007; Sahakyan, Delaney, & Goodmon, 2008; Sahakyan & Kelley, 2002). Furthermore, both a forget cue and a context change instruction produced greater forgetting among participants with a high working memory capacity than among participants with a low working memory capacity (Delaney & Sahakyan, 2007). But support for the context-change account is not unambiguous, as two electrophysiological studies that either employed a directed-forgetting manipulation (Bäuml et al., 2008) or a context-change manipulation (Pastötter et al., 2008), found distinct neural correlates of the forgetting effect in the LMDF and context-change tasks. While reduced phase coupling - a measure of synchrony in local neural assemblies - in the alpha frequency band (8-12 Hz) was related to the forgetting effect in the LMDF task, forgetting in the context-change task was associated by differential power increases in the alpha and theta bands (4-7 Hz).

Thus, while the current literature implies that selective rehearsal may be unlikely to play a dominant role in mediating precue forgetting in the LMDF task, the current data do not yet allow for a definitive decision as to whether an inhibitory mechanism or a context change underlies the forgetting effect. The current work thus intended to gain some more insight about the nature of the process(es) mediating precue forgetting.

The Selectivity of Precue Forgetting

This thesis examined whether the mechanism underlying precue forgetting is able to discriminate between relevant and irrelevant precue information. Such selectivity could be demonstrated experimentally by cuing participants to only forget part of the precue material but to keep remembering the remaining material. Evidence for such selective memory would be in line with the assumption of Pastötter et al. (2012) that the mechanism mediating precue forgetting actively inhibits the precue material, because recent work relating performance in the LMDF task to individuals' working memory capacity (Aslan, Zellner, & Bäuml, 2010; Delaney & Sahakyan, 2007; Soriano & Bajo, 2007) and executive control function (Conway & Fthenaki, 2003; Conway et al., 2000; Hanslmayr et al., 2012) suggests that retrieval inhibition may reflect the action of a fairly flexible control mechanism and, thus, may be targeted selectively at the irrelevant precue information.[2]

[2] Arguably, the selective-rehearsal account may also predict selective LMDF. Because this account claims that, after a forget cue is provided, (only) the irrelevant memories are skipped from the rehearsal process, participants should rehearse the relevant items regardless of whether they were presented before or after the forget cue was provided. However, the numerous LMDF findings that are inconsistent with the selective-rehearsal view seem to disqualify selective rehearsal as a plausible explanation of LMDF from the outset.

In contrast, the context-change account clearly does not predict any selectivity, but instead forgetting of all precue items. Indeed, at test, the encoding-retrieval mismatch for the precue material should arise for all precue material, irrespective of whether they were all to be forgotten or consisted of a mixture of relevant and irrelevant items.

Both two-mechanism accounts also attribute precue forgetting to either retrieval inhibition or a context change. Sahakyan and Delaney's (2003) two-mechanism account clearly proposes that precue forgetting is caused by a context change, and would thus predict no selective LMDF, like the context-change account. The reset-of-encoding account regards inhibition as the responsible mechanism guiding precue forgetting (Bäuml et al., 2008; Hanslmayr et al., 2012; Pastötter & Bäuml, 2010), and would thus predict selective LMDF like the inhibitory account.

Prior Work on Selectivity

So far, few published studies have examined selectivity in LMDF. Sahakyan (2004) used a 3-list variant of the LMDF task. After presentation of each list, participants were told whether to forget or to keep remembering that list. In the remember condition, participants were told to remember each of the three lists, while in the (selective) forget condition, Lists 1 and 3 were to be remembered and List 2 was cued to be forgotten. Thus, relevant and irrelevant items were presented subsequently in separate lists. Each list either consisted of 12 semantically unrelated words (Experiment 1) or 12 semantically related words from specific semantic categories (Experiment 2), for example, all List 1 words might come from the category VEGETABLES, all List 2 words from the category ANIMALS, and List 3 words from the category FRUITS. At test, participants then were asked to recall the three lists' items irrespective of original cuing. Compared to the remember condition, response totals of List 2 were substantially lower in the forget condition, reflecting standard precue forgetting. However, List 1 response totals also decreased in the forget condition compared to the remember condition. This finding arose for both Experiments 1 and 2 and indicates that forgetting extended to the relevant precue information.[3]

Another study on selectivity in LMDF, conducted by Delaney, Nghiem, and Waldum (2009), chose a different approach. The authors employed a 2-list LMDF task, in which relevant and irrelevant precue items were presented alternatingly within a single list (List 1). Subjects studied eight short sentences each describing one of two putative characters, TOM and ALEX, for example "TOM parked downtown", "ALEX went skiing", "TOM played catch", and so forth. In the forget condition, subjects were told after presentation of List 1 that TOM sentences should be forgotten, while ALEX sentences should be remembered for a later test. In the remember condition, subjects were told to remember all List-1 sentences. The postcue list (List 2) should always be remembered and contained 16 sentences that described only one character (JOE). In the thematic condition, List-1 sentences were designed to favor a thematic integration of attributes associated with either TOM or ALEX, for example, one of the characters was characterized as a writer who likes snow sports. In the random condition, they were just randomly assigned to each of the two characters (random condition). While the results of the thematic condition showed no indication of selectivity, recall performance in the random condition indeed seemed to imply that selectivity can arise in LMDF: There was a significant forgetting of TOM sentences in the forget condition relative to the remember condition; ALEX sentences were recalled even slightly better in the selective forgetting condition than in the remember condition.

To sum up, Sahakyan's (2004) data do not show any evidence of selectivity in LMDF, whereas Delaney et al. (2009) did find selective LMDF. Thus, no clear conclusions can be drawn with respect to theoretical accounts of LMDF.

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[3] There was a third condition in Sahakyan's (2004) study that is only of minor relevance for the current work. In this condition, Lists 2 and 3 were to be remembered and List 1 was cued to be forgotten. Forgetting of List 1 did arise in this condition and no forgetting of Lists 2 and 3 relative to the remember condition.

While the context-change account is supported by the findings of Sahakyan but inconsistent with the findings of Delaney et al., the inhibitory account is not consistent with the Sahakyan data, but well in line with the Delaney et al. data.

Given the ambiguous data from the Sahakyan (2004) and Delaney et al. (2009) studies, fresh data are required to gain a clearer picture of selectivity in LMDF and thus, on the nature of the processes mediating precue forgetting. Therefore, the major goal of the second part of the current thesis was to examine whether LMDF is selective in the 2-list and 3-list tasks. In the current Experiment 4, material, procedure etc. were controlled, and thus, it was possible to directly compare the two tasks, and to gain insight as to whether and how forgetting and selectivity differ between them.

1.5 Goals of the Present Work

The modified two-mechanism account of Pastötter et al. (2012) assumes that the forget cue triggers two seperate processes that contribute to postcue enhancement, one (encoding) process that is attributed to a reset of encoding for early postcue items, and one (retrieval) factor that affects all postcue items. Retrieval of the postcue material is assumed to be facilitated due to the inhibition of the precue list context and the resulting release from PI for the postcue material. While compared to previous LMDF accounts, the Pastötter et al. (2012) account may provide a more comprehensive perspective on the processes behind postcue enhancement and precue forgetting, there are several issues that require further testing and specification. For example, evidence from previous work is well in line with that account's proposal that a retrieval factor is crucially involved in postcue enhancement (e.g., Geiselman et al., 1983; MacLeod, 1999), but the very nature of that process has not yet been specified. Furthermore, while retrieval of postcue material is assumed to be facilitated because the forget cue reduces PI from the precue material, it is currently still unclear whether accessibility of the precue context is reduced via an inhibitory mechanism (Bjork, 1989) - as proposed by Pastötter et al. - or an internal context change (Sahakyan & Kelley, 2002). The present work addressed these open questions.

First, Chapter 2 intended to specify the nature of the retrieval process that mediates postcue enhancement and examined whether at test, breadth of search is more focused on the target (postcue) list after a forget cue had been provided (Experiments 1A-1C). Specifically, it was expected that in each experiment, the forget cue should cause a release from PI on the target list that should be reflected in increased response totals and, more important, in decreased response latencies, which would imply that memory search for target items is more refined. This would support the focused-search hypothesis and thus provide the first specific evidence for the nature of the retrieval processes mediating enhancement effects in the LMDF task. Experiments 2 and 3 then tried to determine whether this presumed retrieval mechanism is specific to LMDF or whether a similar mechanism mediates typical enhancement effects in two related memory paradigms, the context-change and the interpolated-testing tasks.

Second, the present work intended to get some insights into the nature of the mechanism underlying precue forgetting by examining whether, when both relevant and irrelevant material is presented prior to a forget cue, this mechanism is capable of targeting only irrelevant precue material without affecting memory of relevant precue material. Such a finding would be in line with the assumption of Pastötter et al. (2012) that an inhibitory mechanism causes precue forgetting because such a mechanism has been suggested to be relatively flexible (e.g., Anderson, 2005), whereas the non-inhibitory context change account (Sahakyan & Kelley, 2002) would predict no such selectivity but forgetting of all precue information. However, previous studies on the issue have yielded ambiguous data, with no evidence for selective LMDF in a 3-list task, in which relevant and irrelevant precue items were presented as Lists 1 and 2 (Sahakyan, 2004), and reliable selective LMDF for a 2-list task, in which relevant and irrelevant items were presented alternatingly within a single list (List 1) (Delaney et al., 2009). Chapter 3 of this thesis thus intended to examine whether selectivity arises in the LMDF task, and whether it arises as a function of task. The 2-list and 3-list tasks were directly compared within one experiment (Experiment 4), holding material and other procedural detail constant for both study formats.

Overall, the present experiments intended to improve our understanding of LMDF. The results of Chapters 2 might show that besides a (reset-of) encoding process, a retrieval process that enables a more refined mental search set for the target material can also contribute to postcue enhancement. Chapter 3 could then provide some evidence as to whether the forget cue induces either an inhibitory process or an internal context change, thus shedding some light at the nature of the mechanism mediating precue forgetting.

Chapter 2

Postcue Enhancement and the Focused-Search Hypothesis

In the modified two-mechanism account of Pastötter et al. (2012), postcue enhancement in LMDF is assumed to arise from two factors, an encoding and a retrieval factor. While there is some evidence about the nature of the encoding factor, i.e., a reset of the encoding processes for early postcue items, it is largely unclear, how exactly retrieval processes might contribute to the enhancement effect. However, a study by Wixted and Rohrer (1993) that examined how retrieval is affected when PI builds up may provide an indication what the nature of the retrieval process might be when PI is released via a forget cue. In particular, the authors found that memory search for the target list is less focused in the presence than in the absence of prior list learning. On this basis, the present thesis tested whether releasing PI through a forget cue may again refine memory search of the target list. The current Experiments 1A-1C examined whether this focused-search hypothesis can account, at least partially, for postcue enhancement in LMDF.

To this end, Experiments 1A-1C examined target list response totals and response latencies in LMDF. Each experiment included the standard remember and forget conditions, as well as a no-PI condition. In each of these three experimental conditions, a target list of semantically unrelated items was studied and tested. While in the no-PI condition, only this single list was studied and an unrelated distractor task preceded the encoding, prior material was studied and cued as relevant in the remember condition. Comparing target list recall between the no-PI condition and the remember condition allowed for an estimate of buildup of PI for both the (standard) response total and the response latency measures: Response totals in the remember condition should decrease relative to the no-PI condition, thus replicating prior findings (Bjork & Bjork, 1996). In addition, response latencies should increase in the remember condition relative to the no-PI condition, indicating an increased search set with prior encoding. This would reaffirm a critical role of retrieval processes in buildup of PI and replicate prior work (Wixted & Rohrer, 1993). The forget conditions of Experiments 1A-1C differed from the remember conditions only in the cue provided prior to presentation of the target list that instructs participants to forget the preceding material. While response totals for the target list should increase in the forget condition relative to the remember condition, replicating the finding of standard postcue enhancement in LMDF (e.g. Geiselman et al., 1983), more important, response latencies should decrease. This would indicate a more focused memory search at test as reflected in a decreased search set size and thus, would provide evidence for the focused-search hypothesis.

The goal of Experiments 2 and 3 then was to examine whether the standard enhancement effects in the context-change and interpolated-testing tasks are also mediated by a more focused search during the test period. If this was the case, the pattern of PI release observed in the response total measure and, especially, in the response latency measure of Experiments 1A-1C should also arise in the context-change and interpolated-testing tasks. Specifically, response latencies should again decrease when a “PI-release treatment” - a context change (Experiment 2) or interpolated testing (Experiment 3) - takes place prior to encoding of the target list, which would imply that the enhancement effects in these two tasks also arise due to a more focused search set at test.

2.1 Response Latency Analysis

Because the interpretation of response latencies as a reliable index of mental search set size plays such a crucial role in Chapter 2, this section aims at going into some detail on the theoretical underpinnings of this proposal. Typically, when subjects are told to recall a previously studied list or when they attempt to generate items from a semantic category, many items are produced early in the recall period and relatively few items later in the recall period. This pattern of retrieval is very regularly found and, in most cases, very well described by a 2-parameter exponential,

$$r(t) = (N/\tau)e^{-t/\tau},$$

where $r(t)$ represents the number of items recalled at a particular time interval t, N represents asymptotic recall (the estimated number of items that could be produced given unlimited time), and τ represents the mean response latency of those N items (Bousfield & Sedgewick, 1944). McGill's (1963) random-search model provides a very prominent account of the exponential form of the latency function. According to this model, items are sampled randomly from a mental search set, one item at a time, at a constant rate. Each sampled item is then classified as either "has already been sampled", in which case it is ignored, or as "has not yet been sampled", in which case it is recalled. Subsequently, every sampled item is replaced into the search set. Although the random search model is an oversimplification of retrieval (Herrmann & Pearle, 1981; Morrison, 1979; Vorberg & Ulrich, 1987), it has proven an extremely useful and robust account of response latencies (see Wixted & Rohrer, 1994, for a review).

However, memory researchers are, in general, not focused on speed of recall, i.e., response latencies, but instead on the percentage of recalled items within a certain time period, i.e., response totals. Indeed, if both the response total and the response latency measures captured the same underlying processes and were thus, usually highly correlated, the response latency measure would be redundant. Indeed, early research on the relationship between these two parameters in semantic memory suggested a close, positive relationship. For example, Johnson, Johnson, and Mark (1951) asked their participants to recall as many words as possible from two semantic categories, cities and animals. Estimates of response total and response latency were correlated for each participant and found to be highly positively related (for related findings, see Herrmann & Chaffin, 1976; Kaplan, Carvellas, & Metlay, 1969).

However, in the last two decades, numerous studies have demonstrated that response totals and response latencies do not always covary but rather are independent. For instance, Bäuml, Zellner, and Vilimek (2005) found that retrieval practice of a subset of studied items reduces response totals for related unpracticed items but does not influence the items' response latencies. Rohrer and Wixted (1994) demonstrated that reducing the length of a study list increases response totals and decreases response latencies at test, whereas manipulating encoding by increasing item exposure times did not influence response latencies, but increased response totals. Further encoding manipulations like increasing study time or number of study trials have been shown to leave response latencies largely unaffected, while response totals increased in both cases (Rohrer, 1996; Wixted, Ghadisha, & Vera, 1997).

Thus, while some earlier studies found a positive correlation between response totals and response latencies (e.g., Johnson et al., 1951), the random search model predicts that, actually, it is mental search set size and response latencies that should be directly related. According to the random search model, response totals and response latencies (τ) were highly correlated in these studies because search set size and response totals are, in some cases, directly related. But if an experimental manipulation (e.g., a manipulation of study time) causes the response total measure to no longer constitute a reasonable index of search set size, the positive relationship between response totals and response latencies disappears (Wixted & Rohrer, 1994). Rather, the model predicts a reliable, direct relationship between response latency and the size of participants' search set, which indicates that response latency can be used as an index of participants' search set size (e.g., Rohrer, 1996).

Apparently, response latencies thus provide important information about the recall process that go beyond the information provided by response totals and may thus add something to our understanding of what causes postcue enhancement as well. In particular, given the assumption that postcue enhancement is caused by reduced PI from the precue material at test (e.g., Geiselman et al., 1983; Sahakyan & Kelley, 2002) search set size should also be reduced and more focused on the target list. The suggestion that participants' search set size may be affected regarding postcue enhancement is not only motivated theoretically but also by the Wixted and Rohrer's (1993) study, which reported increased response latencies for the target list in the presence than in the absence of preceding lists, thus implying an increased search set. The current thesis argues that, with regard to postcue enhancement, the release from PI caused by the forget cue should again reduce search set size of the target list, which should be indicated by an acceleration of the recall process.

Prior work on response latency analysis often distinguished between first-response and subsequent-response latency (e.g., Bäuml et al., 2005; Rohrer, Wixted, Salmon, & Butters, 1995). First-response latency measures the average duration until the onset of the first recalled item and is thought to reflect the initiation of the search set; subsequent-response latency measures the duration between the first response and each subsequent response and is assumed to capture retrieval from the search set, therefore being a purer measure of the recall process itself (for a discussion, see Rohrer et al., 1995). The results by Wixted and Rohrer (1993) reported evidence that the buildup of PI does not affect the initiation process but affects the recall process itself. On the basis of this result, both buildup of PI and release from PI - through either a forget cue, interpolated test, or a context change - may be reflected mostly in participants' subsequent-response latencies and less, if at all, in their first-response latencies.

2.2 Experiment 1A

In Experiment 1A, postcue enhancement was examined using a standard 2-list LMDF task. The experiment included three experimental conditions. In the forget and remember conditions, participants studied a target list subsequent to the cue and one list prior to the cue. The cue they received between the two lists was either a cue to forget (forget condition) or to continue remembering (remember condition) the previously studied list (e.g., Bjork, 1970, 1989). In the no-PI condition, participants studied a single list only, preceded by an unrelated distractor task.

On the basis of prior work on LMDF, both buildup of PI and release from PI should occur in this experiment. Reduced recall of the target list in the remember condition relative to the no-PI condition should arise, as well as enhanced recall of the target list in the forget condition relative to the remember condition, i.e., the standard postcue enhancement. Response total in the forget condition and the no-PI condition might even be similar (e.g., Bjork & Bjork, 1996), which would indicate a perfect release from PI in terms of response total.

Regarding response latencies, increased latencies were expected in the remember condition relative to the no-PI condition, thus replicating results from prior work (Wixted & Rohrer, 1993). More important, on the basis of the hypothesis that a reduction in search set size contributes to postcue enhancement, reduced latencies were expected in the forget condition relative to the remember condition. Both buildup of PI and release from PI should be reflected mainly in subsequent-response latencies and less, if at all, in first-response latencies (e.g., Rohrer et al., 1995; Wixted & Rohrer, 1993). The expected results regarding release from PI would indicate that postcue enhancement is, at least partially, caused by a reduction in the size of participants' mental search set. Providing a forget cue thus would enable participants to (largely) restrict their memory search to the most recent list.

Methods

Participants. Twenty-four healthy students at Regensburg University (Regensburg, Germany) took part in the experiment on a voluntary basis. They received 7 Euros for their participation. The sample consisted of 19 females and 5 males. Their mean age was 22.51 years with a range of 19 to 26 years. All participants spoke German as their native language. They were tested individually.

Materials. One hundred and twenty unrelated nouns of medium frequency were drawn from the CELEX database using the Wordgen v1.0 software toolbox (Duyck, Desmet, Verbeke, & Brysbaert, 2004). Twelve items were assigned to each of the ten lists. For each participant, the ten lists were distributed across the three experimental conditions; four lists were assigned to the remember condition, four lists to the forget condition, and two lists to the no-PI condition. Across lists, words were matched on frequency and word length. Each list was used equally often in the remember condition, the forget condition, and the no-PI condition.

Design. The experiment was composed of three conditions: the forget condition, the remember condition, and the no-PI condition. Participants always studied a target list of items, the postcue list in the forget and remember conditions, and the single list in the no-PI condition. Conditions differed as to what happened before encoding of that list. In the forget and remember conditions, one precue list (List 1) was presented; in the forget condition, List 1 was followed by the cue to forget the list; in the remember condition, List 1 was followed by the cue to remember the list for an upcoming test. In the no-PI condition, there was no prior encoding of another list (e.g., Bjork & Bjork, 1996).

Procedure. All participants were told that several item lists would need to be studied and that following each list they would be given a cue to either remember or forget the preceding list. It was highlighted that the remember cue specified that the preceding list would be tested later, whereas the forget cue specified that it would not. Each participant took part in two successive experimental blocks, each block consisting of a forget condition, a remember condition, and a no-PI condition in random order.

Each of the conditions consisted of a study phase, a distractor phase, and a test phase. In the study phase, participants were always presented a target list of items followed by an instruction to remember the list. In the no-PI condition, the list was preceded by unrelated arithmetic problems (duration 1 min), whereas in the remember condition and the forget condition, participants were presented with another preceding study list (List 1), that was cued to be remembered or to be forgotten, respectively. Item order within lists was random for each participant. Each item was presented individually on a computer screen at a rate of 5 s per item. The distractor phase was the same in every condition and served as a recency control. It lasted for 1 min and participants were told to orally group blocks of five digits in an ascending order. Following the distractor phase, participants were given 1 min to remember as many items as possible from the target list in any order they wished. List-1 items were recalled in the remember condition only, but the results are not reported. Between the single experimental conditions, there was a break of 30 s before the next condition started.

The participants' answers were recorded by a computer program in a pcm-wav format with a sampling rate of 44.1 kHz and a resolution of 16 bit. Latencies were assessed by means of the computer program Cool Edit 2000 (version 4.1, Syntrillium Software Corporation, Phoenix, AZ, USA), whereby the voice onset of each recalled item was manually located in the spectrogram (see Bäuml et al., 2005).

Measure of Latency. For each of the three conditions (forget, remember, no PI), first-response latencies and subsequent-response latencies were analyzed. Exponential functions were fitted to the subsequent-response latency functions of each condition in order to analyze retrieval dynamics. Two parameters describe those functions - N representing asymptotic recall and τ representing the mean latency of those N items - which were derived from fitting the exponential to the data. The best fitting exponentials were determined by least square minimization. Using the asymptotic standard error for each parameter, pairwise comparisons of parameter values were performed by a t-test. For these t-tests, the asymptotic standard error of each parameter value provided a measure of the variability of each parameter, and the degrees of freedom for each of the two curve fits, summed together, provided the number of degrees of freedom (for details, see Rohrer et al., 1995).

Results

Recall Totals. Participants correctly recalled 67.00% of the target list in the forget condition, 55.73% in the remember condition, and 70.31% in the no-PI condition. An overall ANOVA of the three conditions (forget, remember, no PI) showed a significant effect, $F(2, 46) = 8.787, MSE = 0.100, p = 0.002, \eta_p^2 = 0.444$. Pairwise comparisons revealed that the difference of 14.58% between the no-PI condition and the remember condition was reliable, $t(23) = 4.263, p < 0.001, d = 1.342$, illustrating the buildup of PI from the no-PI condition to the remember condition. The difference of 11.27% in response totals between the forget condition and the remember condition was statistically significant, $t(23) = 3.491, p = 0.002, d = 1.069$, reflecting a release from PI in the forget condition compared to the remember condition, and thus standard postcue enhancement. There was no significant difference between the no-PI condition and the forget condition, $t(23) = 1.405, p = 0.173$, demonstrating an almost complete PI reduction in the forget condition.

Response Latencies. Table 1 shows the first-response latencies of the target list for the three conditions. First-response latencies were 1.36 s in the forget condition, 1.57 s in the remember condition, and 1.32 s in the no-PI condition. An overall ANOVA of the three conditions (forget, remember, no PI) revealed no significant effect, $F(2, 46) = 1.709, MSE = 0.206, p = 0.192$. Thus, the

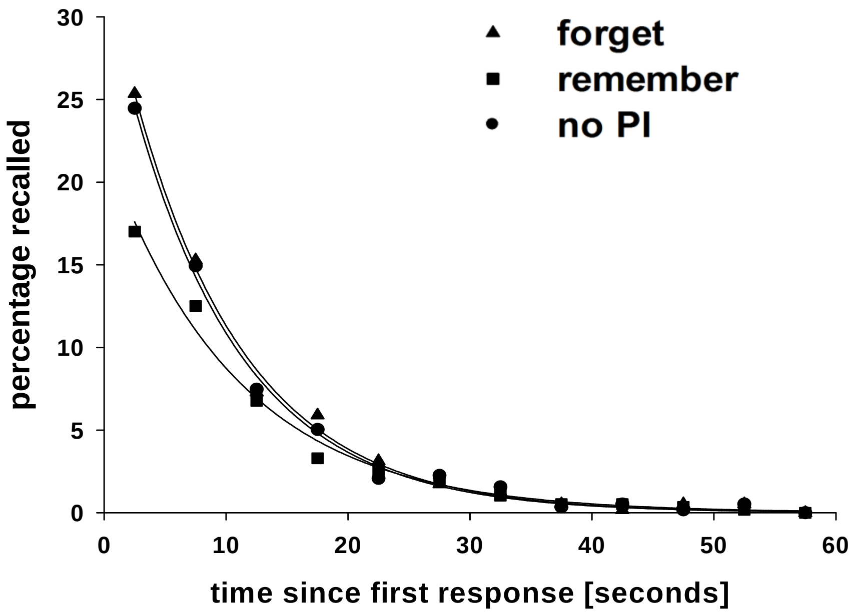

Figure 1. Results of Experiment 1A: Percentage recalled for each 5-s bin of the target list in the forget, remember, and no-PI conditions together with the best-fitting exponentials. Latency is measured from the first response.

buildup as well as the release from PI both have no significant effect on the first-response latency measure.

Subsequent-response latencies were grouped into 5-s bins and plotted as a function of time (see Figure 1). Each data point represents the average percentage of recalled items in that 5-s bin. Figure 1A also shows the best-fitting two-parameter exponential for each of the three conditions. As can be seen in Table 1, the exponential accounts for a large portion of the variance in each condition. The parameter estimate of asymptotic percentage (N) revealed values of 59.35% for the recall of the target list in the forget condition, 47.67% in the remember condition, and 61.78% in the no-PI condition. N is based on subsequent responses only, whereas response totals includes first responses as well. That is why corrected totals were computed, in which only

Table 1. Percentage recalled and response latencies (in seconds) of the target list in Experiment 1A (standard errors in parentheses). VAF = variance accounted for by the exponential.

condition	% recalled	first-response latency	subsequent-response latency(τ)	VAF
forget	67.00 (3.84)	1.36 (0.09)	9.18 (0.33)	0.99
remember	55.73 (4.92)	1.57 (0.14)	10.73 (0.60)	0.99
no PI	70.31 (3.46)	1.32 (0.07)	9.29 (0.35)	0.99

the subsequent responses were included. The corrected values - 58.67% in the forget condition, 47.40% in the remember condition, and 62.00% in the no-PI condition - were very similar to the estimated values of N. This indicates that recall was close to asymptote in Experiment 1A, which is visualized in Figure 1. The main focus was on mean subsequent-response latency (τ). τ parameter estimates were 9.18 s for the forget condition, 10.73 s for the remember condition, and 9.29 s for the no-PI condition. The difference of 1.44 s between the no-PI condition and the remember condition was reliable, $t(20) = 2.089, p = 0.049$. This demonstrates that the buildup of PI is not only reflected in response totals but also in the subsequent-response latency measure. The difference of 1.55 s between the forget condition and the remember condition was statistically significant as well, $t(20) = 2.263, p = 0.035$, which shows the diminished PI in the forget condition. The difference of 0.11 s between the forget condition and the no-PI condition was not reliable, $t(20) < 1$, illustrating that the PI reduction triggered by the forget cue is similar to a no-PI condition.

Discussion

The results of Experiment 1A replicated prior work on buildup of PI by showing reduced response totals and increased response latencies for the target list when a prior list was studied (e.g., Underwood, 1957; Wixted & Rohrer, 1993). The effect on latencies was mainly driven by an effect on subsequent-response latencies but not on first-response latencies, suggesting an effect on retrieval from the search set rather than retrieval initiation. These results are consistent with the temporal discrimination theory of PI (Baddeley, 1990; Crowder, 1976), indicating that PI arises because participants may not be able to restrict their memory search to the target list and instead search other (precue) items that have previously been exposed.

In Experiment 1A, typical postcue enhancement arose as reflected in increased target list recall in the forget condition relative to the remember condition (e.g., Bjork, 1989; MacLeod, 1998). This release from PI was even complete, which is consistent with previous studies (e.g., Bjork & Bjork, 1996, Sahakyan & Goodmon, 2007). The results on response latencies showed reduced response latencies for the target items when a forget cue was provided between study of the two lists; remarkably, latencies in the forget condition were even indistinguishable from those in the no-PI condition, indicating that, in response to the forget cue, speed of recall was no longer affected by the prior study of an item list. Similar to the buildup of PI, the effect on latencies was driven mainly by an effect on subsequent-response latencies, suggesting an effect on retrieval from the search set. The results are consistent with the focused-search assumption, showing that providing a forget cue between encoding of a nontarget and a target list facilitates target list recall due to a more focused search set.

2.3 Experiment 1B

The results of Experiment 1A suggest that LMDF can induce a complete release from PI, both with regard to response totals and response latencies. The size of the PI effect observed in Experiment 1A was typical for 2-list paradigms, being on the order of 15% with regard to response total (e.g., Bjork & Bjork, 1996; Sahakyan & Foster, 2009). To examine whether a forget cue still causes complete release from PI if the PI effect is enlarged, a 3-list LMDF task was employed, in which two lists were studied prior to study of the target list. It was examined whether a cue to forget the two preceding lists still eliminated PI, leading to response totals and response latencies that are similar to a no-PI condition. In particular, similar response latencies in the forget and no-PI conditions would again suggest that a more focused memory search, and thus, a retrieval process is crucially involved in postcue enhancement.

Methods

Participants. Twenty-four healthy students at Regensburg University took part in the experiment on a voluntary basis. They received 5 Euros for their participation. The sample consisted of 19 females and 5 males. Their mean age was 24.86 years with a range of 19 to 34 years. All participants spoke German as their native language. They were tested individually.

Materials. Seven lists of 12 items each were created by drawing 72 items from the pool of the 120 items that were generated for Experiment 1A. Mean item length and item frequency were held constant across lists. For each participant, three lists were randomly assigned to the remember condition, three lists to the forget condition, and one list to the no-PI condition.

Design and Procedure. Design and procedure were identical to Experiment 1A with the exception that two nontarget lists were studied in the forget and remember conditions. Consistently, in the no-PI condition, participants solved arithmetic problems for 2 min before encoding the single list. Similar to Experiment 1A, only items from the target list were tested in the forget condition, whereas in the remember condition participants recalled the target list first, and the two nontarget lists second; again, nontarget results are not reported. The participants' answers were recorded and analyzed identical to Experiment 1A.

Results

Recall Totals. Participants correctly recalled 67.71% of the target list in the forget condition, 41.32% in the remember condition, and 68.40% in the no-PI condition. An overall ANOVA of the three conditions (forget, remember, no PI) showed a significant effect, $F(2, 46) = 26.218, MSE = 0.572, p < 0.001, \eta_p^2 = 0.533$. Pairwise comparisons revealed that the difference of 27.08% in response totals between the no-PI condition and the remember condition was statistically significant, $t(23) = 5.652, p < 0.001, d = 1.440$, reflecting the buildup of PI from the no-PI condition to the remember condition. The difference of 26.39% between the forget condition and the remember condition was reliable, $t(23) = 6.088, p < 0.001, d = 1.792$, demonstrating the typical enhancement effect of LMDF. The difference of 0.69% between the forget condition and the no-PI condition was not reliable, $t(23) = 0.194, p = 0.848$, pointing to a complete release from PI in the forget condition.

Response Latencies. First-response latencies were 1.31 s in the forget condition, 1.85 s in the remember condition, and 1.22 s in the no-PI condition. An overall ANOVA of the three conditions (forget, remember, no PI) showed a marginally significant effect, $F(2, 46) = 3.151, MSE = 0.806, p = 0.053, \eta_p^2 = 0.130$. Thus, like in Experiment 1A, there was no significant impact of the

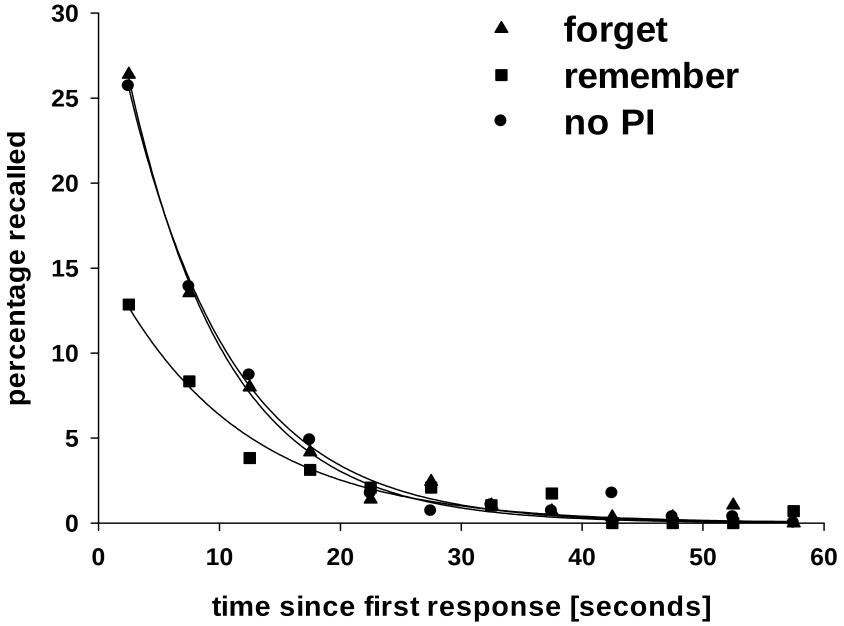

Figure 2. Results of Experiment 1B: Percentage recalled for each 5-s bin of the target list in the forget, remember, and no-PI conditions together with the best-fitting exponentials. Latency is measured from the first response.

Table 2. Percentage recalled and response latencies (in seconds) of the target list in Experiments 1B (standard errors in parentheses). VAF = variance accounted for by the exponential.

condition	% recalled	first-response latency	subsequent-response latency(τ)	VAF
forget	67.71 (3.22)	1.31 (0.10)	8.13 (0.36)	0.99
remember	41.32 (4.53)	1.85 (0.32)	10.86 (0.92)	0.97
no PI	68.40 (3.85)	1.22 (0.08)	8.65 (0.39)	0.99

buildup and release from PI on the initiation stage of the recall process.

Subsequent-response latencies were grouped into 5-s bins and plotted as a function of time (see Figure 2). Figure 2 also shows the best-fitting exponentials. The exponential accounts for a large portion of the variance in each of the three conditions (see Table 2). The parameter estimate of asymptotic percentage (N) revealed values of 57.88% for postcue list recall in the forget condition, 34.70% in the remember condition, and 59.12% in the no-PI condition. Again, corrected totals - 59.38% in the forget condition, 32.00% in the remember condition, and 60.07% in the no-PI condition - were very similar to the estimated values of N. This indicates that recall was close to asymptote in the current experiment.

Estimated subsequent-response latencies were 8.13 s in the forget condition, 10.86 s in the remember condition, and 8.65 s in the no-PI condition. The difference of 2.21 s between the no-PI condition and the remember condition was reliable, $t(20) = 2.210, p = 0.039$, hence reflecting the buildup of PI in the subsequent-response latency measure. The difference of 2.73 s between the forget condition and the remember condition was statistically significant, $t(20) = 2.760, p = 0.012$, pointing to the reduced PI in the forget condition. The difference of 0.52 s between the forget condition and the no-PI condition was not reliable, $t(20) < 1$, again demonstrating an almost perfect release from PI in the forget condition.

Discussion

Using a 3-list task, the results of Experiment 1B replicated those of Experiment 1A with the 2-list task. They showed buildup of PI from the no-PI condition to the remember condition, reflected in decreased response total and increased response latencies. Typical postcue enhancement was again found, reflected in increased response totals in the forget condition as compared with the remember condition. Beyond that, response latencies were again shorter in the forget condition than in the remember condition. Once more, the latency effects were present in the subsequent-response latencies, but not in first-response latencies, suggesting effects in retrieval from search set but not in retrieval initiation.

PI built up more markedly from the no-PI condition to the remember condition, as reflected in considerably larger differences in response totals as well as in response latencies between the two conditions in the present experiment than in Experiment 1A. However, response totals as well as response latencies were again similar for the forget and no-PI conditions, suggesting a complete release from PI by means of a forget cue. Like the results of Experiment 1A, the results of Experiment 1B thus are consistent with the view that a cue to forget previously studied items reduces participants' search set size when subsequently studied items are recalled. Because release from PI was complete in response latency, the results suggest that, in LMDF, the search set during recall of target items hardly contains any nontarget items.

2.4 Experiment 1C

Similar to Experiment 1B, Experiment 1C sought to replicate the results of Experiment 1A under conditions that further increase PI. But while Experiment 1B enhanced PI induction by increasing the number of precue items, Experiment 1C extended the retention interval between study and test from 1 min to 10 min. Prior work has repeatedly demonstrated that long retention intervals substantially magnify PI buildup (e.g., Brown, 1958; Keppel & Underwood, 1962; Peterson & Peterson, 1959; Underwood, 1948; Watkins & Watkins, 1975). Like Experiment 1B, Experiment 1C investigated whether perfect PI elimination in response totals and, more important, in response latencies still occurs when PI from the nontarget material is amplified relative to a standard LMDF task (Experiment 1A). Predictions were analogous to Experiments 1A and 1B.

Methods

Participants. Thirty healthy students at Regensburg University took part in the experiment on a voluntary basis. They received 5 Euros for their participation. The sample consisted of 22 females and 8 males. Their mean age was 23.72 years with a range of 18 to 34 years. All participants spoke German as their native language. They were tested individually.

Materials. Five lists of 12 items were created by drawing 60 items from the pool of the 120 items that were generated for Experiment 1A. Mean item length and item frequency were held constant across lists. Two lists were randomly assigned to the remember condition, two lists to the forget condition and one list to the no-PI condition for each participant.

Design and Procedure. The design and procedure were identical to Experiment 1A with the exception that the retention interval between study and test was extended to 10 min. The participants' answers were recorded and analyzed in the same way like in Experiments 1A and 1B.

Results

Recall Totals. Participants correctly recalled 63.33% of the target list in the forget condition, 43.33% in the remember condition, and 63.33% in the no-PI condition. An overall ANOVA of the three conditions (forget, remember, no PI) showed a significant effect, $F(2, 58) = 13.727, MSE = 0.029, p < 0.001, \eta_p^2 = 0.321$. Pairwise comparisons revealed that the difference of 20.00% in response totals between the no-PI condition and the remember condition was statistically significant, $t(29) = 4.735, p < 0.001, d = 1.263$, reflecting the buildup of PI from the no-PI condition to the remember condition. The difference of 20.00% between the forget condition and the remember condition was reliable, $t(29) = 4.333, p < 0.001, d = 1.145$, demonstrating typical postcue enhancement. There was no difference in response totals between the forget and no-PI conditions (0%), pointing to a complete release from PI in the forget condition.

Response Latencies. First-response latencies were 1.44 s in the forget condition, 1.74 s in the remember condition, and 1.47 s in the no-PI condition. An overall ANOVA of the three conditions (forget, remember, no PI) showed no significant effect, $F(2, 58) = 1.829, MSE = 0.434, p = 0.172$. Thus, like in Experiments 1A and 1B, there was no reliable effect of the buildup and release from PI on the initiation stage of the recall process.

Subsequent-response latencies were grouped into 5-s bins and plotted as a function of time (see Figure 3). Figure 3 also shows the best-fitting exponentials. The exponential accounts for a large portion of the variance in each of the three conditions (see Table 3). The parameter estimate of asymptotic percentage (N) revealed values of 51.47% for target list recall in the forget condition, 35.82% in the remember condition, and 53.47% in the

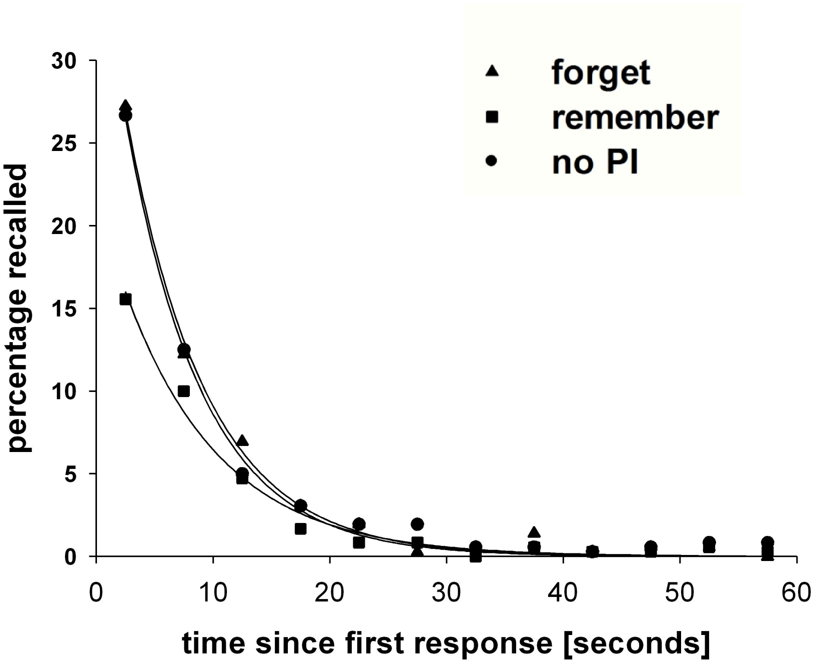

Figure 3. Results of Experiment 1C: Percentage recalled for each 5-s bin of the target list in the forget, remember, and no-PI conditions together with the best-fitting exponentials. Latency is measured from the first response.

Table 3. Percentage recalled and response latencies (in seconds) of the target list in Experiment 1C (standard errors in parentheses). VAF = variance accounted for by the exponential.

condition	% recalled	first-response latency	subsequent-response latency(τ)	VAF
forget	63.33 (3.62)	1.44 (0.09)	6.90 (0.30)	0.99
remember	43.33 (4.78)	1.74 (0.15)	8.26 (0.56)	0.97
no PI	63.33 (3.77)	1.47 (0.06)	6.65 (0.34)	0.99

no-PI condition. Again, corrected totals - 55.00% in the forget condition, 35.00% in the remember condition, and 55.00% in the no-PI condition - were very similar to the estimated values of N. This indicates that recall was close to asymptote in the current experiment.

Estimated subsequent-response latencies were 6.90 s in the forget condition, 8.26 s in the remember condition, and 6.65 s in the no-PI condition. The difference of 1.61 s between the no-PI condition and the remember condition was reliable, $t(20) = 2.439, p = 0.024$, hence reflecting the buildup of PI in the subsequent-response latency measure. The difference of 1.36 s between the forget condition and the remember condition was statistically significant, $t(20) = 2.142, p = 0.045$, pointing to the reduced PI in the forget condition. The difference of 0.25 s between the forget condition and the no-PI condition was not reliable, $t(20) < 1$, again demonstrating an almost perfect release from PI in the forget condition.

Discussion

Using a longer retention interval between the study phase and the test phase, the results of Experiment 1C replicated those of Experiments 1A and 1B. They showed buildup of PI from the no-PI condition to the remember condition, reflected in decreased response totals and increased response latencies. Again, typical postcue enhancement arose, as reflected in increased response totals in the forget condition as compared with the remember condition. Response latencies were again shorter in the forget condition as compared with the remember condition. Also like in Experiments 1A and 1B, the latency effects were present in the subsequent-response latencies, but to a lesser degree in first-response latencies, suggesting effects in retrieval from search set but not in retrieval initiation.

Regarding response totals, the PI effect was 20 % and thus roughly between the PI effects of Experiments 1A (ca. 15%) and 1B (ca. 27%). Regarding response latencies, the PI effect of 1.61s was also between Experiments 1A (1.41s) and 1B (2.01s). Interestingly, like in the previous experiments, release from PI was (almost) complete, leading to similar response totals and similar latencies in the forget condition relative to the no-PI condition. Like the results of Experiments 1A and 1B, the results of Experiment 1C thus are consistent with the view that LMDF of previously studied nontarget material reduces participants' search set size when target material is recalled. Because release from PI was complete in response latency, the results suggest that in LMDF, during recall of target items, the search set hardly contains any nontarget items.

Experiments 1A-1C were not the first experiments to examine response latencies in LMDF. In a recent study, Spillers and Unsworth (2011) addressed the issue as well. However, whereas in the present study the focus was on postcue enhancement and its underlying mechanisms and subjects were asked to recall the postcue items first, in this prior work the focus was on precue forgetting and subjects were asked to recall the precue items first. Recent work has shown that postcue enhancement arises mainly if postcue items are recalled first and may be reduced, or even be eliminated, if the precue items are recalled first (Pastötter et al., 2012). Supporting this view, Spillers and Unsworth did not find any evidence for PI release, both in response total and response latencies, whereas Experiments 1A - 1C of the present work demonstrate release from PI, both in response total and response latencies.

The present experiments thus go beyond this prior work by demonstrating for the first time that release from PI in response to a forget cue is accompanied by a reduction in mental search set size. Furthermore, the findings of Experiments 1A-1C are consistent with both the inhibitory (Bjork, 1989; Geiselman et al., 1983) and context-change accounts (Sahakyan & Kelley, 2002) of precue forgetting, because both accounts assume that postcue enhancement arises due to reduced PI from the precue material. This issue will be addressed in more detail in Experiment 4, which sought to discriminate between these two explanations of precue forgetting.

2.5 Experiment 2

Both providing a cue to forget prior nontarget material as well as a context change between nontarget and target material have been shown to cause a release from PI and thus, enhanced memory for the target material (e.g. Sahakyan & Kelley, 2002; Delaney & Sahakyan, 2007). While Experiments 1A-1C found that a focused-search process mediates the enhancement effect in the LMDF task, Experiment 2 intended to investigate whether such processes are also crucial for the enhancement effect in the context-change task. Examining whether similar mechanisms mediate enhancement effects in the two tasks is relevant because they are generally both regarded as memory updating paradigms. While the LMDF task has been suggested to tap intentional memory updating (Bjork, 1972, 1989), the context-change task has been argued to capture contextual memory updating (Pastötter & Bäuml, 2007; Sahakyan & Kelley, 2002). Thus, Experiment 2 hoped to gain some insight as to whether a more focused search is specific to intentional updating or whether such processes extend to contextual updating.

Experiment 2 employed a standard 2-list context-change task to examine buildup of PI and release from PI. Like in the previous LMDF experiments, the experiment included three experimental conditions. In the context-change and no-change conditions, participants studied a (target) list of items and one preceding nontarget list. Between study of the two lists, participants performed a mental imagination task (context-change condition) or counted backwards from a three-digit number (no-change condition). The mental imagination task (i.e., imagining being back in one's childhood home; e.g., Pastötter & Bäuml, 2007; Sahakyan & Kelley, 2002) was similar in content to daydreams, which are known to mentally transport people to another place or time (Delaney et al., 2010). On the contrary, the counting task is known to induce no such mental context change (Klein, Shiffrin, & Criss, 2007). In the no-PI condition, participants again only studied the single (target) list, preceded by an unrelated distractor task. After study of the target list, in all three conditions memory for the items of this list was tested; both response totals and response latencies were measured.

On the basis of the results of the previous experiments and the prior work on context-dependent forgetting (e.g., Pastötter & Bäuml, 2007; Sahakyan & Kelley, 2002), both buildup of PI and release from PI should arise in this experiment. It was expected that, analogous to the remember condition, recall of the target list should be reduced in the no-change condition relative to the no-PI condition, thus reflecting buildup of PI. Relative to the no-change condition, recall of the target list should be enhanced in the context-change condition, thus reflecting release from PI.

Regarding speed of recall, response latencies should be increased in the no-change condition relative to the no-PI condition. Similar to using a forget cue in previous experiments, it was expected that "treating" subjects with an internal context change in the context-change condition should reduce latencies relative to solving an unrelated task in the no-change condition. Again, both buildup of PI (from the no-PI to the no-change conditions) and release from PI (from the no-change to the context-change conditions) should be mainly reflected in subsequent-response latencies and less, if at all, in first-response latencies. The expected results would indicate that, like with LMDF, release from PI after context change can be mediated by a reduction in participants' search set size, so that, in response to the context change, participants are able to (largely) restrict their memory search to the target list. This would imply that the focused-search hypothesis may not only account for the enhancement effect in intentional memory updating, as has been demonstrated in Experiments 1A-1C, but also regarding contextual memory updating.

Methods

Participants. Twenty-four healthy students at Regensburg University took part in the experiment on a voluntary basis. They received 5 Euros for their participation. The sample consisted of 19 females and 5 males. Their mean age was 23.62 years with a range of 20 to 28 years. All participants spoke German as their native language. They were tested individually.

Materials. Five lists of 12 items were created by drawing 60 items from the pool of the 120 items that were generated for Experiment 1A, with mean item length and item frequency being held constant across lists. Each list was used equally often in the context-change condition, the no-change condition, and the no-PI condition.

Design and Procedure. The design and procedure were identical to Experiment 1A with one central exception: Instead of presenting a forget or remember cue before encoding of the target list, participants dealt with an imagination task (context-change condition) or with a backward counting task (no-change condition). In the context-change condition, participants were instructed to mentally walk through their childhood home and tell details to the experimenter for 45 s. In the no-change condition, participants counted backwards in steps of three from a random three digit number for 45 s. This distractor task is not assumed to cause a change of the mental context. The distractor phase in the no-PI condition was prolonged to 2 min to account for the context change/backward counting task.

Results

Recall Totals. Concerning recall of the target list, an overall ANOVA of the three conditions (context change, no change, no PI) showed a significant effect, $F(2,46) = 24.269, MSE = 0.012, p = 0.801, \eta_p^2 = 0.513$. Pairwise comparisons revealed that the difference between the no-PI condition and the context-change condition (78.82% vs. 56.94%) was reliable, $t(23) = 6.665, p < 0.001, d = 1.532$, reflecting the buildup of PI in the no-change condition compared to the no-PI condition. The difference between the context-change condition and the no-change condition (65.61% vs. 56.92%) was significant,

$t(23) = 2.687, p < 0.013, d = 0.649$, showing a release from PI for the target list and thus, the typical enhancement effect of the context change. The difference between the no-PI condition and the context-change condition (78.82% vs. 65.62%) was also reliable, $t(23) = 4.452, p < 0.001, d = 0.877$, which points to an only partial release from PI in the context-change condition compared to the no-PI condition. Concerning List 1, participants recalled, on average, 58.33% of the items in the no-change condition compared to 46,53% in the context-change condition. This difference of 11.80% was statistically significant, $F(1, 23) = 11.561, MSE = 0.082, p = 0.002, \eta_p^2 = 0.335$, reflecting the typical forgetting effect of the context change.

Response Latencies. Table 4 shows the first-response latencies of List-1 and List-2 recall. Mean first-response latencies for the target list were 1.31 s, 1.46 s, and 1.33 s for the context-change condition, the no-change condition, and the no-PI condition. An overall ANOVA of the three conditions (context change, no change, no PI) revealed no significant differences, $F(2, 46) < 1$. Again, this latency measure is obviously not affected by the buildup or release from PI.

Once again, subsequent-response latencies were grouped into 5-second bins and plotted as a function of time (see Figure 4). The parameter estimates of asymptotic percentage (N) revealed values of 56.52% for target list recall in the context-change condition, 50.88% in the no-change condition, and 70.56% in the no-PI condition. Again, corrected totals - 57.29% in the context-change condition, 48.61% in the no-change condition, and 70.49% in the no-PI condition - were very similar to the estimated values of N. This indicates that recall was close to asymptote in the current experiment.

Estimated subsequent-response latencies for the target list were 6.97 s, 8.67 s, and 7.06 s for the context-change condition, the no-change condition, and the no-PI condition. The difference of 1.61 s between the no-PI condition and the no-change condition was reliable, $t(20) = 2.176, p = 0.042$, demonstrating the buildup of PI in the no-change condition in the subsequent-response latency measure. The difference of 1.70 s between the

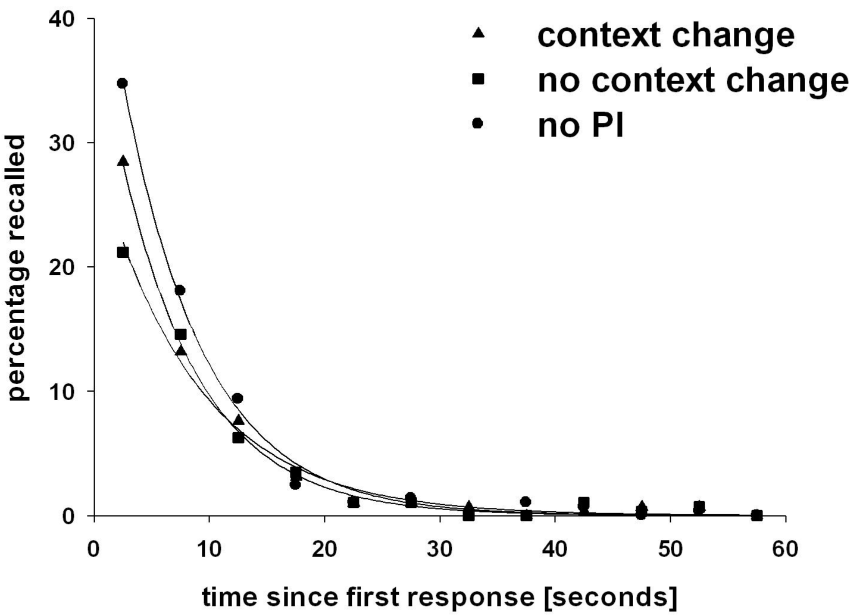

Figure 4. Results of Experiment 2: Percentage recalled for each 5-s bin of the target list in the context-change, no-change condition, and no-PI conditions together with the best-fitting exponentials. Latency is measured from the first response. PI = proactive interference.

Table 4. Percentage recalled and response latencies (in seconds) of the target list and List 1 for Experiment 2 (standard errors in parentheses). CC = context-change condition, no CC = no-change condition; VAF = variance accounted for by the exponential.

	condition	% recalled	first-response latency	subsequent-response latency(τ)	VAF
target list	CC	65.62 (3.34)	1.31 (0.08)	6.97 (0.24)	0.99
	no CC	56.94 (5.08)	1.46 (0.21)	8.67 (0.67)	0.98
	no PI	78.82 (3.51)	1.33 (0.08)	7.06 (0.32)	0.99
List 1	CC	46.53 (3.44)	3.54 (1.16)	7.86 (0.46)	0.99
	no CC	58.33 (5.33)	1.53 (0.17)	7.06 (0.47)	0.96

context-change condition and the no-change condition was also significant, $t(20) = 2.297, p = 0.033$, showing the typical enhancement of the context change. The difference between the context-change condition and the no-PI condition was not reliable, $t(20) < 1$, pointing to a complete release from PI in the subsequent-response latency measure caused by the context change. Concerning List-1 recall, subsequent-response latencies for were 7.86 s in the context-change condition, and 7.06 s in the no-change condition; this difference of 0.80 s was not significant, $t(20) = 1.212, p = 0.240$.

Discussion

The results of Experiment 2 replicated those of the previous experiments on buildup of PI by showing reduced response totals and increased response latencies for the target list when previous material was studied. Again, the effect on latencies was mainly driven by an effect on subsequent-response latencies but not on first-response latencies, suggesting an effect on retrieval from the search set rather than retrieval initiation, which is consistent with temporal discrimination theory (Baddeley, 1990; Crowder, 1976).

Regarding release from PI, the results on response totals showed enhanced memory of the target list when, prior to the encoding of that list an internal context change was induced (e.g., Sahakyan & Kelley, 2002), although, contrary to Experiments 1A-1C, the release from PI was not complete. The results on response latencies demonstrated reduced response latencies for the target list after the context change, with speed of recall being indistinguishable from that in the no-PI condition. The release effect on latencies was again driven by an effect on subsequent-response latencies, suggesting an effect on retrieval from the search set. The current results on release from PI are consistent with the view that changing the internal context between study of multiple lists enhances list segregation and thus reduces mental search set size when the target list is recalled. Response latency results even suggest that, after the context change, the search set can be about equally focused as in the no-PI condition.

In a recent study, Unsworth, Spillers, and Brewer (2012) also examined response latencies in context-dependent forgetting. However, whereas in this prior work, a 1-list paradigm was used and it was examined whether a change in context after study of a list affects later recall of the list, in the present experiment, the focus was on release from PI and a 2-list paradigm was employed to study the effect of inter-list context change on later recall of the second-list items. Unsworth et al. found that response latencies for the single list did not differ in the presence and in the absence of a context change. In the current Experiment 2, the finding of similar response latencies for List 1 in the presence and in in the absence of a context change essentially replicates their results.

Overall, the present experiment goes beyond prior work by demonstrating that the enhancement effects of intentional and contextual memory updating are both mediated by a more focused memory search that enables participants to largely restrict their memory search to the target items.

2.6 Experiment 3

The goal of Experiment 3 was to examine whether the focused-search hypothesis is also capable of explaining the target list enhancement effect in the interpolated testing task. Indeed, Szpunar et al. (2008) have previously argued that interpolated testing may help to segregate nontarget from target lists and thus enable a more focused search set during retrieval. The interpolated testing technique seems to be a relatively unique memory phenomenon, because it leads to enhancement of both nontarget and target material (e.g., Szpunar et al. 2008; Weinstein et al., 2011), whereas both a forget cue and a context change produce forgetting of nontarget material as well as enhancement effects for target material (e.g., Sahakyan & Kelley, 2002). Thus, it might be interesting to explore whether in the interpolated testing task, the mechanisms underlying the target enhancement effect are, nonetheless, similar to those in intentional and contextual memory updating.

Like Experiment 1B, Experiment 3 employed a 3-list paradigm. In contrast to Experiment 1B, which examined how a forget cue enhances memory of subsequently studied material, the present experiment examined how testing of previously studied material enhances memory of subsequently studied material. As in the previous experiments, Experiment 3 included three experimental conditions. In the no-PI condition, participants studied a list of items, preceded only by an unrelated distractor task. In the other two conditions, participants studied two prior lists before they were presented the target list; in the restudy condition, each of the two prior lists was re-exposed after study to provide opportunity for additional learning, whereas in the testing condition, participants were asked to recall each of the two prior lists after list study. Szpunar et al. (2008) showed that interpolated testing but not restudy of the prior lists can insulate against PI, with restudy of the single lists being similar in effect to participants' engagement in an unrelated distractor task (see also Pastötter et al., 2011; Weinstein et al., 2011). After study of the target list, in all three conditions memory for the items of this list was tested; both response totals and response latencies were measured.

On the basis of the results of Experiment 1B and prior work on interpolated testing (e.g., Pastötter et al., 2011; Szpunar et al., 2008), both buildup of PI and release from PI should arise in this experiment. Analogous to the remember condition, recall of the target list in the restudy condition was expected to decrease relative to the no-PI condition, and recall of the target list in the testing condition was expected to increase relative to the restudy condition. If interpolated testing was similar in amount of PI release to LMDF, response totals in the testing condition and the no-PI condition might even be similar, which would point to a perfect release from PI with interpolated testing.

Regarding response latencies, increased latencies were expected to arise in the restudy condition relative to the no-PI condition. More important, on the basis of the hypothesis that a reduction in search set size contributes to PI release, reduced latencies should again arise in the testing condition relative to the restudy condition. Like in the previous experiments, both buildup of PI and release from PI were expected to be mainly reflected in subsequent-response latencies and less, if at all, in first-response latencies. The expected results would indicate that, like LMDF or a context change, interpolated testing can reduce PI by a reduction in the size of participants' search set.

Methods

Participants. Thirty healthy students at Regensburg University took part in the experiment on a voluntary basis. They received 10 Euros for their participation. The sample consisted of 21 females and 9 males. Their mean age was 23.43 years with a range of 20 to 26 years. All participants spoke German as their native language. They were tested individually.

Materials. Like in Experiment 1B, seven lists of 12 items were created by drawing 72 items from the pool of the 120 items that were generated for Experiment 1A, with mean item length and item frequency being held constant across lists. Three lists were randomly assigned to the testing condition, three lists to the restudy condition, and one list to the no-PI condition for each participant.

Design and Procedure. Design and procedure were identical to Experiment 1B, with a few exceptions: The main difference was the treatment prior to encoding of the target list (List 3): instead of presenting a forget cue, subjects were tested in a free recall for 1 min after study of each Lists 1 and 2 (testing condition). There was 1 min of backwards counting between encoding of Lists 1 and 2 and testing each list. Responses from both tests were recorded. Unlike the remember condition in Experiment 1B, subjects restudied Lists 1 and 2 after their initial study (restudy condition) instead of being provided with a remember cue prior to encoding of the target list. There was 1 min of backward counting between study and restudy of Lists 1 and 2. In the no-PI condition, the arithmetic task was extended to 6 min to match the additional time for the testing/restudy and distractors. Another difference between Experiment 1B and the current experiment was the final cumulative test of all three studied lists that took place 2 min after the free recall of the target list (subjects solved short reasoning tasks in that 2 min interval). In the final cumulative test, subjects were given 3 min to recall in any order they wished as many words as possible from all three lists of words they had studied. They wrote down the words on a sheet of paper. It was emphasized to subjects that they should use the 3 min efficiently in their attempt to recall study materials. Results of the final test are only marginally relevant concerning the main hypothesis and will not be reported.

Results

Recall Totals. Immediate recall totals for the target list are depicted in Table 5. An overall ANOVA of the three conditions (testing, restudy, no PI) revealed a significant effect, $F(2, 58) = 5.411, MSE = 0.032, p = 0.007, \eta_p^2 = 0.157$. Pairwise comparisons showed a reliable difference in recall levels of the target list between the restudy condition and the no-PI condition (58.89% vs. 71.11%), $t(29) = 2.138, p = 0.041, d = 0.512$, demonstrating the buildup of PI caused by the study (and restudy) of preceding material. Studying two additional lists also resulted in lower recall levels in the restudy condition than in the testing condition (58.89% vs. 72.78%), $t(29) = 2.924, p = 0.007, d = 0.749$, showing the beneficial effect for the target list when preceding material is tested compared to when it is restudied. There was no reliable difference between the recall levels of the testing condition and the no-PI condition (72.78% vs. 71.11%), $t(29) < 1$, reflecting the release from PI caused by interpolated testing of the preceding material. Within the testing condition, an overall ANOVA showed no significant differences in the recall levels between Lists 1, 2 and the target list, $F(2, 58) < 1$.

Response Latencies. First-response latencies of the target list were 1.42 s in the testing condition, 2.29 s in the restudy condition, and 1.46 s in the no-PI condition (see Table 3). An overall ANOVA of the three conditions (testing, restudy, no PI) revealed no significant differences, $F(2, 58) = 2.747, MSE = 3.398, p = 0.075$. Thus, replicating the findings from Experiments 1A and 1B, the initiation process is neither affected by the buildup of PI nor by the reduction in PI. Within the testing condition, first-response latencies for List 1 were 1.19 s and 1.41 s for List 2. An overall ANOVA revealed no significant differences in the first-response latencies between Lists 1, 2 and the target list, $F(2, 58) = 2.734, MSE = 0.155, p = 0.075$.

Like in the previous experiments, subsequent-response latencies were grouped into 5-s bins and plotted as a function of time (see Figure 5). The data points were well described by the two-parameter exponential, which accounts for a large portion of the variance in each condition (see Table 5). The parameter estimate of asymptotic percentage (N) revealed values of 62.66% for recall of the target list in the testing condition, 51.17% in the restudy condition, and 59.78% in the no-PI condition. Like in the previous experiments, corrected totals - 64.45% in the testing condition, 50.56% in the restudy condition, and 62.78% in the no-PI condition - were very similar to the estimated values of N. This indicates that recall was close to asymptote in the current experiment. Estimated mean subsequent-response latencies of the target list were 8.10 s in the testing condition, 9.87 s in the restudy condition, and 7.88 s in the no-PI condition. The difference of 1.99 s between the no-PI condition and the restudy condition was reliable, $t(20) = 2.391, p = 0.027$, demonstrating that the buildup of PI from the no-PI to the restudy condition is also present in subsequent-response latencies. The difference of 1.77 s between the testing and the restudy condition was also reliable, $t(20) = 2.091, p = 0.049$, pointing to the diminished PI in the testing condition. Recall in the testing condition and no-PI condition did not differ statistically, $t(20) < 1$, obviously showing that testing preceding material causes a release from PI for the target list.

Within the testing condition, subsequent-response latencies were 7.73 s for List 1 and 8.61 s for List 2. Pairwise comparisons showed no significant differences in the subsequent-response latencies between List 1 and 2, List 1 and the target list, or List 2 and the target list, all $ts(29) < 1$.

Discussion

The results of Experiment 3 replicated those of Experiments 1A-1C and 2 on buildup of PI by showing reduced response totals and increased response latencies for a list when prior material was studied (and restudied). Again, the effect on latencies was mainly driven by an effect on subsequent-response latencies but not on first-response latencies, suggesting an effect on retrieval

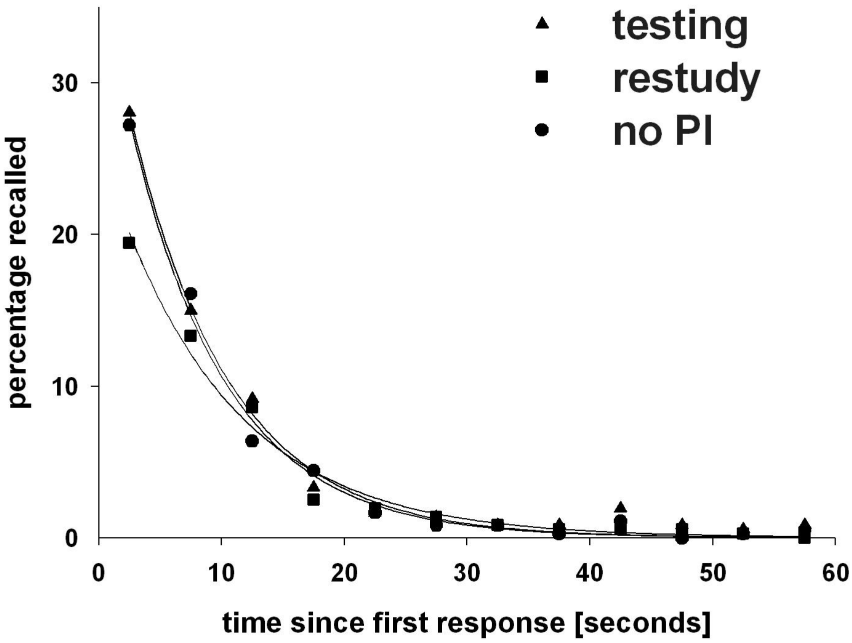

Figure 5. Results of Experiment 3: Percentage recalled for each 5-s bin of the target list in the testing, restudy, and no-PI conditions together with the best-fitting exponentials. Latency is measured from the first response (PI = proactive interference).

Table 5. Percentage recalled and response latencies (in seconds) of the target list, Lists 1 and 2 for Experiment 3 (standard errors in parentheses). VAF = variance accounted for by the exponential.

	condition	% recalled	first-response latency	subsequent-response latency(τ)	VAF
target list	testing	72.78 (3.48)	1.42 (0.08)	8.10 (0.44)	0.99
	restudy	58.89 (5.39)	2.29 (0.54)	9.87 (0.73)	0.98
	no PI	71.11 (3.74)	1.46 (0.09)	7.88 (0.40)	0.99
List 1	testing	74.17 (4.08)	1.19 (0.06)	7.73 (0.51)	0.99
List 2	testing	69.44 (3.84)	1.41 (0.09)	8.61 (0.94)	0.96

from the search set rather than retrieval initiation, which is consistent with temporal discrimination theory (Baddeley, 1990; Crowder, 1976).

Regarding the enhancement effect of prior interpolated testing, the results on response totals replicated prior work by Szpunar et al. (2008) and Pastötter et al. (2011) by showing enhanced recall of the target list. Recall was even comparable between the testing and no-PI conditions, suggesting a complete release from PI. This extends on the prior work that did not include a no-PI condition. More important, the results on response latencies also go beyond the prior work by showing reduced response latencies for the target list when the prior lists were tested after study; latencies in the testing condition were even indistinguishable from those in the no-PI condition, which indicates a perfect release from PI. The release effect on latencies was again driven by an effect on subsequent-response latencies, suggesting an effect on retrieval from the search set. The results on release from PI are consistent with the view that testing of prior lists after study enhances segregation between the target list and prior lists and thus reduces mental search set size when the target items are recalled. This proposal was already suggested in prior work (Szpunar et al., 2008), but without testing it directly. Experiment 3 is the first experiment to demonstrate the adequacy of this view.

Additional Analysis

Concerning first-response latencies of the target list, a fairly consistent numerical pattern emerged in all five experiments (Experiments 1A - 1C, 2, and 3): the latencies increased slightly when PI built up, and they decreased slightly when PI was reduced (see Tables 1-5). When each experiment was analyzed separately, these effects were, at best, marginally significant (like in Experiments 1B and 2). To increase power, the effect of PI and PI release on first-response latencies was analyzed by examining the latencies simultaneously for all four experiments. In the following paragraphs, the term PI condition is used as an umbrella term for the remember condition

(Experiments 1A-1C), the no-change condition (Experiment 2), and the restudy condition (Experiment 3), because PI is built up in each of these conditions. Accordingly, the term release-from-PI condition refers to the forget condition (Experiments 1A-1C), the testing condition (Experiment 2), and the context-change condition (Experiment 3), because PI is released in each of these conditions.

A 3 (condition: release from PI, PI, no PI) x 5 (experiment: 1A, 1B, 1C, 2, 3) mixed design ANOVA revealed a main effect of condition, $F(2, 228) = 8.103, MSE = 0.934, p < 0.001, \eta_p^2 = 0.066$, no main effect of experiment, $F(3, 114) = 1.004, MSE = 1.399, p = 0.409$, and no interaction between the two factors, $F(6, 228) = 1.243, MSE = 0.934, p = 0.275$. Pairwise comparisons revealed a significant difference between the no-PI condition (1.36 s) and the PI condition (1.79 s), $t(131) = 2.885, p = 0.005, d = 0.420$, showing an increase in latencies with PI; and they revealed a significant difference between the PI (1.79 s) and release-from-PI conditions (1.37 s), $t(131) = 2.830, p = 0.005, d = 0.441$, reflecting a decrease in latencies with PI release. The difference between the no-PI condition (1.36 s) and the release-from-PI conditions (1.37 s) was not reliable, $t(101) < 1$. These results suggest that there was a small effect of both PI and release from PI on first-response latencies and thus on the initiation phase of the retrieval process. This effect did not vary across experiments and therefore did not depend on how exactly release from PI was induced.

2.7 Interim Summary

The first part of the present work tested whether the standard enhancement effect in the LMDF task arises, at least partially, because the forget cue enables a better segregation of nontarget and target items and thus, a more refined mental search set that hardly contains any nontarget items. In addition, the specificity of this focused-search hypothesis was tested by examining whether a release from PI via a context change between study of nontarget and target lists as well as via testing of previously studied nontarget lists similarly allows for a more limited mental search set for target material.

Experiments 1A-1C tested the focused-search assumption of postcue enhancement in the LMDF task. In each experiment, response totals as well as response latencies were analyzed. Further, the inclusion of a no-PI condition in each experiment allowed to assess whether breadth of memory search was also affected when PI builds up in the remember condition. Replicating prior work (Wixted & Rohrer, 1993), the presence of prior nontarget material was found to increase PI on the target list, as reflected in decreased response totals increased response latencies. Because the subsequent-response latency measure serves as an index of search set size (Rohrer, 1996), these findings imply that breadth of memory search is increased in the presence of PI from nontarget material. More important, across experiments, providing a forget cue between nontarget and target material again reduced PI on the target list, as reflected in increased response totals and, most notably, in decreased subsequent-response latencies. Subsequent-response latencies in the forget condition were even indistinguishable from those in the no-PI condition, suggesting a complete release from PI. This was not only the case for a standard 2-list LMDF task (Experiment 1A), but also when buildup of PI had been amplified by doubling the amount of precue material (Experiment 1B) or by extending the interval between study and test (Experiment 1C). The finding of decreased target list latencies supports the focused-search hypothesis, suggesting that the forget cue enhances discrimination of the target material and therefore, enables participants to focus their memory more efficiently on the target list. The present results thereby imply that retrieval processes are crucially involved in postcue enhancement, which is consistent with the Pastötter et al. (2012) framework.

Two subsequent experiments found that a context change between nontarget and target material (Experiment 2) as well as testing of nontarget material (Experiment 3) reliably increased response totals and reduced subsequent-response latencies of the target list as well. Because these findings show that both a context change and interpolated testing produced effects on target list retrieval similar to a forget cue, it might be argued that a retrieval process which enables a more focused memory search for the target list is involved in all 3 tasks. Thus, a focused-search mechanism may not only play a crucial role for the LMDF task, but may in general play a crucial role for treatments that can cause a release from PI.

Figure 6 depicts response totals as well as subsequent-response latencies for Experiments 1-3 for the release-from-PI conditions (forget, context-change, testing), PI conditions (remember, no change, restudy), and no-PI conditions.

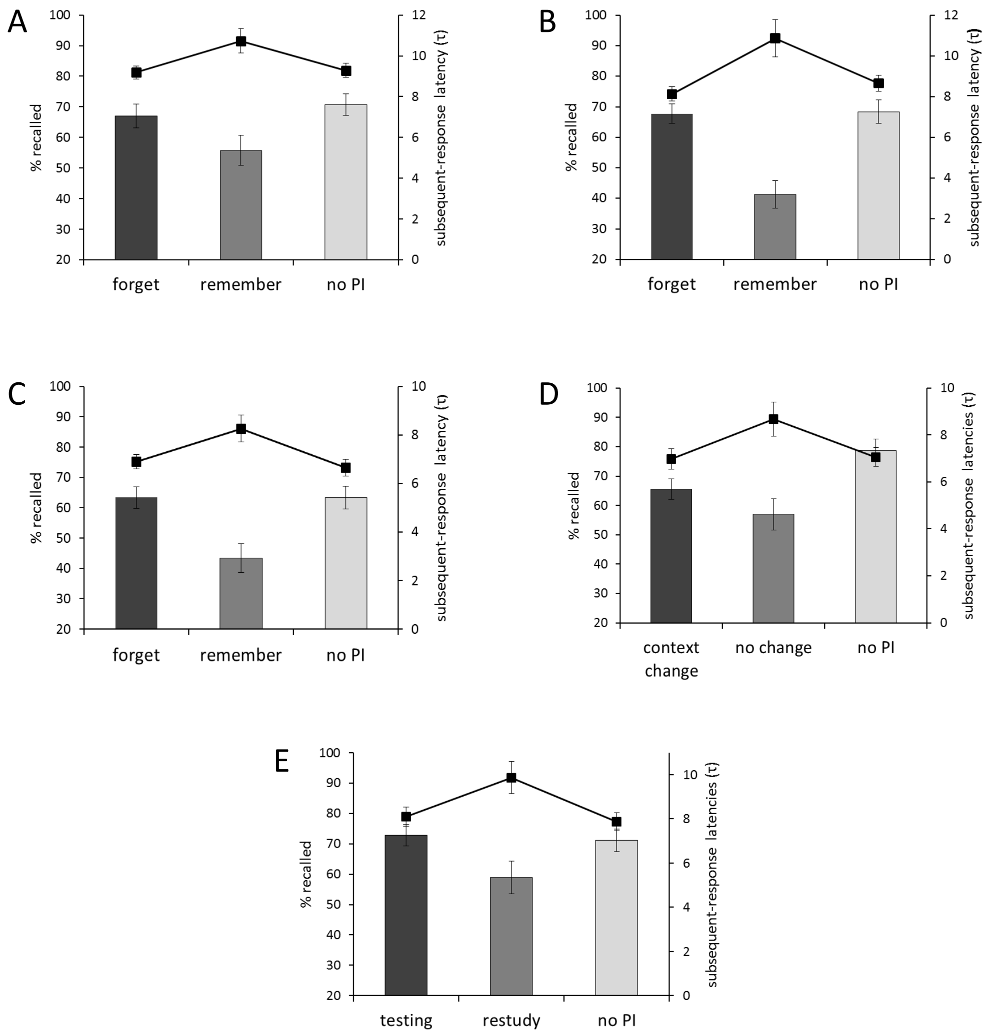

Figure 6. Percentage recalled (bars) and subsequent-response latencies in seconds (small squares) for the release-from-PI conditions (forget, context-change, testing), PI conditions (remember, no change, restudy), and no-PI conditions of (A) Experiment 1A, (B) Experiment 1B, (C) Experiment 1C, (D) Experiment 2, and (E) Experiment 3. Error bars represent standard errors.

Chapter 3

Precue Forgetting and the Issue of Selectivity

3.1 Experiment 4

The findings of Experiments 1A-1C suggest that a retrieval component contributes to postcue enhancement in LMDF, which is consistent with the Pastötter et al. (2012) proposal that accessibility of the precue context is reduced via an inhibitory mechanism (Bjork, 1989; Geiselman et al., 1983). However, the findings would also be in line with the assumption that a context change is responsible for the impaired access of the precue material (Sahakyan & Kelley, 2002; Sahakyan & Delaney, 2005). Experiment 4 addressed the nature of the precue forgetting effect and sought to segregate between the inhibitory and context-change accounts.

While previous work tried to resolve the issue whether an inhibitory or a non-inhibitory (context-change) mechanism mediates precue forgetting in LMDF, evidence is relatively mixed. However, testing whether the process that mediates the forgetting in LMDF can flexibly discriminate between relevant and irrelevant material might potentially constrain theory. Such selectivity would arise if participants were able to forget only part of the previously studied material but to keep remembering the remaining part when cued to do so. Indeed, the inhibitory and non-inhibitory accounts of precue forgetting make different predictions with respect to selectivity in LMDF. An inhibitory mechanism has repeatedly been suggested to be flexible (e.g. Anderson, 2005), and consequently, selective LMDF should be expected under that process. However, no selective LMDF should arise under the context-change view, because the forget cue should reduce precue accessibility for all precue material, irrespective of whether it has been declared relevant or irrelevant.

Prior research on selective LMDF has yielded ambiguous results. Whereas Sahakyan (2004) did not find evidence for selectivity in LMDF, Delaney et al. (2009) reported reliable selective LMDF. Different experimental tasks were used in these two studies. While Sahakyan employed a 3-list task, in which relevant and irrelevant precue material was presented subsequently as Lists 1 and 2, Delaney et al. made use of a 2-list task, in which relevant and irrelevant precue material was presented alternatingly in List 1. Although the two studies differed not only in task but also in other aspects, including material and procedure (see "Background" section), one possibility for the conflicting results in these prior works might have been that selective LMDF varies with task, and selectivity is easier to achieve in the 2-list task than the 3-list task. To date, this issue has not been investigated. The goal of Experiment 4 was to provide such a direct comparison and to investigate directly whether selectivity in LMDF varies with type of task.

In both the 2-list and 3-list tasks of Experiment 4, relevant and irrelevant precue items were spoken by different speaker voices. In the 2-list task, relevant and irrelevant precue items were assigned to the same list (List 1) and were presented in alternating order. However, in the 3-list task, relevant and irrelevant precue items were assigned to separate lists and were presented successively as Lists 1 and 2. After study of these precue items, participants in both tasks were cued in the (selective) forget condition to forget the irrelevant precue items, but to remember the relevant precue items. In the remember conditions of both tasks, all precue items should be remembered. Perfect selectivity in both tasks would be reflected in decreased recall of irrelevant precue items in the forget condition relative to the remember condition, whereas recall of relevant precue items should be similar for the forget and remember conditions. While selective LMDF was expected to arise for both tasks, selectivity in the 2-list task might be even more pronounced, because prior work suggested that selectivity might be easier to find in the 2-list task than in the 3-list task (Delaney et al., 2009, Sahakyan, 2004).

Methods

Participants. Two hundred and forty students (139 females, 101 males) at Regensburg University participated in Experiment 4. All participants were tested individually with 120 participants in each of the two tasks.

Material. Forty-eight unrelated German nouns of medium frequency were drawn from CELEX database which differed from Experiments 1-3. For each participant, six item sets were prepared: three sets for the forget condition and three sets for the remember condition. The assignment of items to sets was random. Sets 1 and 2 in both conditions consisted of 6 items each, Set 3 of 12 items. In the 2-list task, Sets 1 and 2 were presented as List 1 and Set 3 was presented as List 2; In the 3-list task, Sets 1, 2, and 3 were presented as Lists 1, 2, and 3; Prior to the experiment, for each of the 48 words, two auditory stimuli were created, consisting of 16-bit stereo speech from one female and one male adult speaker. Stimuli were recorded with a sampling rate of 22 kHz and a maximum stimulus length of 1 s. Recording and segmentation of auditory stimuli were done with Cool Edit 2000 v1.1 software.

Design. The experiment had a 2 × 2 mixed design with the within-participants factor of CUING (forget vs. remember) and the between-participants factor of TASK (2-list task, 3-list task). Conditions differed as to whether the relevant and irrelevant precue items were assigned to separate lists and were presented in an alternating order (2-list task), or the two sets of items were part of the same list and were presented in a blocked format (3-list task). Conditions also differed as to what type of cue was provided, either a cue to forget half of the precue items but to keep the remaining precue items in mind (forget condition), or a cue to remember all precue items (remember condition).

Procedure. Like in Experiments 1A-1C, the multiple-cue version of LMDF was used (see Pastötter & Bäuml, 2007, 2010; Zellner & Bäuml, 2006). Participants were told that they would be presented with lists of words to learn for a later recall test and that following each list they would be given a cue to remember or forget the previously studied item list(s). Participants were told that a forget-cued (irrelevant) list would not be tested on the later recall test. In the 2-list task, participants were informed prior to encoding of

List 1, that each item would be read by either a male or female voice and that both the "female" and "male" would have to be remembered separately in a later test. In the 3-list task, prior to the encoding of each single list, participants were told that either a "female" or a "male" list of items would be presented next.

Each lists' items were presented in the center of a computer monitor with a presentation rate of 4 s per item. Item order within list was random for all participants. In the 2-list task, female and male items were presented alternatingly within List 1; in the 3-list task, female and male items were presented successively as Lists 1 and 2. After presentation of List 1, a cue to remember List 1 was provided. In both tasks, after presentation of the female and male item sets, a cue was provided to either remember all previously studied items (remember condition), or to forget the female (male) items but keep on remembering the male (female) items (forget condition). Following the encoding phase, participants counted backward from a three-digit number in steps of threes for 30 seconds as a recency control.

At test, participants were asked to recall all of the previously presented items, irrespective of original cuing. Because the focus of this study was on precue item recall, participants were asked to recall precue item sets first. Half of the participants recalled relevant precue items first and irrelevant precue items second; for the other half, list output order was reversed. All participants were asked to recall the postcue list last. Participants wrote down the items of the three sets (relevant precue items, irrelevant precue items, postcue items) on separate sheets of papers. Recall time for relevant and irrelevant precue items was 30 s each; recall time for postcue items was 1 min. If a participant indicated that he or she would need additional time to recall a list's items, the recall period was prolonged. Between the two experimental conditions, there was a break of 30 s before the next condition started.

Results

Figure 7 shows mean response totals for the 2-list and 3-list tasks as a function of cuing (forget, remember) separately for each list.

Recall of Relevant Precue Items

A 2 × 2 ANOVA with the factors of CUING (forget vs. remember) and TASK (2-list task vs. 3-list task) revealed a main effect of CUING, $F(1, 238) = 7.759$, $MSE = 0.041$, $p = 0.006$, $\eta_p^2 = 0.030$, and a main effect of TASK, $F(1, 238) = 23.052$, $MSE = 0.127$, $p < .001$, $\eta_p^2 = 0.089$, but no interaction between factors, $F(1, 238) = 1.009$, $MSE = 0.041$, $p = 0.317$. Response totals of relevant precue items were higher in the 3-list task than the 2-list task (61.32% vs. 45.64%), and they were higher in the forget condition than the remember condition (56.03% vs. 50.79%). Pairwise comparisons showed that the effect of condition was reliable in the 2-list task (49.22% vs. 42.14%), $t(119) = 3.152$, $p = 0.002$, $d = 0.409$, but was not reliable in the 3-list task (62.88% vs. 59.61%), $t(119) = 1.121$, $p = 0.267$. These results indicate that, in both tasks, there was no cue-induced forgetting of relevant precue items, rather there was (a tendency for) a small beneficial effect of the forget cue.

Recall of Irrelevant Precue Items

A 2 × 2 ANOVA with the factors of CUING (forget vs. remember) and TASK (2-list task vs. 3-list task) revealed a main effect of CUING, $F(1, 238) = 22.693, MSE = 0.051, p < 0.001, \eta_p^2 = 0.092$, and a main effect of TASK, $F(1, 238) = 10.960$, $MSE = 0.110$, $p < 0.001$, $\eta_p^2 = 0.040$, but no interaction between factors, $F(1, 238) = 1.302, MSE = 0.051, p = 0.255$. Response totals of irrelevant precue items were higher in the 3-list task than the 2-list task (47.5% vs. 37.4%), and they were lower in the forget condition than the remember condition (37.48% vs. 47.42%). Pairwise comparisons showed that the effect of condition was reliable in both the 2-list task (33.61% vs. 41.14%), $t(119) = 2.941$, $p = 0.004$, $d = 0.378$, and 3-list task (41.42% vs. 53.64%), $t(119) = 3.745$, $p < 0.001$, $d = 0.488$.

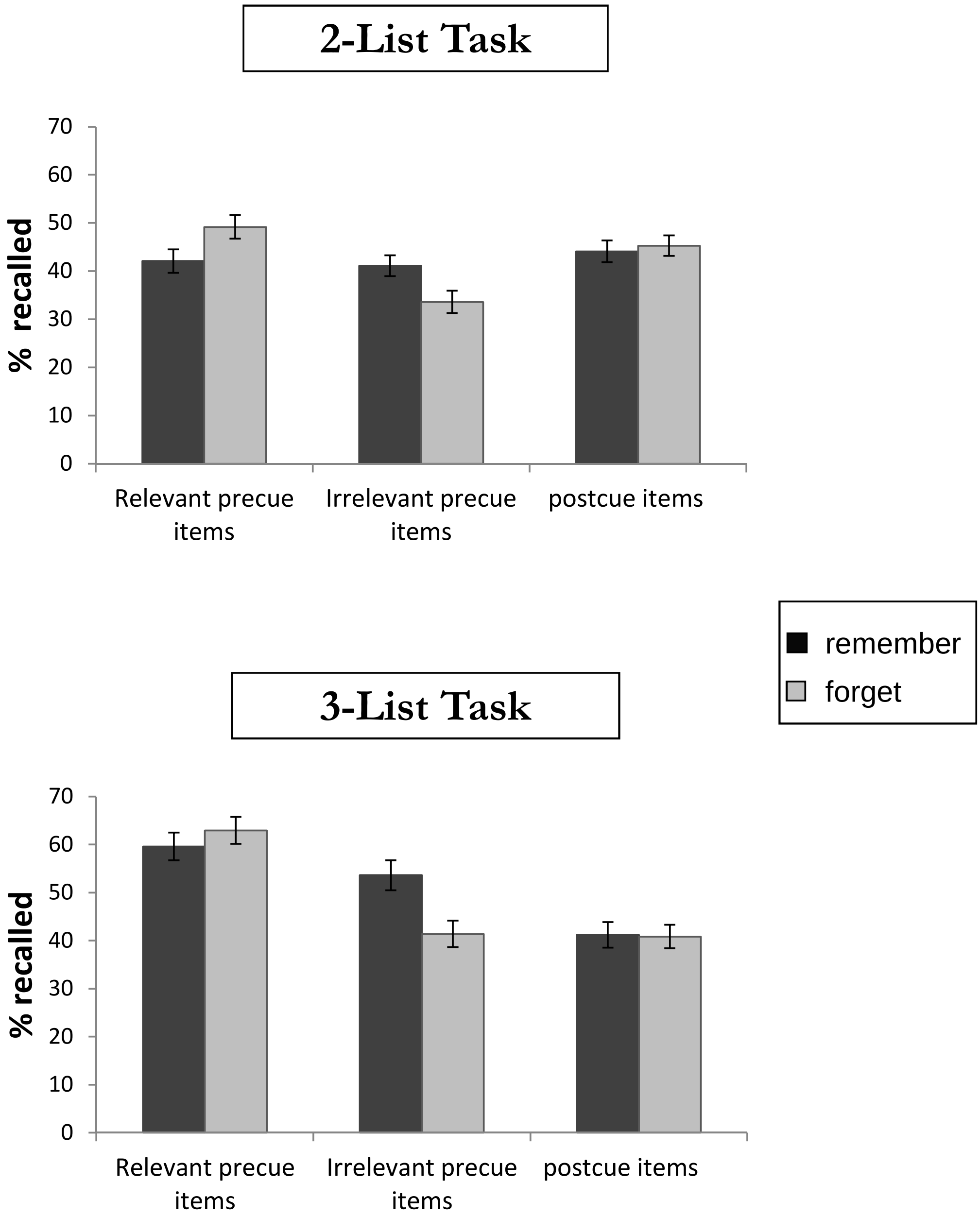

Figure 7. Percentage recalled as a function of CUING (forget vs. remember), and TASK (2-list task, 3-list task) in Experiment 4, separately for relevant precue items, irrelevant precue items, and postcue items. Remember = participants were asked to remember all precue items as well as the postcue items; forget = participants were asked to forget the irrelevant precue items but to remember the relevant precue items as well as the postcue items.

Recall of Postcue Items

A 2 × 2 ANOVA with the factors of CUING (forget vs. remember) and TASK (2-list task vs. 3-list task) showed no main effect of CUING, $F(1, 238) < 1$, no main effect of TASK, $F(1, 238) = 1.429$, $MSE = 0.110$, $p = 0.234$, and no interaction between factors, $F(1, 238) < 1$. Cuing participants to selectively forget some of the precue items thus did not induce enhancement of the postcue items, neither in the 2-list task (45.27% vs. 44.14%), $t(119) < 1$, nor in the 3-list task (40.78% vs. 41.23%), $t(119) < 1$.

Intrusions

Table 4 shows intrusion rates in Experiment 4, separately for each set. Three 2 × 2 ANOVAs with the factors of CUING (forget vs. remember) and TASK (3-list task vs. 2-list task) showed no main effects or interaction, for either relevant precue items, for irrelevant precue items, or for postcue items. *all* Fs < 2.3. Intrusion rates were generally low, on the order of 4% in the single conditions, independent of cuing and task.

Table 4. Mean Intrusion Rates (and Standard Errors) as a Function of CUING and TASK in Experiments 4 (standard errors in parentheses).

	relevant precue items		irrelevant precue items		postcue items	
	2-list task	3-list task	2-list task	3-list task	2-list task	3-list task
remember	4.0 (1.0)	5.0 (0.9)	7.6 (1.6)	4.4 (0.9)	3.2 (0.6)	2.2 (0.6)
forget	3.1 (0.7)	3.8 (0.8)	7.6 (1.6)	5.4 (0.9)	2.8 (0.6)	1.3 (0.3)

Discussion

Regarding the 2-list task, typical precue forgetting for the irrelevant precue items arose. Importantly, the forgetting effect showed up exclusively for these items. Cuing participants to selectively forget half of the previously studied items caused forgetting of these items, but it did not cause forgetting of the remaining list items. Rather, there was even a small beneficial effect for these precue items, which may reflect a list-length or list-strength effect for the relevant precue items, assuming that access to the irrelevant precue items was reduced or even (partly) eliminated. Different from the previous LMDF experiments of the present thesis (Experiments 1A-1C) there was no beneficial effect for the postcue items. All of these findings replicated the results reported in Delaney et al. (2009) and indicate that LMDF is selective in the 2-list task, implying that the mechanism mediating precue forgetting can discriminate between relevant and irrelevant precue items when they had been presented in an alternating order within a single list.

The results in the 3-list task also showed typical precue forgetting for the irrelevant precue items, and they also showed selective forgetting of these items. Indeed, cuing participants to selectively forget the List-2 items caused forgetting of these items, but it did not cause forgetting of the relevant List-1 items. Again, there was no enhancement effect for the postcue items. Thus, selectivity also arose for the 3-list suggesting that the mechanism underlying precue forgetting is also capable of discriminating between relevant and irrelevant precue items when they had been presented in a blocked format as Lists 1 and 2.

The direct comparison of results between the 2-list task and the 3-list task did not provide any evidence for a difference in LMDF between the two types of tasks. The two LMDF tasks did not differ in forgetting of irrelevant precue items, "forgetting" of relevant precue items, and enhancement of the postcue items. The only difference between tasks was a difference in general recall level, with higher recall rates in the 3-list than the 2-list task. This difference reflects the well-known finding that recall of a set of items is typically better when the items are presented as two separate lists than when being part of a single larger list. The conflict in results between the studies of Sahakyan (2004) and Delaney et al. (2009) thus should not be due to the difference in task - 2-list versus 3-list task - but be caused by other factors (see General Discussion).

Thus, for both the 2-list and 3-list task, Experiment 4 found evidence that a flexible process underlies precue forgetting. The finding of selective LMDF is in disagreement with the non-inhibitory context-change account of precue forgetting (Sahakyan & Kelley, 2002) which would assume that forgetting should arise for both irrelevant *and* relevant precue information. However, the current results are arguably in line with the assumption put forward by Pastötter et al. (2012) that an inhibitory mechanism mediates precue forgetting because this mechanism has been suggested to be featured with such flexibility (e.g., Anderson, 2005). The next chapter will address the theoretical implications of these findings in more detail.

Chapter 4

General Discussion

The first part of this thesis (Experiments 1-3) aimed at shedding light on whether retrieval processes contribute to the postcue enhancement effect in LMDF and what the nature of such a retrieval process might be. The analysis of response latencies implied that, indeed, retrieval processes are involved because a more refined memory search at test mediates the enhancement effect in the LMDF task. Breadth of search was also affected in two related memory tasks, thereby suggesting that the focused-search mechanism is not specific to the enhancement effect in LMDF. The second part of this thesis intended to clarify how exactly accessibility of precue material is reduced in LMDF so as to enable a more focused memory search. A priori, both an inhibitory or an non-inhibitory mechanism might be responsible for the impaired access of the precue context. But because Experiment 4 found that the mechanism mediating precue forgetting is capable of segregating between relevant and irrelevant precue information, the inhibitory view is favored. Overall, the present results support and specify the recent two-mechanism account of LMDF proposed by Pastötter et al. (2012).

4.1 Postcue Enhancement

Release from PI in List-Method Directed Forgetting

The first part of this thesis examined the focused-search hypothesis which assumes that releasing PI via a forget cue enables a more refined memory search for subsequently studied target (postcue) material at test. Experiments 1A-1C provided the first direct evidence for the involvement of such a mechanism. Experiment 1A was a standard 2-list LMDF experiment, with the exception that besides the standard remember and forget conditions, a no-PI condition was included in which only a target list of items was studied and no prior list was presented. Release from PI was reflected in increased response totals of the target list in the forget condition as compared with the remember condition, replicating the standard finding of postcue enhancement in LMDF (e.g., Bjork, 1989; MacLeod, 1998). More important, subsequent-response latencies in the forget conditions decreased relative to the remember condition. This pattern of increased response totals and decreased response latencies of the target list also arose when two precue lists had to be encoded (Experiment 1B) and when the retention interval between encoding and test was ten minutes instead of one minute (Experiment 1C).

Because subsequent-reponse latencies have been suggested to constitute a reliable index of mental search set size at test (e.g., Rohrer, 1996), these findings indicate that retrieval processes play a crucial role for postcue enhancement, which is in line with prominent theoretical accounts of LMDF (e.g., Geiselman et al., 1983; Sahakyan & Kelley, 2002), and with previous empirical findings that also seemed to imply a central role of retrieval due to the absence of a reliable enhancement effect in recognition and implicit tests (e.g., Basden et al., 1993; Block, 1971; MacLeod, 1999). Going beyond prior work, Experiments 1A-1C provided some insights about the nature of this retrieval process, indicating that a cue to forget previously studied material facilitates segregation of nontarget and target material as reflected in a more focused search set size for the target list.

This release from PI from the remember condition to the forget condition was mainly due to a decrease in subsequent-response latencies. This suggests that the study of prior lists affected the breadth of search at test. It has to be mentioned, however, there was also an effect on first-response latencies in the single experiments, which became significant only when the results of all four experiments were analyzed simultaneously. The effect in first-response latencies suggests that release from PI does not only reduce breadth of search but accelerates initiation of the retrieval process itself. This holds while the effect on retrieval initiation is much smaller than the effect on breadth of search.

Overall, the consistently found effect of the forget cue on subsequent-response latencies in Experiments 1A-1C supports the focused-search hypothesis which assumes that a more refined search set plays a crucial role for postcue enhancement. Experiments 2 and 3 examined the specificity of these findings, employing a context-change task (Experiment 2) and an interpolated-testing task (Experiment 3). Both of these treatments have previously been shown to effectively reduce PI on the target list with regard to response totals (Sahakyan & Kelley, 2002, Szpunar et al., 2008). However, while the beneficial effects of both treatments on the target list are indeed similar to the effect of a forget cue, those earlier studies remained silent as to whether similar mechanisms create these effects. The current work demonstrated that, in fact, subsequent-response latencies for the target list also increased when the internal context was changed prior to the encoding of the target list or when the preceding material was tested. Again, these findings speak in favor of the focused-search hypothesis, suggesting that a confined memory search may generally be a prerequisite for human memory updating, while also for the "unique benefit" (Szpunar et al., 2008) of interpolated testing, a more focused search set seems to be crucial.

The finding that search set size of the target list is similarly decreased after a forget cue, a context change, or testing is especially noteworthy given the fact that the old material is arguably affected in quite different ways in each of the three paradigms. The forgetting effect in LMDF has often been attributed to an inhibitory mechanism (e.g., Bjork, 1989; Geiselman et al., 1983), and, as will be argued later, the results of the current Experiment 4 actually support such an inhibitory view. However, the forgetting effect in the context-change paradigm has been suggested to arise due to a non-inhibitory mechanism, i.e., due to an inaccessibility of the original encoding context of the old material at test (Sahakyan & Kelley, 2002). While, empirically, the old material was forgotten in these two memory updating paradigms (i.e., the LMDF and context-change paradigms), memory for the old material is actually enhanced in the interpolated testing paradigm, suggesting that testing benefits *all* study material, not only the most recently studied list (Szpunar et al., 2008). Thus, while the old list(s) in the LMDF, context-change, and interpolated-testing tasks are subject to different "fates", the enhancement on the target list in all three paradigms involved is surprisingly similar effects on both response totals and response latencies.

Buildup of PI in List-Method Directed Forgetting

While the focus of the first part of this thesis was on the nature of the retrieval process that mediates release from PI in the LMDF task (as well as in the context-change and interpolated-testing tasks), the current Experiments 1A-1C also replicated prior work regarding buildup of PI in the LMDF task. Buildup of PI was reflected in decreased response totals of the target list in the remember condition as compared with the no-PI condition. Similar findings have previously been reported (Bjork & Bjork, 1996, Sahakyan & Goodmon, 2007). More important, the prior nontarget material increased subsequent-response latencies of the target list in the remember condition as well. This pattern of decreased response totals and increased response latencies for the target list also arose for the target list in the no-change condition of Experiment 2 and the restudy condition of Experiment 3. In all five experiments, the increase in latencies was mainly due to an increase in subsequent-response latencies (in parallel to release from PI), suggesting that the study of prior lists increased the breadth of search at test. There was also a slight numerical effect on first-response latencies in each of the five experiments, which became significant only when the data of all experiments were analyzed simultaneously. The effect suggests that the study of prior lists can also slow initiation of the retrieval process itself, although, relative to the increase in breadth of search, the influence is small.

Decreased response totals and increased subsequent-response latencies for the target list have previously been reported by Wixted and Rohrer (1993). This finding is consistent with the view that, in the presence of prior lists, participants are unable to restrict their memory search to the subsequent list and instead extend their search to items from the previously studied lists (e.g., Wixted & Rohrer, 1993). This interpretation is in line with the temporal discrimination theory of PI, according to which PI is caused by a failure to distinguish items from the target list from items that appeared on the earlier lists (Baddeley, 1990; Crowder, 1976).

Both buildup of PI through prior encoding and release from PI through a forget cue thus seem to affect search set size, adding precue items to the search set when PI is built up and eliminating precue items from the search set when PI is reduced.

Contributions of Retrieval and Encoding Processes

While the current results confirm the focused-search hypothesis and reinforce the notion that retrieval processes are crucial for postcue enhancement in the LMDF task, it has to be stressed that the results of the present experiments do not rule out a crucial role of encoding processes in postcue enhancement. Rather, the response latency measure has been demonstrated to be largely unaffected by encoding manipulations (e.g., Rohrer, 1996; Rohrer & Wixted, 1994; Wixted et al., 1997). Thus, on the basis of the present findings, it cannot be claimed that retrieval processes are the only relevant factors for postcue enhancement. Indeed, Pastötter and Bäuml (2010) analyzed serial position curves and found that, while memory for all precue items was impaired, an enhancement effect only arose for the first few items presented subsequent to the forget cue, supporting the view that an reset of encoding processes contributes to postcue enhancement. In addition, recent EEG studies also found consistent evidence for such an encoding factor (Bäuml et al., 2008; Hanslmayr et al., 2012). Furthermore, because prior work implies that a reset of encoding processes may not only play a central role in the LMDF task but also when PI is released with a context change (e.g., Pastötter et al., 2008) or interpolated testing (e.g., Pastötter et al., 2011), neither a focused-search nor a reset process may be specific to the enhancement effect in LMDF.

Indeed, both retrieval and encoding factors may contribute to release from PI in each the LMDF, context-change, and interpolated-testing tasks. Findings from two recent studies by Jacoby and colleagues seem to support this notion. In the first study, Jacoby et al. (2010) used paired associates as item material and found that two rounds of experience with PI caused a substantial release from PI the second round relative to the first round. The results were suggested to reflect an enhanced encoding strategy in the second round. However, in a subsequent study (Wahlheim & Jacoby, 2011), the authors found that experience with PI causes a release from PI not only due to superior encoding, but also as a result of a more elaborate retrieval strategy. Specifically, Wahlheim and Jacoby found that experience-induced release from PI was not accompanied by an increased use of post-retrieval monitoring processes, intended to reject a competitor *after* it came to mind, but rather was accompanied by a reduced reactivation of the nontarget item while the target item was produced. This finding suggests a more focused memory search and thus parallels the current findings.

Overall, the results of the first part of this thesis seem to indicate that cuing participants to forget previously studied material enables a more focused memory search for subsequently studied material. In addition, the current data imply that for other treatments which are known to cause release from PI, like a context change or interpolated testing, breadth of memory search is similarly affected. While this focused-search retrieval factor significantly improves memory of a target list, recent research suggests that a (reset-of) encoding factor is also crucially involved with respect to the postcue enhancement effect in the LMDF task (as well as with respect to the enhancement effects in the context-change and interpolated- testing tasks).

4.2 Precue Forgetting

Selectivity in the 2-List and 3-List Tasks

The first part of this thesis found evidence that a retrieval factor is crucially involved in postcue enhancement. This finding, however, remains silent as to how PI from the precue material is reduced. Indeed, both the assumptions that accessibility of the precue material is reduced via an inhibitory mechanism (Bjork, 1989) or an internal context change (Sahakyan & Kelley, 2002) can explain the findings of Experiments 1A-1C. Therefore, the second part sought to discriminate between these two views by addressing the nature of the processes mediating precue forgetting. Specifically, Experiment 4 examined whether or not LMDF is selective, i.e., whether participants can forget only irrelevant precue material, but retain relevant precue material. While an inhibitory mechanism would arguably produce selectivity in LMDF, because such a process has been suggested to be capable of flexibly targeting only irrelevant precue material (e.g., Anderson, 2005), a context-change mechanism would predict no such selectivity, but forgetting of all precue material.

Experiment 4 employed two variations of the standard 2-list LMDF task, a 2-list task in which relevant and irrelevant precue items were presented alternatingly within a single list, and a 3-list task in which relevant and irrelevant precue items were presented subsequently as Lists 1 and 2. Selectivity arose for both tasks and was reflected in (i) forgetting of irrelevant precue items in the (selective) forget condition, relative to to a remember condition, and (ii) intact memory for relevant precue items in the (selective) forget condition, relative to the remember condition. The findings of Experiment 4 thus seem to imply that a crucial feature of the process mediating precue forgetting is its ability to discriminate between relevant and irrelevant precue material. This finding that LMDF can be selective implies that an inhibitory mechanism mediates precue forgetting, as will be discussed below.

The Current Results and Prior Work on Selectivity

Several studies previously addressed the issue of selectivity in LMDF, with the first study reporting no evidence of selective remembering of relevant precue material in a 3-list task (Sahakyan, 2004), whereas a subsequent study did find selective remembering of relevant precue material in a 2-list task (Delaney et al., 2009). Very recently, two additional studies by Gómez-Ariza et al. (in press) and Storm, Koppel and Wilson (2013) examined selectivity in the 2-list task, both of which employed very similar material to the study by Delaney et al. (i.e., short sentences about two characters). While Gómez-Ariza et al. replicated the Delaney et al. results for healthy individuals (and found no selectivity for adolescents with social anxiety disorder), Storm et al. surprisingly did not find forgetting of either relevant or irrelevant precue material and therefore, failed to detect any selectivity. Thus, the results of the current Experiment 4 are very well in line with the results of Delaney et al. and Gómez-Ariza et al., demonstrating a reliable selective LMDF effect in a 2-list task that is similar in size to the one reported by both Delaney et al. and Gómez-Ariza et al., whereas the failure of the Storm et al. study to detect any selectivity in a 2-list task is hard to reconcile with these findings and may be attributed to subtle differences in their instructions or other experimental details. Taken together, the current evidence arguably seems to favor the idea that people can selectively remember relevant precue material in a 2-list task.

Regarding the 3-list task, the current finding of selective LMDF in that task is obviously in disagreement with Sahakyan's (2004) results. The 3-list task used in the current study is similar to Sahakyan's Experiment 2, because precue list discriminability was boosted in both studies by either using different speaker's voices for the precue lists or, in Sahakyan's case, different semantic categories. However, there are still a number of significant differences between both studies which may account for the differences in results. For example, while the current Experiment 4 used relatively short sets of relevant and irrelevant precue items - 6 items each - Sahakyan (2004) used relatively short sets - 12 items each. Thus, length of precue lists may influence discriminability of the precue material and thus constitute a decisive factor as to whether or not selectivity arises in LMDF. Indeed, Delaney et al. (2009) and Gómez-Ariza et al. (in press) used relatively short sets of relevant and irrelevant precue items - 8 items each - and did find selective LMDF in a 2-list task.

However, Sahakyan's (2004) Experiment 2 not only contrasts with previous and present selectivity experiments because she employed longer lists, but also due to the fact that she did not control list output order at test. Control of list output order may be important, because, in the absence of such control, subjects in the remember condition may tend to recall List-1 items first in a 3-list task, whereas subjects in the forget condition may tend to recall postcue items first (e.g., Geiselman et al., 1983). If so, the observed reduction in List 1 response totals in the forget condition of Sahakyan's Experiment 2 may be due to output interference rather than a failure of selectivity in LMDF. Future work is necessary to examine the adequacy of this view.

To sum up, the current results showed that selectivity arises for both the 2-list and 3-list task, thus implying that type of task does not play a major role for selectivity in LMDF. These findings suggest that the mechanism underlying precue forgetting is capable of discriminating between relevant and relevant precue information, regardless of whether relevant and irrelevant information is presented alternatingly within a single list (2-list task) or blocked as Lists 1 and 2 (3-list task).

Inhibition or Context Change?

The finding that LMDF is selective has important implications for prominent accounts of LMDF (forgetting). The context-change account of LMDF (Sahakyan & Kelley, 2002) proposes that accessibility of the precue material is reduced via a non-inhibitory mechanism: the forget cue is assumed to induce an internal context change, and thus at test, a mismatch between the encoding and retrieval context causes precue forgetting. Because a context change should cause forgetting of all precue items, the current finding of selective remembering of relevant precue items challenges the context-change account. The current data on selectivity in LMDF are, however, in line with the retrieval-inhibition account which assumes that an inhibitory mechanism reduces context accessibility of the precue list(s) (Geiselman et al., 1983). Because retrieval inhibition has been proposed to be a fairly flexible control mechanism (e.g., Anderson, 2005) with several studies supporting this assumption (Aslan et al., 2010; Conway et al., 2000), it might be argued that selectivity should arise in LMDF: participants in the (selective) forget condition should well be able to target inhibition to the irrelevant precue items without affecting relevant precue material.

While the results of Experiment 4 thus are in line with an inhibitory view of precue forgetting and challenge the context-change account, they, of course, do not imply that an inhibitory mechanism necessarily mediates LMDF in all types of situations. Indeed, participants may substantially differ in what strategy they use in a LMDF task after being presented with a forget cue. The present findings suggest that retrieval inhibition may be a viable LMDF mechanism in most empirical situations, whereas reliable precue forgetting as a result of a context change may be limited to tasks in which only irrelevant items are presented prior to the forget cue.

Interestingly, a recent LMDF study that employed a standard 2-list task and simultaneously recorded EEG along with fMRI provides new evidence for the notion that an inhibitory mechanism, as opposed to a context-change mechanism, may indeed play the more dominant role for precue forgetting (Hanslmayr et al., 2012). Replicating previous work (Bäuml et al., 2008), the authors found that precue forgetting was associated with a decrease in phase synchronization during study of the postcue list, which has been suggested to reflect an unbinding process that impairs access to the precue items in a later test (e.g., Fuster, 1997). While this result alone is already well in line with the inhibitory view, interestingly, this reduction in neural synchrony was also correlated with a BOLD signal increase in the left dorsolateral prefrontal cortex, an area that has been associated with inhibitory modulation of memory retrieval (Conway & Fthenaki, 2003; Anderson et al., 2004; Depue, 2012). This finding is consistent with recent work suggesting that precue forgetting is associated with executive control function (Conway & Fthenaki, 2003; Conway et al., 2000) and individuals' working memory capacity (Aslan et al, 2010; Delaney & Sahakyan, 2007), and overall, speaks in favor of a prominent role of an inhibitory mechanism.

Thus, while the context-change account may be capable of explaining a number of behavioral LMDF findings, the current Experiment 4 as well as recent imaging and behavioral studies challenge context change as a reasonable explanation of precue forgetting. In contrast, these findings support an inhibitory view of precue forgetting, suggesting that the forget cue actively inhibits accessibility of the precue material.

4.3 Broader Theoretical Implications

This thesis intended to test and, potentially, substantiate the modified two-mechanism account of LMDF proposed by Pastötter et al. (2012). In this final section, I will discuss what the combined data of Chapters 2 and 3 imply for that account. But before doing so, I want to address in how far these data are in line with earlier accounts of LMDF.

Fit with One-Mechanism Accounts

As mentioned above, previous work has cast doubts on the validity of Bjork's (1970) selective-rehearsal account of LMDF (e.g., Bjork et al., 1983; Bjork, 1989). Yet, the finding that LMDF is selective is actually compatible with the selective-rehearsal account, which claims that, after a forget cue is provided, (only) the irrelevant memories are skipped from the rehearsal process, while only the relevant (precue and postcue) items are rehearsed.

However, the current data seem to disagree with the account's view that postcue enhancement is based on a purely encoding-based process, because Experiments 1A-1C clearly indicated that retrieval processes are at least partially responsible for the enhancement effect.

The context-change account (Sahakyan & Kelley, 2002) attributes postcue enhancement to a retrieval mechanism, i.e., reduced PI at test due to a decreased accessibility of the precue material. While the current Experiments 1A-1C confirm a major role of retrieval processes in postcue enhancement, the data of Experiment 4 found evidence for selective LMDF in both the 2-list and 3-list tasks and thus disagree with the context-change explanation of precue forgetting.

In contrast, the inhibitory account (Geiselman et al., 1983) is upheld by the present data which are in line with the view that precue forgetting arises due to an inhibitory mechanism that reduces interference from the precue information at test, thus enabling postcue enhancement. But while this account seems appropriate in the isolated context of the present findings, recent studies (e.g., Bäuml et al., 2008, Hanslmayr et al., 2012; Pastötter & Bäuml, 2010) clearly indicate that encoding processes also play a crucial role in postcue enhancement, casting doubt on explanations that attribute postcue enhancement solely to a retrieval mechanism.

Fit with Two-Mechanism Accounts

Regarding two-mechanism accounts of LMDF, the current findings seem hard to reconcile with the two-mechanism explanations of either Sahakyan and Delaney (2003) or Pastötter and Bäuml (2010). Both accounts attribute postcue enhancement exclusively to encoding factors, either a more elaborate encoding strategy or a reset of the encoding process after the forget cue. However, the results of the present Experiments 1A - 1C, which indicate the involvement of a focused-search retrieval mechanism, do not support purely encoding-based accounts. Furthermore, while Pastötter and Bäuml's assumption that an inhibitory mechanism underlies precue forgetting is in line with the current finding that LMDF is selective, Sahakyan and Delaney's account, which attributes precue forgetting to a context change is not supported by that finding.

Fit with the account of Pastötter et al. (2012)

While the results of the first part (Experiments 1-3) and the second part of this thesis (Experiment 4) challenge these previous accounts of LMDF, they affirm and further substantiate central assumptions of the Pastötter et al. (2012) account. The first part of this thesis was consistent with the assumption that, besides a reset-of-encoding factor, a retrieval factor can contribute to postcue enhancement. Beyond that, the analysis of response latencies helped to specify the nature of this retrieval mechanism, showing that breadth of memory search is more focused in the forget condition than the remember condition. The second part of this thesis provided a crucial test of Pastötter et al.'s (2012) hypothesis that an inhibitory mechanism reduces access of the precue context by showing that participants' were able to keep remembering part of the precue material when the remaining material should be forgotten.

The current data are also in line with the Pastötter et al. (2012) proposal that the reset-of-encoding factor is effective regardless of list output order, whereas the retrieval factor only comes into play when the postcue list is tested first, thereby adding to the enhancement effect. In fact, while Experiments 1A-1C found reliable postcue enhancement in response totals ranging from approximately 11-26 %, there was virtually no postcue enhancement effect for both the 2-list and 3-list tasks of Experiment 4, in which the postcue list was tested last. Indeed, this failure to find postcue enhancement in Experiment 4 may be due to the atypical nature of the (selective) forget instruction, but a recent meta-analysis by Pastötter et al. (2012) suggests that the presence or absence of postcue enhancement is closely related to list output order at test: When postcue items are tested first and precue items are tested subsequently, both postcue enhancement and forgetting generally arise. However, when the output order is reversed and postcue items are tested subsequent to precue items, postcue enhancement is nonexistent or at least reduced, while precue forgetting still arises.

Future work may like to provide further tests of the Pastötter et al. (2012) account, for example by analyzing response latencies of the postcue list in a LMDF experiment in which list output order at test is manipulated systematically. Because the account predicts that retrieval processes should only play a crucial role for postcue enhancement when the postcue list is tested prior to the precue list, breadth of memory search should only be affected in that experimental situation. Thus, testing postcue material prior to precue material should replicate the results of Experiments 1A-1C, showing decreased response latencies in the forget condition, relative to the remember condition, due to the precue items' reduced interference potential. However, testing postcue material subsequent to precue material should reactivate the precue items' interference potential and thus, breadth of search should again increase for the postcue list. This should be reflected in more similar response latencies for the forget and remember conditions.

It might also be interesting to employ the response latency measure in a selectivity experiment in which the postcue list is tested first. Similar to the current Experiment 1B, a 3-list LMDF task could be used in which, after List 2, a cue is provided to either forget or remember both precue lists. Again, this should lead to shorter List-3 response latencies for the forget than for the remember condition, because Lists 1 and 2 interfere less in the forget condition. However, a selective forget condition, in which List 1 should be remembered, but List 2 can be forgotten, should yield intermediate response latencies for List 3.

4.4 Conclusions

In the LMDF task, intentional memory updating is operationalized by cuing participants to forget previously studied material. Typically, in this task, forgetting of precue material arises while memory for postcue material is enhanced. The present work yielded some evidence how this updating might proceed: the forget cue reduces accessibility of the irrelevant precue material and, on this basis, memory search of postcue material may be more focused because the precue material is less interfering. There has been a long-running dispute as to whether accessibility of the precue material is reduced via an inhibitory process or a context change. But because the present results suggest that the mechanism underlying precue forgetting is capable of seperating relevant and irrelevant precue material, it seems more likely that an inhibitory mechanism is responsible for the forgetting effect. Overall, the current results support and specify the Pastötter et al. (2012) proposal of postcue enhancement and precue forgetting.

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